III Fundamentals of Shaped Charges, Zukas and Walters[pp 374], show these linear shaped charges and what can be expected from them. In practice they are used as demolition devices often. According to their chart [figure 64], these charges can penetrate about 1.5 diameters into mild steel, at upto 2 diameters standoff. If it follows normal patterns for shaped charges this is the opimum , with penetration falling off before and after this point.

Given that the penetration is mild steel the penetration into a heavymetal penetrator would be more like 3/4 diameter. Given a 36mm diameter @60° this suggest most effective at 7cm , resutling in about 3cm penetration, with the rows either side of this penetrating alot less.

Using Figure 14 & 15 and Tates target resistance factor to determine the H factor [Tates R_t figure 'target resistance'] .

Note : Formula is UTS[0.67+In(2E/3*UTS)]

Where UTS = UTS of the target. [3.9 x BHN (Tates suggested figure)]

E = youngs Modulus[~70 Al ; ~200 Steel (Int.J.Mech Sci Vol 28,pp 599- 612)]

I got ...

550 BHN VHS @2.0 UTS = Tate 'R' resistance figure of about 9.7 [ricochet ~ 41°]

400 BHN SHS @1.5 UTS = Tate 'R' resistance figure of about 7.7 [ricochet ~ 42°]

300 BHN RHA @1.1 UTS = Tate 'R' resistance figure of about 6 [ricochet ~ 51°]

260 BHN RHA @0.9 UTS = Tate 'R' resistance figure of about 5.1 [ricochet ~ 55°]

190 BHN MS @0.63 UTS = Tate 'R' resistance figure of about 3.8[ricochet ~ 58°]

110 BHN SS @0.36 UTS = Tate 'R' resistance figure of about 2.4[ricochet ~ 64°]

***190 BHN @0.63 UTS = Tate 'R' resistance figure of about 3.2 [ricochet ~ 60°] ***

***110 BHN @0.36 UTS = Tate 'R' resistance figure of about 2.0 [ricochet ~ 67°] ***

For the last two results the experimental results were a lot lower with ricochet for 1000m/s impact around 51° while 1500m/s impact resulted in about 67° ricochet.

The following represents various immunity figures for a number of materials vs. various forms of attack. For Example:

Material Thickness required to Protect against various forms of Kinetic Energy Attack at 0- degrees obliquity:

Material	Attacking Projectile	Thickness Required (Inches)
Concrete	7.62mm MG	8
Concrete	Antitank Rifle	12
Concrete	20mm AP @ 200yrd	18
Concrete	37mm AP @ 400yrd	36
Concrete	57mm AP @ 400- yrd	42
Concrete	75mm AP @ 500 to 1000yrd	48
Wood	7.62mm MG	24
Wood	Antitank Rifle	38
Wood	20mm AP @ 200yrd	48
Sand	7.62mm MG	20
Sand	Antitank Rifle	30
Sand	20mm AP @ 200yrd	30
Sand	37mm AP @ 400yrd	60
Sand	57mm AP @ 400- yrd	70
Sand	75mm AP @ 500 to 1000yrd	80

These are obviously fairly general figures , but appear to be empirically based. I have also found a number of relationships that have been developed for shell penetration of soil, concrete, timber, etc. Penetration of these materials is typically expressed as a function of:

Shell Velocity
Shell Weight
Shell Caliber
Target Material Resistance
Nose Geometry of the Shell

Unlike Armor penetration, the sharper the projectiles nose the more efficiently the projectile will be at penetrating soil, gravel, rock, timber and concrete. Moreover a projectile with a 4- CRH nose will penetrate more soil than a 2- CRH projectile.

A cone has been determined to be by far the most efficient head shape for piercing soil, concrete, rock or timber. A cone shaped nose with a 15- degree half- angle will penetrate about twice as much material as an 8- CRH projectile (8- CRH is a fairly long ogival nose. Most WWII'ish AP projectiles had an ogival penetrator nose shape in the range of about 1 to 3- CRH). The efficiency of a cone shaped nose seems consistant with various Desert Storm accounts of 120mm APFSDS penetrating multiple feet of sand berms before destroying T55s or T72s hidden behind such berms.

Here are some additional immunity thicknesses to consider regarding HEAT attack on sand bags, logs and such:

Material	Attacking Projectile	Thickness Required (Inches)
Concrete	RPG- 7	30

Soil- RPG- 7- 78

Wood (dry)- - - - - - - - - - - - - - - - - - - RPG- 7- 90

Wood (wet, green)- - - - - - - - - - RPG- 7- 48

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These values again represent 0- degree obliquity attack.

Doing a bit of digging on the RPG- 7's rated Armor penetration, I have come of with a wide range of values. Many sources – including TRADOC – imply 0- degree penetration of RHA of about 330mm. However I have found at least one source indicating penetration is as high as 18- inches.

Running with an RHA equivalency for the above materials, and using the TRADOC figure for RHA penetration for RPG- 7 of 330mm we get the following:

Material- - - - - - - - Attacking Projectile- - - - - - - - - - - - - RHA Equivelency (Inches)

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Concrete- RPG- 7 - - - - - - - - - - - - - - - 1" of Concrete ~0.43" RHA

Soil- RPG- 7- - - - - - - - - - - - - - - - 1" of Soil ~0.167" RHA

Wood (dry)- - - - - - - - - - - - - - - - - - - RPG- 7- - - - - - - - - - - - - - - - 1" Dry Wood ~0.14" RHA

Wood (wet, green)- - - - - - - - - - RPG- 7- - - - - - - - - - - - - - - - - 1" Green Wood ~0.27" RHA

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Fighting in conditions far removed from the north European plains for which it was designed, the Abrams tank has proved its value in the war in Iraq, according to the U.S. Army's chief of armor.

Not a single tanker has been killed by a conventional anti- tank weapon, Army Maj. Gen. Terry Tucker said. The few fatalities suffered aboard tanks have been caused by roadside bombs or small arms, he said.

Nonetheless, the Army is considering upgrades so the Abrams will prevail on battlefields for the next quarter century. Among changes under consideration for the near term are better protections for the tank's commander and loader while they fire their machine guns, and a new anti- personnel round for the Abrams' 120mm main gun. The long- term upgrades on Tucker's mind include improved armor and a new main gun.

About 4,500 troops have served on tanks in Iraq. Of those, three soldiers have been killed inside their tanks by roadside bombs. An additional 10 to 15 crew members have been killed while riding with their heads out of the hatch, standing on the tanks, or, in one case, by an insurgent who climbed onto the tank and shot down into the crew compartment, Tucker said.

“I am unaware of any case where any tanker in Iraq has been killed inside of a tank by a penetration of a tank round or RPG [rocket- propelled grenade] or any other munition,” Tucker said. “It’s a pretty safe place to be.”

About 1,135 Abrams tanks have seen action in Iraq, Tucker said, some more than once. Of those, he said, “probably 70 percent have been hit or damaged in some way. In fact, it’s hard to find an Abrams tank out there that has fought in Iraq that has not been damaged.”

Eighty tanks have sustained damage that required them to be sent back to the United States for repairs, said Tucker, noting that the damage was “fairly minor” in some cases. “If a seam or a weld was broken, that’s pretty delicate work, and we couldn’t do that in theater, so we’ve brought tanks back to the U.S. for welding repairs,” he said. “About 63 of those 80 tanks will go back to the fleet.”

Those figures mean that 1 percent to 1.5 percent of the tanks involved in the fight in Iraq might not return to action. “I’ll take those numbers any day,” Tucker said.

A Different Fight

Tucker acknowledged that the loss of even a few Abrams tanks has come as something of a reality check to the armor community. In the 1991 Persian Gulf War, during which Tucker commanded a cavalry squadron, combat involved Abrams tanks engaging and destroying their Iraqi counterparts with overwhelming fire in the open desert.

“This fight’s different,” he said. “The enemy’s learned from that. And the technique that they’re using is massed fire against one tank: 14, 18, 20 RPGs — I’ve heard reports of tanks taking 50 RPG hits. It’s a new technique that they’re using, and in fact we’re having some significant damage on tanks that has to be repaired before we put them back in the fight.”

Tucker cited an Abrams with the 3rd Infantry Division (Mechanized) that took part in the first “thunder run” into Baghdad as an example. The tank was struck by 14 to 18 rocket- propelled grenades, one of which knocked out the hydraulics system so the crew had to operate the turret in manual mode. Nevertheless, the tank completed the first thunder run and then went on the second, its crew still fighting with the tank in manual mode. “That crew refused to get off of it, because that tank couldn’t be killed,” he said.

Early Problems

Not every Abrams was quite as resilient. Tucker estimated that the number of tanks that had to be temporarily abandoned or pulled out of the fight immediately due to combat damage was “at least 17 and probably in the 20s.”

However, no tanks have been abandoned in Iraq, he said. Even when U.S. forces needed to scuttle a damaged tank to prevent sensitive equipment from falling into enemy hands, and destroyed it with fire from another tank or called in an Air Force strike with Maverick missiles, U.S. troops retrieved the carcass and brought it back to the United States.

"That tank is designed with the ammunition separated from the crew compartment, and if the ammunition is ignited in the storage compartment, the tank is designed for the back of the turret to blow out, so the fire and the explosion goes outward, as opposed to inward, so you don't injure or kill the crew," Tucker said.

The general estimated that Iraqi insurgents have used a dozen different types of RPGs against the Abrams. "My concern is that in the future we'll see more of the newer types, which are more powerful and have more capability," he said.

But contrary to rumor, he said, there is no indication that any exotic anti-tank rounds — including foreign-made missiles such as the Milan, new versions of the RPG, or new tank main gun rounds - have been used against the Abrams in Iraq, the general said. Meanwhile, the officials the Army pays to plot the future of the Abrams are not resting on their laurels, according to Tucker.

"We still think of the Abrams tank as the king of the fight, and I'm here to tell you that it is, but I'm also here to tell you that the Abrams tank is 25 years old," he said. "We've improved it a lot over the years ... but it's still a 1980 tank, and we have more work to do to keep the Abrams tank king of the battlefield for the next 25 years, because 25 years from now, when the American Army goes to fight, it will go to fight in Abrams tanks."

In the near term, the Army has studied how the Abrams has fared in Iraq and come up with a series of improvements that it refers to collectively as the tank urban survivability kit (TUSK). But these capabilities are not funded in the Army budget, said Maj. Chad Young, assistant product manager for M1, M1A1 and TUSK. The service has not yet finalized how much it would cost to put TUSK on each tank, Young said.

A program that is funded and will be fielded to tank units in Iraq "probably this summer," according to Tucker, is an anti-personnel canister round for the Abrams' 120mm main gun. Tucker refers to it as "a big shotgun round."

Meanwhile, looking further into the future, "the Abrams tank needs to become more lethal ... [and] more survivable than it is now," Tucker said. "It's fairly easy to make it more lethal and more survivable," he continued. "The challenge is going to be to do that while we try to make it lighter and more mobile."

Studying New Armor

To solve the mobility problem, the Army is examining new types of composite armor and electrified armor that have the potential to be lighter yet provide more protection than the composite armor package currently equipping the Abrams, according to Tucker.

In 2008, the Army will begin to field its next-generation family of combat vehicles, the Future Combat Systems. That won't mean the end for the Abrams, which is scheduled to serve until at least 2040. In fact, the first FCS-equipped unit of action probably will include one FCS battalion and one battalion of Abrams tanks and Bradley fighting vehicles, Tucker said. The challenge for the Army's doctrinal community will be to figure out how the Abrams and the FCS family of vehicles will operate together, according to Tucker.

One issue that remains unsettled is what type of gun the FCS mounted combat system should have. "There's lots of debate," he said. "Is it 105 [mm]? Is it 120 [mm]? Is it electromagnetic? Is it a death ray? What's that gun going to be? We're not quite sure yet, but ... we probably ought to put the same gun on the Abrams that we're going to have on the FCS. That would make sense."

Having different main guns on the two systems would entail an unnecessary logistical burden, he added. "I can see some day that the gun in the Abrams tank will be more lethal than it is now, and half the size, half the weight," Tucker said.

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In the TM E 30-451 Handbook on German Military Forces p. VII-100 it says about the German 46mm hollow-charge anti-tank rifle grenade:

"Static tests indicate, that the penetration at long ranges is approximately 90mm of homogenous armor. At short range (approx. 18 feet) the penetration was 70mm. A 1/4 inch mild steel plate, spaced 11 inches in front of the armour completely nullified the effect on the armor."

The same is said about the 61mm round except that the penetration is 126mm and 100mm respectively.

This seems to suggest that the Schürzen - skirts - used by the Germans in WWII to protect the sides of some of their tanks would in fact be effective in combatting HEAT warheads, even though they were not designed for that purpose.

However, I've seen it suggested, that the Schürzen would not have such a significant effect due to various issues with stand-off etc. Basically, the argument goes, most HEAT rounds would have enough punch to go through the Schürzen and maintain enough penetrative force to carry through the main armour as well.

So I wonder if anyone can explain what is going on here? Is the disruptive effect of a simple, one-layer spaced plate sufficient to distort a HEAT-jet enough for it to fail against the main armour? In the case above, I think the 46mm grenade had a cone diameter of about 32mm and in-built stand-off of about 1 (i.e. ~30mm). As I recall some notes made by Paul Lakowski a while back, the plate would retard penetration somewhat, but not nearly enough to prevent any effect on the main armour as the above quote suggests?

Claus B

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ARMOR BASICS

Modern AFVs are rated in three important areas; firepower, armor and mobility. Mobility is often the most important capability viewed from an operational context but armor and fire power seem to determine success and failure on the modern tactical battle field .**Historically the battle between projectile and plate has determined the out come of most tank battles.** Its probably true to say that fire power is the more important of the two, but often it is the level armor that becomes the 'rate determining step' in the firefight.

In order to keep pace with gun penetration in WW-II, armor designers were forced to focus more and more armor to the front of the AFV at the expense of flank protection, while to combat this, gun designers resorted to higher tech ammunition. The priority in trainig would be to orientate the tank to the threat , forcing the advesary to penetrate the thicks part of the tanks armor. Conversely tactical manuver became a valuable way to bring fire to bare on the more vulnerable sections of the tanks profile. After WW-II, the Soviets and Americans both experimented with Explosive Reactive Armor [ERA] equipped tanks, while the Americans also experimented with the silica ceramic armored T-95. These technologies offered potential but were too costly to include in contemporary tank design so the main solution adopted ,was to up the weight . The main battle tank went from 20-30 tons in WW-II to 35-48 tons in the fifties. **In other words this years heavy tank turned into next years medium tank just by changing the name.**

In the 60 & 70s the dramatic rise in the potential of the Anti Tank Guided missile [ATGM] forced another evolutionary step . The British resorted to the 'heavy tank' concept with 13 inches of armor, called Conqueror which gave way to the lighter Chieftain which was able to amass 16 inches of frontal armor protection. Meanwhile the French opted for a medium tank and the Americans developed the M-48 tank into the M-60 which was a cross between the M-48 medium tank & M-103 heavy tank designs .**The German solution was a 40 ton hybrid tank , with the turret armored like a heavy tank while the hull armor was that of a medium tank,** clearly the idea was to always fight from 'Hull down'. This was based on the extensive historical experience the Germans gained fighting on the eastern front. For there part the Soviets developed the T-64,which was there own version of the 'T-95' in expectation of the proposed "MBT-70" tank programe[which never entered production due to costs]. In some respects the T-64 was still the heavy tank of the 40s & 50s as the armor of the T-64 was on the same level of the Chieftains in most places but in other places it was medium tank armor. The Soviet armor solution was similar to the German hybrid solution, just arranged differently.

The 80s saw the introduction of western Chobham armor to counter ATGMs,[**A**nti **T**ank **G**uided **M**issiles], while the germans added energetic appliqué armors to the Leopard 1 tank. The Soviets were able to keep pace by there own applique solution in the form of ERA added to their existing fleet of T-64-80 tanks ,but the western gun designers were able to keep pace with improved APFSDS designs.So by the 1990s even these armors were obsolete and required upgrading to compete against the latest technology warheads.The current solutions are DU [Depleted Uranium] armor for the M-1s and Challengers tanks and "Wedge armor" for the LE0-2s and heavy ERA [K-5] for the Russians. **The one thing in common with all these upgrades , is that the new heavy armor only covers about ½ the front profile.** This suggest that too best exploite these heavy armors the tanks must follow the german practice of mostly fighting hull down**.**

In short we've seen in the last half century

Armor levels	S Hvy	V Hvy	Hvy	Med	Low	V low	**Threat penetration** KE &	HEAT
End WW-II							low > Medium	Medium
Heavy	-	-	-	Front	rest	-		
Medium	-	-	-	-	Front	rest		
Light	-	-	-	-	-	rest		
50s Technology							Medium	Heavy
Heavy	-	-	Front	Side Tur	rest	-		
Medium	-	-	-	Front	side	rear		
60/70s Technology							Medium > Hvy	Heavy > V Hvy

50Ton	-	-	Front	Side Tur	rest*	-
LEO-1	-	-	Frt tur	Hull	side*	rear
T-64/72	-	-	½ front*	½ front	side	rear
80s Technology Heavy V Hvy > S Hvy						
60tons	-	Front#	-	Side Tur#	rest*	-
50ton	-	-	Front#	Side Tur#	rest*	-
LEO-2	-	Frt tur#	hull*	Side Tur*	rear*	-
T-64-80	-	½ front*	½ front	Side Tur*	skirt*	rear*
90s Technology V Hvy > S Hvy Super Heavy plus						
60ton	Frt Tur#	Hull#	Side tur#	-	rest#	-
T-72-90	½ front#	¼ front#	¼ front *	Side Tur*	skirt#	rear#

* Special armor that rasies HEAT one level.
# Heavy HEAT armor rasies HEAT two levels.

So the first solution in the every increasing upward need for more protection, **is to transfer more armor mass to the most vunerable sections of the tank at the expense of the less exposed vehicle areas.** Traditionally post WW-II tanks focused 50% of there steel mass to the frontal arc of the tank. The Israeli Merkava tank apparently focuses 70% of its armor mass to the frontal arc. In addition special materials have been increasingly relied on to help boost the protection levels at some cost to the tanks design.Any review of modern armor must start with steel. According to the [**A**merican **S**teel **M**anufactures] ASM-96 guide there are literally hundreds of steels in use through out the world ,but only a few qualify as good armor material.

Firstly the type of steel must be relatively cheap as its still the most common material used in tank design accounting for about ½ the tanks weight . In order to survive the pressure and strain of impact, this steel must be both strong and ductile, but retain sufficient hardness to defeat impacting projectiles. A class of steels- that currently fit the bill - have been developed called '**h**igh **s**trength **l**ow **a**lloy steel' [HSLA], and the most common of these in research papers is 'Type 4340 steel'. This steel features low carbon [0.3- 0.5%] ,with moderate manganese content [1- 3%] and good ductility[on the order of 8- 10%] and reasonable strength[~ 1.0- 1.2 GPa - ultimate tensile strength]. The hardness range from ~240- 300 **B**rinnel **H**ardness **N**umber [BHN] to BHN 350- 390 [BHN = is a rating system for metal hardness].. **Other steels are available that are stronger - like 'Maraging Steel' - and harder - like 'Tool Steel'- but test reveal these offer only 90% of the resistance of RHA.**

Plate Hardness

Usually **R**olled **H**omogenous **A**rmor [RHA]appears in three forms; armored steel[**RHA**] ,**s**emi **h**ardened **s**teel [**SHS**] & **h**igh **h**ard ness **s**teel [**HHS**]. Armored steel is about 240- 300 BHN and is most often found in thick plates and can appear as cast or rolled . All modern tanks feature rolled plate , while some feature both cast and rolled plates**. It appears that modern cast homogenous armor offer's only ~95 %of the resistance of rolled plate[RM Ogorkiewcz Technology of Tanks pp359], while WW-II cast can offer anywhere from 100- 80% resistance depending on the exact t/d of the impact and how flawed the plates were [Liviginston & Bird WW-II Armor & Gunnery].** All Soviet tanks and British tanks feature cast turrets while the British tanks and Russian tanks feature 270BHN cast armor . Russian sources[Vasiliy Fofanov] report the T-54 tank "cast turret is 270- 286 BHN" while the hull is "rolled plate 290- 300 BHN" ,while Serbian sources report there M-84 tank [T-72 clone] also used BHN 270 armored steel. Thinner plates of RHA [several cms] can be rolled to higher hardness [350- 390 BHN] , while still remain easy to'machine & weld'. These armors offer12- 18% more resistance than RHA Vs **A**rmor **P**iercing **F**in **S**tabilized **D**iscarded **S**abot [**APFSDS**] type projectiles. The M-1 is reported to feature **H**igh **Y**ield - **120** plate [HY-120] that is about 350 BHN plate , while the Chinese tanks & early American tanks feature HY 80 steel [~ 240 BHN] , and the T-54 turret top is reported to have 330- 370 BHN rolled plate.

Semi hardened steel is usually 400- 500 BHN and appears in moderate thickness of several cm's and offers a Thickness Effectiveness [**TE**]of 1.2 to 1.25 , that's 20- 25% more resistance than RHA, the LEO-1A3 turret apparently features this kind of armor. Most western Chobham armored tanks feature semi hardened steel as a part of their layered structure. This steel is harder to weld into the structure which limits its use.

High hardness steel is about 500- 600BHN and offers about 30- 34 %more resistance than RHA steel ,but its costly [twice the price of RHA] , difficult to weld and can only be manufactured in thin rolled plates. Often this armor has to be bolted on to the main armor wall .**The French Leclerc tank and German Leopard - 1A3 features this armor layered with RHA and SHS , its assumed Leopard - 2s also featured these dual hardness and 'triple hardness steel'** . Layered steel with 250- 430 and 515 BHN - as in the Leopard 1A3 – thought to act like dual hardness and triple hardness armors.

It has been shown that Dual hardness armor plates offer about 1.6- 1.8 Te & Me suggesting there is a synergistic effect over and above what has already been reported, some sources suggest this advantage in layering is 15%.The Leclerc is reported to feature 80mm & 100mm plates of 430BHN 600BHN & 340BHN steel, with the hard plate in the middle.

[Gerard Turbe IDR 6/87 pp 758 & RM Ogorkiewcz IDR-4/91 pp352] **Infact these sources report the French Leclerc tanks frontal armor of Dual hardness armor combined in a sandwich of ceramics, offers a Mass efficency of 2:1 compared to RHA. This means the tanks armor offer twice as much protection against APFSDS projectiles as the same mass of steel would.** The Chieftains weight & volume are similar to the Leclercs and offers > 40cm of steel mass on the front turret. This suggest the Leclercs frontal turret armor protection is more than 80cm RHAe Vs APFSDS type projectiles. Taking the Leclerc example, these plates offer a t/d of ~ 2:1 so the steel component should resist as an averaging of [1.2+ 1.27 + 1.0/3]=1.16 times RHA but factoring in confinement , the dual hardness advantage becomes [1.16 x 1.25] 1.45 times RHA ….if we also add this 15% synergistic layering effect that's 1.66, close to whats reported above . This should making the potential of the LEOPARD 1A3 armor as ~ 1.5 times RHAe.

Generally speaking the ME of the above armors also applies to their effectiveness against shaped charges [HEAT], however its probable that Dual and triple hardness steels offer combinded ME of 1.4-1.6 depending on the research.

Sloped Armor

The next factor in determining the effectiveness of a tanks armor is slope. **On the face of it ,slope should not impact on armor design at all, since the more you incline a plate to armor a volume or profile, the more material you need to cover that profile**. Where slope becomes a factor is in the effect it has on the attacking projectile, this means that what ever effects it has ,is tied to the projectile nose design as much as the armor slope. However since the rear part of the plate will start to fail when the tip of the projectile reaches about 2 diameters from the back plate, this will become an increasing factor in sloped armor resistance.

Firstly All projectiles will ricochet, the real question is at what angle and velocity do they ricochet. Ricochet occurs when a attacking projectile glances of the sloped armor of a AFV without digging in far enough to penetrate the plate , if it has no time to dig in before it ricochets, it can't penetrate even modest amounts of armor. A complex model has been developed to predict the angle at which a projectile is expected to ricochet, see; **J Phys D Appl. Phys. Vol 12-1979pp 1825-1829.** There is not much research into the actual effects of ricochet so alot has to be based on theory. From **J Phys D Appl. Phys. Vol 35-2002 pp 2676-2686 ,** heavy metal 10:1 APSFDS rods ricochet is compared to theory and compared to the chart below is close to the ricochet for RHA. However its clear that the ricochet figures against Hard steel are much lower [easier to ricochet].

The longer the rod - the higher the ricochet angle and the faster the rod the higher the critical ricochet angle .In addition heavy metal rods of WHA or DU [**Wolfram Heavy Alloy –Tungsten & Depleted Uranium**] ricochet at higher angles than steel . Measuring angles from the vertical [I.E. 90° is horizontal] , a 10:1 L/d [**L**ength to rod **D**iameter] steel rod striking at 1.7km/s , should start to ricochet at ~ 78° while the same shape WHA /DU rod will start to ricochet @ 81°. Stretching the rod to a longer thinner projectile [15 times as long as it is wide (L/d=15:1)], should increases this ricochet angle to 82-83°. It is likely that 30 :1 L/d rods will start to ricochet at >84-85° .Comparisions between Tates Ricochet formula and the experimental values seem to show a 10° spread between 0° and 100° chance of ricochet . So 50% of the 10:1 steel rods should ricochet @ ~ 83° while ricochet will occur as high as 88°and as low as 78°. The above cases apply to thin targets plate ,but if the plate is over 4:1 T/d [**T**hickness / rod **d**iameter] the ricochet angles should go down a few degrees.

The following chart is simplified presentation of expected ricochet situations ased on A Tates critical Ricochet formula modified with experimental data from Rosenberg & Dekel as well as Lee etal.

Rough Summery of ricochet results……

Target is Composite armor	~1:1 T/d or less	~2:1 T/d	~4:1 T/d or more		
Target is RHA steel	Vs 0.5 :1 T/d or less	~1:1 T/d	~2:1 T/d or more		
Target is HARD steel	Vs 0.2 :1 T/d or less	0.21-0.59 :1	0.6- 0.9 :1	~1:1-1.5	1.5:1 T/d or more
All warheads without probe/proximate fuse					
HE & HEAT @ 200m/s & **LAW/GL** @ 50m/s	40±5°	20±5°	10° ±5°	7° ±5°	4° ±5°
HE & HEAT @ 300m/s & **LAW /GL** @ 100m/s	45±5°	30±5°	20° ±5°	15° ±5°	10° ±5°
AP/H @ 200m/s ; **HE & HEAT** @ 400m/s & **LAW/ATGM** @ 150m/s	51±5°	40±5°	30° ±5°	25° ±5°	20° ±5°
AP/H @ 300m/s ; **HE & HEAT** @ 500m/s & **LAW/ATGM** @ 200m/s	55±5°	46±5°	40° ±5°	35° ±5°	30° ±5°
AP/H @ 400m/s ; **HE & HEAT** @ 600m/s & **LAW/ATGM** @ 300m/s	58±5°	50±5°	47° ±5°	42° ±5°	38° ±5°
AP/H @ 500m/s; **HE & HEAT** @ 700-800m/s & **LAW/ATGM** @ 400m/s	59±5°	54±5°	52° ±5°	47° ±5°	44° ±5°
AP/ H @ 600m/s ; **HE & HEAT** @ 900m/s & **ATGM** @ 500m/s	64±5°	58±5°	56° ±5°	51° ±5°	48° ±5°

AP/ H @ 700m/s & **HE & HEAT @**1000m/s	66±5°	60±5°	59° ±5°	54° ±5°	50° ±5°
AP/H @ 800m/s & **APDS @** 700m/s	68±5°	63±5°	62° ±5°	56° ±5°	52° ±5°
AP /H @ 900m/s & **APDS @** 800m/s	69±5°	65±5°	64° ±5°	58° ±5°	54° ±5°
AP /H @ 1100-1000m/s ; **APDS@** 900m/s &**H-APDS**@ 600m/s	71±5°	68±5°	66° ±5°	60° ±5°	56° ±5°
AP /H @ 1200m/s ; **APDS @**1000 m/s & **H-APDS**@ 700m/s	72±5°	70±5°	67° ±5°	61° ±5°	57° ±5°
Steel APFSDS @ 0.8.km/s **APDS** @ 1100 & **H-APDS**@ 900-800m/s	73±5°	71±5°	69 ±5°	62° ±5°	58° ±5°
Steel APFSDS @ 0.9.km/s **APDS** @ 1.2.1.3km/s & **H-APDS**@ 1000m/s	75±5°	73±5°	72 ±5°	65° ±5°	61° ±5°
Steel APFSDS @ 1.0.1km/s **APDS** @ 1.4-1.5km/s & **H-APDS**@ 1.1-1.2km/s	76±5°	74±5°	73 ±5°	66±5°	62° ±5°
Steel APFSDS @1.2-1.3km/s **APDS** @ 1.6km/s **& H-APDS**@ 1.3-1.4km/s	78±5°	76± 5°	75±5°	68±5°	64±5°
Steel APFSDS @1.4-1.7km/ s **Sheathed** @1.2-1.3km/s	80±5°	78± 5°	77±5°	69°±5°	65±5°
Steel APFSDS @1.8-2.0km/s **Sheathed** @1.4-1.5km/s **H Sheath** @1.0-1.1km/s	82±5°	79± 5°	78±5°	70±5°	62°±5°
Sheathed @1.6-1.8km/s **H Sheath** @1.2-1.3km/s	81±5°	80± 5°	79±5°	71±5°	67±5°
1st APFSDS @ 0.9 - 1.0km/s **H Sheath** @1.4-1.6km/s	82±5°	81± 5°	80±5°	72 ±5°	68±5°
1st APFSDS @1.1-1.3km/s **H Sheath** @1.7-1.9km/s	83±5°	82± 5°	81±5°	76± 5°	72 ±5°
1st APFSDS @1.4-1.6km/s **2nd APFSDS** @1.0-1.2km/s **H Sheath** @ 2.0km/s	84±5°	83± 5°	82±5°	79±5°	76± 5°
1st APFSDS @1.7-1.8km/s **2nd APFSDS** @1.3-1.6km/s **3rd APFSDS** @1.0-1.4km/s	85±5°	84±5°	83 ±5°	81±5°	79±5°
2nd APFSDS @1.7-1.9km/s **3rd APFSDS** @1.5-2.0km/s	86±5°	85±5°	84±5°	83 ±5°	81±5°

AP/H = APC /HVAP
APDS = Tungsten carbide core[20-30mm APDS 76 & 84mm APDS/105mm L28/36 & M-329 100mm BM-8 & 122mm BM-11]
H-APDS = Tungsten Heavy alloy core [105mm M-729/L52 ; 120APDS ; 20mm DM-63; Rarden 30mm APDS & 35-40mm APDS]
GL= Grenade launcher
Steel APFSDS [Steel BM-6/9/12/15/17]
Sheathed [Sheathed with WC BM-3/20/21/22/]
H Sheath [Sheathed with Heavy metal DU/WHA BM-26/29/32/42/M- 735/120mmDM- 13]
1st APFSDS 2nd Generation monoblock 10-20:1L/d ; M-744/M833/M- 111/105 & 120mm DM-23
2nd APFSDS [21-29:1L/d monoblock; M-413 ,OF1-105,DM33/63 (105/120) NOR 125 ; BM-42M,L26/27,OFL-120 M-829A1
3rd APFSDS [30-40:1L/d monoblock; M-900,OF1-120, DM43/53(120),BM-5X, L-28, M-829A2/3/4
If old HEAT warheads [< 1970s] hits at angle above ricochet it has a 2/3 chance of failing to fuse altogether.
If old LAW/ATGM [< 1970s] warheads hits at angle above ricochet it has a ¾ chance of failing to fuse altogether
If modern LAW/ATGM [> 1979] warheads hits at angle above ricochet it has a 1/3 chance of failing to fuse altogether
Advanced HEAT /LAW/RPG/ATGM [probe/proximate fuze] = ignore ricochet [ricochet after jet penetration]

Since the time it takes a projectile to 'turn' is around 40-60 micro seconds, while the entire penetration event takes 200-400 microseconds [Medium to large warhead] , then even Shaped Charge warheads [**HEAT**] will ricochet when the right combination of striking velocity and angle are reached . **Modern HEAT rounds will ricochet, the only question is this whether this is before or after the Jet penetration**. Modern shaped charges with standoff probes and base initiation ,will start the jet penetration process before the main round impacts the slope armor. Since this is a ¼ to ½ a millisecond [200-500 micro second] event, its likely the main body of the round will not even have reached the sloped plate by then, in other wards ricochet should occure after jet penetration. Ofcourse modern HEAT warheads with proximity fuses will complete the firing process long before they make physical contact with the armor surface, so those shells can only ricochet after jet detonation and penetration is completed.

The second aspect of slope is the asymmetrical force acting on the penetrator. When a projectile strikes a sloped plate, the side of the penetrator closest to the plate will suffer more force/erosion and damage than the opposing side , this puts a unbalanced force on the penetrator turning it in towards the plate as it starts to penetrate. The penetrator can take a longer or shorter overall route through the armor resulting in less or more penetration of sloped armor, due to the projectile nose design.See; **1982 Rheinmetall Hand book on Weaponary [figure 1128] As a rule sharp nosed**

penetrators turn away from the sloped armor initially and then turn into to the plate , while blunt projectiles turn into the sloped armor immediatly.

This asymmetrical force on the penetrator varies from projectile to projectile , but it is tied to the nose shape of the penetrator. **Anderson Jr et al has shown the effects of nose shape disappear after the projectile has penetrated to a depth of two projectile diameters , therefore so does the effect on sloped penetration.** Now since AP shot only reach two projectile diameters penetration this nose effect is quite dramatic , but for 20:1 and 30:1 L/d long rod penetrators at higher velocity, the effect is marginal at best. What it means is that by the time you stretch to these rod lengths, any effect of slope is only a few % at best and by the time you reach shaped charge jet [100:1 L/d]the effect is no more than 1%.

The change of effect from slope [45- 60°] .All values are for a blunt rod and show how much the LOS thickness is effectively reduced by the change in plate thickness and increaseing rod length.

T/L	AP	APDS	APFSDS 1st Gen	2nd Gen	3rd Gen
L/d	3:1	4.5:1	10:1	20:1	30:1
thin	0.97	0.98	1.00	1.0	1.0
moderate	0.71	0.82	0.89	0.95	0.97
Semi Inf	0.68	0.79	0.88	0.94	0.96

See Int J Impact Engng Vol- 22 1999 - pp 189- 192 Int J Impact Engng Vol 17' pp263- 274 1995. 1982 Rheinmetall Hand book on Weaponary....[figure 1128]

The effect of increasing the armor resistance by slope can also be achieved by curving the armor. What happens is the slope is now a combination of both the 'tangent' of the horizontal and the vertical planes . To determine the net 'compounded armor slope' the following formula is used.

$$\sqrt{\left(\left(\frac{1}{\cos(V^\circ)}\right)^2+\left(\frac{1}{\cos(H^\circ)}\right)^2\right)-1}$$

COS= Cosine
V°= Vertical angle
H °= Horizontal angle

The problem with the above formula is that looking at vectors, the compounded angle should be V angle x H angle . In addition this might work for old thinner armors that were highly sloped , with the inner face of the plate parallel to the outer face of the armor , but with the armor on modern tank turrets, the inner wall rearly parallels the outer wall, so the only way to get a good LOS thickness is to measure from the AFV itself or a scale plan view of the AFV....this will lead to a certain amount of increased error in such armor estimates.

In a number of works [Zukas **High Velocity Impact Dynamics", [Figure 69]],** the resistance of finite thickness plates at normal and slanted impact angles have shown a increase in penetration of about 1.3 projectile diameters over the penetration into semi infinitie targets of the same materials. This is a figured averaged over 50 published test results, but there is considerable variation from test to test **[Hohler and Stilp (1987); Magness (Properties and Performance of KE Penetrator Materials) ; Leonard ("Improving mechanical properties of tungsten heavy alloy composites through thermomechanical processing.") & others]** .This advantage appears to decrease as the projectile velocity increases.So if the target is at 0°, the difference between semi infinite and finite penetration should be ~ 1.3d [1.0-1.7d], while at 60°, the increase should be + 1.3d @ 60° or roughly + 2.6d , LOS penetration.But a lot depends on the nose shape of the penetrator. In some tests **{Leonard 1997APG MD 21005- 5066, "The effecty of nose shape on depleted Uranium {DU} long –rod penetrators"},** sharp nosed penetrators achieved 1d penetration increase over semi infinite targets @ 0°, while - 0.25d @ 70°.So if the projectile is 4cm diameter and the semi infinite penetration was 40cm , then the finite penetration at 0° should be 44cm, while @ 70° it should be 37.1cm [LOS] or 12.6cm @ 70°. In the same tests blunt penetrators got +1.2d @ 0° and +1.3d @ 70°, while frustum nosed [truncated conical] got +1.2d @ 0° and +1.0d @ 70°.

With the increasing use of special armors there impact on sloped armor must also be assessed. When ceramics are struck the effect is to create a hugh 'shatter zone' radiating outwards in an elliptical pattern that's conical shaped in depth and larger than the same crater radiated into a Steel target. **When the Ceramic plate is slanted the effect is to dramatically reduce the efficiency of the sloped armor.** Tests on sloped ceramic - steel targets struck by AP shot show the effective resistance is only 1.6 times the **L**ine **O**f **S**ight [LOS] thickness @ 60° . The impact of the same type of projectile [API] on an all steel target should result in the effective LOS increasing from 2.1 to 2.5. See; **Int.J.Imapct Engng Vol 19- pp 811- 819.& Shock under Impact IV pp 91- 101 .** Test of APFSDS on slanted ceramic steel targets report no difference in the penetration compared to the LOS thickness suggesting this problem doesn't necessarily apply to the all important APFSDS case. See; **Int.J.Imapct Engng Vol 23- pp 771- 782.**

T/d & Free Edge Effect

When determining the resistance of steel plate several additional factors should be included . These are ‘lateral confinement’ and the ‘T/d effect’. T/d refers to the ratio of the thickness of the armored plate to that of the attacking projectile, while lateral confinement refers to the ratio of the diameter of the attacking projectile to the width of the armored plate. **Tests done on armor material will always yield different results if either the T/d or the Lateral confinement ratios are too low**. For modern APFSDS the width of the plate must be more than 30 times the diameter of the attacking rod , for all results to be stable and transferable to another case for comparison. Along the main turret walls of a real tank target, this effect is marginal, but near the mantle the effect reduces the armored resistance to 80%. Further, test on ceramic steel targets show the effect is much more dramatic .

	Mantle	1 Oclock	2 Oclock	(Front turret Hit location)
All Steel	**~ 0.80**	**~ 0.90**	**0.95**	(%reduction in resistance)
Ceramic/Steel	**~ 0.60**	**~ 0.85**	**~0.90**	(%reduction in resistance)

However ceramic tile are have a limited size which controls the lateral confinement instead of its relative position on the turret etc. In some cases these may be 12- 14 inches on a side leading to a 85% lateral confinment value, if these tiles where a lot smaller the value should be about 70% of the resistance due to Lateral confinment.For example the ceramic tiles used in the T- 80A [prototype] had lateral dimensions of only ~ 6cm . So if these where struck by 3cm diameter rod they ould only offer 50% of their effective thickness resistance.

In addition the ratio of the thickness of the plate to the diameter of the projectile can further reduce the expected resistance of a target plate.
Penetration of 4:1 L/d Tungsten alloy rod [same alloy as above] into a Ceramic Steel target made of AIN and Mild steel at velocities form 1300- 2600 m/s. Here are some results from Int.J.Impact Eng Vol 26 pp 831- 841.

T/d	**5:1**	**2.5:1**	**1.2:1**	**0.9 :1**	**Thickness/ rod diameter**
P/L	0.7	0.83	0.9	1.02	penetration of target
P/L	0.64	0.64	0.64	0.64	penetration of RHA
Te	**0.91**	**0.77**	**0.71**	**0.63**	**comparison of resistance to RHA**

Select 'AIN ' layered [Aluminum Nitride Cerami.] targets are subjected to impacts of long rod penetrators at velocities from 1100m/s to 2600m/s. Target 'AIN ceramic with Aluminum' backing and the penetrator is a 6:1 Tungsten alloy penetrator with a impact velocity of 1150 m/s and a density of 18.6 g/cm³ and a hardness of Rc 29 with a UTS of 0.88 GPa.

These are important results since the targets are multilayered , sometimes with as many as 12 layers, so they parallel the expected armor layout in modern tanks. P/L means that the rod can expect to get a penetration into that target of this proportion of the rod lenght .So if its reported tobe 0.9 then it can expect to penetrate 90% of its length. The plate was only 24 times the rod diameter so the penetration is slightly increased due to 'lack of sufficent lateral confinement'. That adds up to a 78% resistance difference between 3:1 t/d [2- 4 layers] & 0.5:1 t/d [12- 14 layers] Here are the results...
- -

Velocity				
	1310m/s	**1790m/s**	**2580 m/s**	
T/d	**3:1**	**5.8:1**	**6.2:1**	**Thickness / rod diameter**
	25- 75	**40- 60**	**40- 60**	**%ratio of Ceramic to steel**
P/L	0.97	1.38- 1.49	1.9 - 1.96	penetration of target
P/L	1.11	1.42	1.72	penetration of mild steel
P/L	0.91	1.39	~ 1.57	penetration of RHA [Anderson] pp
Te	**0.89**	**0.93- 0.86**	**0.83- 0.8**	**comparison of resistance to RHA. [adjusting for Lateral confinement effects]**

1.31 x 1.044 - 0.48 = 0.91
1.79 x 1.044 - 0.48 = 1.39
Source ; Int.J.Impact Engng Vol 25 pp 211- 231 [2001]
Here the resistance loss is ~ 69% total between 5:1 T/d & 0.9:1 T/d ...lateral confinement figures were 16:1 to 24:1

Summarizing data

T/d 6:1	**5:1**	**3;1**	**2.5:1**	**1.2:1**	**0.9 :1**	**Thickness/ rod diameter**
0.93	**0.91**	**0.8**	**0.77**	**0.71**	**0.63**	**@ 1150m/s**
		0. 79				**@ 1310 m/s**

0.89* **@ 1790m/s [*0.93- 0.86]**
0.82* **@ 2580 m/s[* 0.83- 0.8]**
Te comparison of resistance to RHA 1150m/s 6:1 L/d WHA

Ceramic t/d Model [Ratio of plate thickness / projectile diameter]

9.0	**8.0**	**7.0**	**6.0**	**5.5**	**5.0**	**4.0**	**3.0**	**2.7**	**2.5**	**1.8**	**1.2**	**0.9 :1**	**0.67:1**	**Thickness/ rod diameter**
0.96	0.95	0.94	**0.93**	0.92	**0.91**	0.85	**0.8**	0.78	**0.77**	0.74	**0.71**	**0.63**	**0.58**	**@ 1150m/s**
0.95	0.94	0.93	0.92	0.91	0.85	**0.8**	**0.78**	0.77	0.74	0.71	0. 63	0.58	0.53	**@ 1310 m/s**
0.94	0.93	0.92	**0.91**	**0.85**	**0.85**	**0.8**	0.78	0.77	0.74	0.71	0. 63	0.58	0.54	**@ 1790m/s**
0.93	0.92	0.91	**0.85**	**0.8**	0.78	0.77	0.74	0.71	0. 63	0.58	0.54	0.5	0.46	**@ 2580 m/s**

Result is the relative resistance of the ceramic.

For WW-II AP type shot @ ~ 800m/s the effect of free edge and effect of previously penetrated plate is different and test conditions suggest that the maximum area of effect for the free edge is only 3-5 projectile diameters before the plate is considered to be confined. This means rougly the number of projectile diameters from the gun embrassure or MG port and effective resistance is …..**See Int.J.Impact Engng Vol 19 pp 311 – 318. And Int.J.Impact Engng Vol 19 pp 297-309. As well as Int.J.Impact Engng Vol 16 pp 293-320.**
Author estimates of free edge effect on AP projectiles

1 diameter	2 diameter	3 diameter	4 diameter s
~ 60-70%	80-90%	~ 95%	~ 100%

A good old example of this effect is the front turret armor on the WW-II Tiger –1 tank. While the front turret armor was RHA & cast , ranging from 140-200mm LOS thickness [either 100mm cast mantle plus 100mm front turret or 140mm cast mantle] but reoportedly the 76mm APCBC round could not penetrate at muzzle @30°, which is a penetration of over 5.25 inches of RHA or 133mm @0°. On the other hand the M-36 Tank destroyer firing the M-82 [early] 90mm APC round should penetrate < 50 m range from straight on while the late model should penetrate @800m from straight on , these represent penetrations of 6.1 –6.2 inches or 155-157mm , so the effective resistance should be between 133 & 155mm.

In all cases, the T/d must be 1.6 times the rod expected penetration for a target to be considered "semi Infinite". **Confinement is important because as the shock wave of impact moves through a target plate it reflects from the 'free edge' ,crosses back over new waves eminating from the impact point, creating a 'weakened zone'through interference** . In the case of ceramics and composites ,this area is much larger than steel and is visible in the form of ceramic tile shattering and composite 'delamination'. See;**Int.J.Imapct Engng Vol 19- pp 49- 62.**

The APFSDS T/d effect starts to diminish rapidly so that after 3:1 its not that much different than the semi infinite case [3-5% below]. This has its greatest impact on multilayered and spaced armor . Against such plates, the resistance of the plate is reduced anywhere from 95 to 60% .See;**Int.J.Imapct Engng Vol 23- pp 639- 649.**Lateral confinement has its greatest impact in the turret armor on modern tanks .The gun embrasure area presents a 'free edge' which goes along way to explaining why most tank turret armor thickens as you approach the mantle area. In the past this effect was also responsible for reducing the strength and resistance of glacis plates around the hatch and MG-port areas, which is why this practice has been discontinued. The corner of a turret or hull does not consitute a 'free edge' because the shock waves travel around the corner and don't bounce back to the impact point.This would not be the case if the corners of the turret or hull were poorly welded as was the case in some WW-II tanks [some T-34s and late model German tanks].In these cases the weld lines would constitue a weakened zone leading to unusually large penetrations.

Light metals

Aluminum — The post WW-II period saw a number of special armors developed to enhance armor resistance to Shaped Charge warheads including, ERA, aluminum and ceramic armor, to name a few but all these were too expensive, except for aluminum. At 1/3 the density of steel ,Aluminum was an attractive alternative to steel especially in the construction of light AFVs and support vehicles. Unfortunately along with the lighter construction comes a corresponding lower resistance, AL5083 [M113; M2/3 and LTVP-7 AFVs] offers only 30-40% of the resistance of RHA [14.5mm API shot]. This type of aluminum is only 2.66 g/cm³ [compared to 7.83 g/cm³ for RHA], and resists corrosion well, but cost twice as much as RHA .

The main way in which armor is rated in relation to RHA, is by thickness effectiveness [Te].As already noted Al-5xxx series aluminum offers a resistance of ~ 0.3 'Te', what this means is that 100mm AL-5xxx will offer

the equivalent to 30mm RHA[even though its mass is only equivalent to ~ 30mm RHA] . The 5xxx series Aluminum has been supplemented by the AL 7xxx series aluminum [AMX-10, Scorpion /Simitar AFVs & Warrior ICV and BMP-3 ?] . This suffers from corrosion and stress cracks but offers better ballistic resistance[Te =0.47 Vs 14.5mm API]. See ; **Int Defence Review 4/91 pp 349- 352** Some resent Aluminum ballistic test reveal that new Aluminum Lithium alloys like the 2090 series and "weldalite" feature ballistic resistance of 65% and 100% of RHA standard [270 BHN type 4340 steel] against API projectiles. See ; **Metallurgical & Materials Transactions Vol- 29A [Jan '98] pp 227- 234.** Aluminum was experimented in the MBT-80 design and is included in the side hull skirting and rear armor of a number of tanks and Russian author V.Chobitok's "Main battle tank T-64", reports the T-64 turret has cast armor and aluminum, its also possible the original LEO-2 armor may have featured aluminum sandwiched between semi harded steel plates. Many Infantry Combat Vehicles feature aluminum as their main armor especially in tandem with hard steel plates .

Titanium An interesting alternative to Aluminum is Titanium , which has a density of only 4.5 g/cm³ and offers resistance of 90% of RHA [APFSDS] , however Titanium is very expensive and many times that of aluminum which its self is twice as expensive as RHA. Titanium is known to be used in select items of the M-1s armor to reduce weight and maybe used in the modern version of BDD armor in Russian tanks ?See:**Int.J.Impact Engng Vol- 20; pp 121- 129 .** Recently its been reported that a cheaper method of manufacturing Titanium has been perfected so increasingly Titanium should be used in tank armors in the future**!** **http://www.ciar.org/~ttk/mbt/rha.Montgomery- 9705.html**

Honeycomb structure & Fuel Cells.Tests of 7.62mm AP & 12.7mm AP striking thick aluminum honeycomb structures sandwiched between thin aluminum plates reportedly offered ~ 70% of the resistance of RHA , when the same mass resistance of solid Aluminum should be 47% of RHA; that's 1.5 times better. Apparently this kind of construction is quite cheap compared to modern layered armors and is already in wide spread use inauto industry construction ...always an important consideration.This is considered to be an ideal ultra light interlayer materials [along with foamed metals] to preserve as much mass for the Ceramic component in the construction of sandwich armor.

The fuel cells mounted around the driver of the M-1 tank are thought to feature honeycomb structure to increase resistance in the front hull. In addition Desiel fuel has been shown to be a reasonable armor and by integrating it into the armor ,opens doors to increased levels of protection. However great care has to be taken to avoid vapour build up in these armors as this will lead to fires. Its thought that the inclusion of honeycomb structure into such fuel cells helps to condense these vapours, thereby reducing the likely hood of fuel related fire damaging the tank and crew. Events in Operation Iraq Freedom would tend to support this, however in a limited number of cases such impacts do infact lead to fuel fires. **To model fuel cells a value between water and Methanol was used** , Methanol has a **'Te'** of 0.63 against shaped charges . See;**Int.J.Impact Engng Vol19 pp361- 379.** Water cells offer a **'Te'** resistance of 0.15 Vs APFSDS, while a target of 600mm of water offers the same resistance to shaped charges as 300mm Aluminum which offers the same resistance as 150mm RHA [Te of 0.25] .This suggesting a overall **'Te'** value for diesel fuel of 0.45 HEAT . See; **Int.J.Impact Engng Vol- 23,pp585- 595.**

In a research paper [Int.J.Impact Engng Vol-23,1-12] "Long Rod Penetration into highly oblique water-filled targets". APFSDS penetration of varing strength penetrated multiple steel tanks filled with water. These resulted in a erosion rate of

Sheathed 0.1- 0.15cm/cm [V =1.5- 1.75km/s]
Monoblock 0.05- 0.1cm/cm [V =1.5- 1.75km/s]
High Strength 0.0- 0.03cm/cm [V =1.5- 1.75km/s]

This suggest that fluid resistance to long rod penetration is controlled by striking velocity and projectile strength.So the 1m fuel cell on the M-1 front hull [either side of the driver], should result in ~ 10-15cm of additional resistance against a sheathed penetrator [like most soviet cold war APFSDS round].If the penetrator is a monoblock penetrator, that would be 5-10cm additional resistance instead infact add the walls of the fuel cells and this is 5cm additional resistance, while if this is a honeycomb structure , the additional resistance should go up a further 10-15cm.. There was reported to be a large incidence of rods shattering while penetrating water filled targets.
So a M-1 glacis resistance [Vs 3-4cm sheathed penetrator] should be 5cm HRHA @ 82° x 0.9[t/d] =35.6cm plus 15cm [Water]+2cm [walls] = **52cm RHAe**. With a honey comb fuel cell this becomes **57- 62cm RHAe**. Later as the 2.5cm monblock BM-42m is introduced,this becomes 5cm HRHA @ 82° x 0.92[t/d] =36cm plus 5-10cm[Water]+2cm [walls] +10-15cm [honeycomb]= **53- 58cm RHAe.**

Composites Many lightweight materials , like Fiberglas have also been tested **,** in an effort to replace part of the dependence on heavy steel in AFV design. Usually these composites involve fiber material that is suspended in a medium for reinforcement and stiffening. The mediums can be Epoxy, Thermoplastic's ,Vinylester ,Polyester or some Phenolic type material. These also boost the density of the material and allow it to change from 'cloth or fabric' to 'panels'.See; **DREV paper Sept'95 M-Szymczak** . Steltexolite is a example of a light weight Russian Fiberglas that uses 'glass cloth' and is also known to be used extensively in Russian tank armor. **Steltexolites material compares well with aluminum in terms of resistance Vs KE projectiles and is slightly better Vs Shaped Charges . This despite the fact that its 2/3 the density of aluminum**. See ;**Int.J.Impact Engng Vol 17 ; pp 751- 762.** Modern advanced composites carry ceramic strands reinforced with coatings of Boron or Carbon, these have been shown to boost the strength of composite armor by as much as 50% . In some cases these offer the same strength as high strength

Aluminums or mild steel @ only 40% fractional volume.Thus a composite with a density of around 1.3 to 1.5g/cm3 could have the resistance of Aluminunm or mild steel [50- 60% of **RHA] .** See ;**Int.J.Impact Engng Vol 25 ; pp 29- 40.**

Spall Liners Polyurethan and Kevlar are a common composite material used in the west as "spall liners" in tanks like the British Chieftain ,but is also used as backing material for ceramics, in armor like the M-1 Abrams & LEO-2[?]. Kevlar offer less resistance to AP shot compared to Fiberglas but comparable figures Vs APFSDS and HEAT. Not as good as Steltexolites but lighter at ¾ of the density , its good as a Spall liner .**The effect of spall is like a 'small grenade' going off inside the AFV , but with the addition of spall liners this is reduced to a 'shot gun blast'**[50% reduction in particles and blast cone]. Newer materials like 'Spectra Shield' and 'Dyneema' achieve the same effect as Kevlar, but at 2/3 of their weight. Dyneema is of note as being the liner in Canadian and German AFVs[in particular the LEO-2A5] and offers comparable resistance to Fiberglas at 1/3 its density. See ; **DREV paper Sept 1995 M-Szymczak .**

In a research paper [Int.J.Impact Engng Vol 26,pp 21- 32], the effects of simple polyurethane spall liners were tested against 115mm Shaped charges and the resultant BAD [Behind Armor Damage] effects estimated based on the 'German tank vulnerability model' [PVM] where tested. This was based on a NATO damage model 'hamonized with vulnerability models' used in the USA, UK and France. In these simulations the resistance of the side armor of a T-72 Type target Vs a 115mm HEAT warhead [penetration listed at 800mm] was reported at 60% kill, while the frontal kill chance was estimated at 50%. With the addition of a 20mm liner ,the 'BAD' figures dropped enough to be similar to a 10% drop in penetration. While a 50mm liner resulted in a drop in simulated 'BAD' figures similar to 20% drop in penetration.The paper makes a tentative assessment that each 10% kill change is 'similar' to the effect of 80mm additional RHA , in the above mentioned test case. That suggests a drop of about 1/10th of the penetration per 20mm spall liner ! Simple [~ 4- 5cm thick] polyurthen spall liners have been noted on Russian/Ukrainian tanks since the mid 1990s and is known to have been installed in German LEO-2A5/6 tank and APCs like the British Warrior, French VABNG, Canadian M-113 & LAVs and American Bradely and Stryker APC vehicles.

In a follow up paper [Int.J.Impact Engng Vol-29,pp 95- 104], the effects of sloped armor and spall liners was studied in contrast to impacts on vertical targets.The general shape of the BAD cloud behind the armor is elliptical and results in about a 1 meter radius of debree that can injure kill or damage essential components in the AFV. When a shaped charge warheads impact sloped plates the shape of the BAD cloud is redirected some what into a downward pointing elliptical shape. Which means BAD cloud can be redirected by slope. However when the sloped plate included a spall liner it dramatically altered the BAD cloud into a 'funnel' shaped cone that's much less effective. Infact the image of the debree from the 80% overmatch case [800mm warhead vs 160mm armor] with a 50mm spall liner at 60° , was similar to the BAD debree cloud from a 20% over match [IE 800mm vs 640mm]. So it would appeat that the BAD effects are greatly reduced by sloping armor and adding a spall liner.

CERAMICS

By far the most common 'special armor' studied to increase AFV protection is ceramic and its assumed to be the main component in Chobham armor, infact many research papers report that modern armor is composed of layers of confined ceramics , composite and steel. Ceramics are very light hard materials, over 4 times as hard as the hardest steel at only half the weight.

> Rolf Hilmes reports in his book "Main Battle Tanks –development in design since 1945",
> *"Back in the mid 1976 the British put there 'Chobham Armor' on show. This was a part laminated part spaced armor array with elements of steel ceramics and aluminum, claimed to give higher protection against both CE & KE attack than steel armor , and for less weight"….."the ballistic effectiveness of the compouned armors against KE penetrators shows an improvement of only 1.2 to 1.4 over homogeneous rolled steel plate (incontrast to a factor of 2 against shaped charges." [pp 76&77]*

In point of fact the above tests results are for openfaced sandwiches and once the cover plate is added the Chobham armor can reach 1.5 to 1.6 times the RHAe standard [Type 4340 steel @ BHN 270].

This combination of light weight and high hardness ,offers resistance to KE warheads comparable to RHA and more importantly resistance to shaped Charge warheads up to twice the amount RHA offers. While this makes them good armor material, there are several draw backs to the use of ceramics in tank design. Firstly ceramics lack mechanical strength and can't be used as support structures .Therefor to be most effective they must be encased in metal thus diluting some of the 'mass effectiveness' benefit . While the most basic ceramic - Alumina [AL^2O^3] - is about as expensive as Aluminum or hard steel [twice the price of RHA] , the really mass efficent ceramics can be up to 10 times the cost of Alumina [20 times the cost of RHA] . [see JoBt Vol]

Ceramics have additional performance problems since they shatter ,due to there highly brittle nature. In test, the resistance of a shattered steel- ceramic has been shown to only drop a few %to ~ 97%vs AP threats . In addition, test on AP impacts of sloped Ceramic- steel targets show that resistance is less than the LOS value, when the slanted resistance of RHA is often more than the LOS against the same projectile . However , **In tests with APFSDS against slanted ceramics [SiC,AIN, AD- 96, B4C &TiB^2] offered about the same resistance as the LOS suggests.** [See Int.J.Impact Engng Vol Horsefel].

A large number of ballistics tests have been conducted over the decades with ceramic and other layers of steel aluminum and kevlar in order to improve the resistance of light AFVs to attack from LMG; HMG and autocannon fire . These appear to have surfaced in recent decades in ceramic applique armor on the British Warrior ICV and the LAV as well as the XM-8 and Stryker.In future this may become common place in almost all infantry carrier type vehicles. Here are some interesting results from some tests published [Stuctures under Shock and Impact IV,pp 91-101].

10mm Kevlar = 2mm RHAe [**Ballistic limit thickness to stop** 7.62mm FSP]
9mm Alumina/Aluminum = 9mm RHAe [**Ballistic limit thickness to stop** 7.62mm Ball]
8mm AL 6xxx & 9mm Alumina = 29mm RHAe [**Ballistic limit thickness to stop** HMG]
9mm AL 6xxx & 8mm Alumina = 29mm RHAe [**Ballistic limit thickness to stop** HMG]
17mm Alumina/Aluminum = 29mm RHAe [**Ballistic limit thickness to stop** HMG]

21mm AL 6xxx & 6mm Alumina = 29mm RHAe [**Ballistic limit thickness to stop** HMG]
13mm MS & 6mm Alumina = 29mm RHAe [**Ballistic limit thickness to stop** HMG]
10mm RHA & 6mm Alumina = 29mm RHAe [**Ballistic limit thickness to stop** HMG]

[Ballistic limit thickness to stop a LMG= 7.62mm APM2 @ muzzle]
20mm Alumina/Kevlar @ 0° = 15mm RHAe [LMG] = 0.74 Te
18mm Alumina/Kevlar @ 30°= 13mm RHAe [LMG] =15mm LOS RHAe
14mm Alumina/Kevlar @ 45°= 10mm RHAe [LMG] = 14.5mm LOS RHAe
10mm Alumina/Kevlar @ 60°= 7.4mm RHAe [LMG] =14.8mm LOS RHAe

19mm B4C/Kevlar @ 0° = 15mm RHAe [LMG] = 0.79 Te
15mm B4C/Kevlar @ 30°= 12mm RHAe [LMG] = 13.5mm LOS RHAe
13mm B4C/Kevlar @ 45°= 10mm RHAe [LMG] =14.5mm LOS RHAe
11mm B4C/Kevlar @ 60°= 8mm RHAe [LMG] =17mm LOS RHAe

[Ballistic limit thickness to stop a HMG= 12.7mm M2 AP @ muzzle]
41mm Alumina/Kevlar @ 0° = 29mm RHAe [HMG]= 0.71 Te
36mm Alumina/Kevlar @ 30°= 26mm RHAe [HMG] =30mm LOS RHAe
31mm Alumina/Kevlar @ 45°= 22mm RHAe [HMG] = 31mm LOS RHAe
26mm Alumina/Kevlar @ 60°= 19mm RHAe [HMG] =37mm LOS RHAe
21mm Alumina/Kevlar @ 70°= 14.7mm RHAe [HMG] =43mm LOS RHAe
13mm Alumina/Kevlar @ 80°= 9.1mm RHAe [HMG] =52mm LOS RHAe

38mm B4C/Kevlar @ 0° = 29mm RHAe [HMG]=0.75 Te
33mm B4C/Kevlar @ 30°= 25mm RHAe [HMG] = 29mm LOS RHAe
29mm B4C/Kevlar @ 45°= 22mm RHAe [HMG] =31mm LOS RHAe
24mm B4C/Kevlar @ 60°= 18mm RHAe [HMG] =36mm LOS RHAe
19mm B4C/Kevlar @ 70°= 14mm RHAe [HMG] =42mm LOS RHAe
12mm B4C/Kevlar @ 80°= 9mm RHAe [HMG] =52mm LOS RHAe

[Ballistic limit thickness to stop a 30mm APDS @ muzzle]
120mm B4C/Kevlar @ 0° = 74mm RHAe [APDS]=0.62Te
110mm B4C/Kevlar @ 30°= 68mm RHAe [APDS] = 79mm LOS RHAe
94mm B4C/Kevlar @ 45°= 58mm RHAe [APDS] =82mm LOS RHAe
76mm B4C/Kevlar @ 60°= 47mm RHAe [APDS] =94mm LOS RHAe
55mm B4C/Kevlar @ 70°= 34mm RHAe [APDS] =100mm LOS RHAe
32mm B4C/Kevlar @ 80°= 20mm RHAe [APDS] =116mm LOS RHAe

Here are the results of a battery of ‘normal angled’ impact tests from the engineering Journals.

Resistance relative to RHA Vs APFSDS

Ratio of thickness of ceramic to steel in target	1:3	2:2	3:1	Sources
Resistance of Plexiglas / RHA	**0.48**	**0.47**	**0.4**	Int.J.Impact Engng Vol-17,pp 195-204
Resistance of Pyrex /Steel	**0.58**	**0.87**	**0.8**	Int.J.Impact Engng Vol-23,pp 771-782
Resistance of Pyrex /Tungsten	**1.06**	**1.12**	**1.16**	Int.J.Impact Engng Vol-23,pp 771-782
Resistance of Pyrex /Aluminum	**0.46**	**0.6**	**0.78**	Int.J.Impact Engng Vol-23,pp 771-782
Resistance of fuzed Quartz/RHA	**0.62 [.9]**	**0.58 [.78]**	**0.5 [.62]**	Int.J. Impact Engng Vol-17,pp195-204
Resistance of AD-85/RHA @ 1.7k/ms	**0.96**	**0.99**	**0.89**	
Resistance of AD-96/RHA @ 1.7 k/ms	**0.96?**	**0.98**	**0.93**	
Resistance of AD-95/SHS @ 1.7k/ms	**1.2**	**1.07**	**1.05**	Int.J.Impact Engng Vol-17,pp 409-418
Resistance of AD-95/SHS @ 1.3 k/ms	**1.3**	**1.18**	**0.98**	Int.J.Impact Engng Vol-17,pp 409-418
Resistance of AD-95/RHA @ 1.5 k/ms	**1.0**	**1.03**	**0.96**	
Resistance of AD-99/RHA @ 1.7k/ms	**1.04**	**1.08**	**?**	Int.J.Impact Engng Vol-18,pp 1-22
Resistance of AD-99/SHS @ 1.7k/ms	**1.08**	**1.15?**	**?**	Int.J.Impact Engng Vol-18,pp 1-22
Resistance of UO^2-87/RHA @ 1.5 k/ms	**1.04**	**1.6**	**2.0**	**[estimated]** Adv Comp’93 pp 141-146

Resistance of UO^2-100/RHA @ 1.5 k/ms **1.22 1.8 2.34 [estimated]** Adv Comp'93 pp 141-146
Resistance of AIN /RHA @ 1.8k/ms **0.96 1.06 0.97**
Resistance of SiC /RHA @ 1.7k/ms **0.96 1.02 1.02**
Resistance of B4C/RHA @ 1.7 k/ms **0.93? 0.91 0.87**
Resistance of B4C/SHS @ 1.7 k/ms **0.? 0.87 0.81** [Shock Compression of Condensed Matter 1997 pp917-920]
Resistance of B4C/RHA @ 1.7 k/ms **0.? 0.76 0.71 [adjusted x 0.873]**
Resistance of SiC / SHS @ 1.7k/ms **0.? 1.07 1.04** [Shock Compression of Condensed Matter 1997 pp917-920]
Resistance of SiC /RHA @ 1.7k/ms **0.? 0.93 0.9 [adjusted x 0.873]**
Resistance of TiB^2 / SHS @ 1.7k/ms **0.? 1.34 1.6** [Shock Compression of Condensed Matter 1997 pp917-920]
Resistance of TiB^2 /RHA @ 1.7k/ms **0.? 1.17 1.42 [adjusted x 0.873]**

Resistance relative to RHA Vs HMG/API

Ratio of thickness of ceramic to steel in target	**1:3**	**2:2**	**3:1**	**3.5 : 0.5**
AL-6061 /AD-85 Vs AP [Al 6061 = 0.47 Te]	**0.56**	**0. 85**	**0.94**	**0.75**

7.62mm AP vs Alumina/aluminum targets compared to penetration into aluminum [source IJIE Vol 9,pp-455-474]
840m/s Vs 9.1mm Alumina +1mm aluminum = 48mm aluminum penetration.
780m/s Vs 6.3mm Alumina +1mm aluminum = 48mm aluminum penetration.
940m/s Vs 9.1mm Alumina +1mm aluminum = 51mm aluminum penetration.
880m/s Vs 9.1mm Alumina +4mm aluminum = 115mm aluminum penetration. Projectile had a W2 tungsten core.
12.7mm FSP @ 1km/s = 17mm aluminum or 9mm alumina + 5mm aluminum
12.7mm FSP @ 1.66km/s = 33mm aluminum or 12.7mm alumina + 15mm aluminum

Semi Infinite penetration test into the following …..
APFSDS into Aluminum Nitrite ceramic target [AIN] offers 0.97 the resistance of RHA.
APFSDS into Boron Carbide ceramic target [B4C] offers only 0.82 the resistance of RHA.
APFSDS into Silicon Carbide ceramic target [SiC] offers 1.1 times the resistance of RHA.
APFSDS into Titanium Diboride target [TiB^2] offers 1.2 times the resistance of RHA.
APFSDS into"Syndie' target [Composite Diamond] offers 2.2 times the resistance of RHA.
APFSDS into DU ceramic/steel target [UO^2-87] offers 1.93 times the resistance of RHA.
APFSDS into DU ceramic/steel target [UO^2-100] offers 2.67 times the resistance of RHA.

Shaped Charge resistance vs multi layered ceramic steel targets.

RMOgorkiewicz in his IDR article [April 1991] reported that the ME of glass struck by shaped charges [HEAT] was 2.32 with a density of 2.45g/cc , which suggests the per thickness effective resistance [Te] is 73% of RHAe. That means 200mm glass should offer 146mm RHAe. In the same chart [pp351] he also reports that Alumina [AD-90] with a density of 3.6g/cc boasts a ME of 2.97 , which suggests the Te [thickness effectiveness] of ~ 1.36 compared to RC-27 RHAe. That means that 200mm Alumina should offer ~ 272mm RHAe protection against HEAT warheads.

However real targets are sandwiched between steel and other materials to fit into the construction of modern tanks etc. When such combinations of armor are tested they appear to exhibit much higher levels of resistance to shaped charge attacks. In a paper from the the International Symposium on Ballistics [TB-16 '1988] penetration into HV 475 steel reached 190mm while a multi layered steel –glass- steel target [8-12 layers] resulted in a penetration of only ~ 105mm [same charge]..Thus the combination of the hard steel and the glass result in an overall Te of 1.81 . Experimentally the jet penetration should be ~ 215mm penetration suggesting the hard steel –glass layered target offered 14% improvement over RHAe [@ 6 diameter standoff]. At 2 diameters the figures were 194 mm & 170 mm , also 14%. So theoretically combining the materials should provide a ~14% improvement in resistance , but when the standoff is increased to 6 diameters the resistance becomes 1.81 when the theoretical figures should be 0.93 .**At the increased standoff the same projectile target combintion <u>doubles</u> the effectiveness of the elements instead of increase of 14%.** Even at the shorter 2 CD standoff the effectiveness of the glass steel sandwich increased by 40% if the ratio of glass to steel reached ½ and ½ .

In a separate study [IntJ Impact Engng Vol-20,pp 375-386], the same authors used alumina ceramic , layered with steel [8-12 layers] and subjected to the same sized shaped charged warhead attacks. The combined resistance should have resulted in [(1.36+ 0.95) ÷ 2] a 16% increase compared to RHAe [for the ½ & ½ case] . In fact the effective resistance turned out to be 1.81 Te @ 6 CD standoff [215 mm /119 mm] and or a Te of 1.34 [194 mm /145 mm] at 2CD standoff. **That means the real sandwiching of steel and ceramic resulted in a 16% improvement @ 2 CD standoff and a 56% improvement at 6 CD standoff.**

In a 1995 study [Int J. Impact Engng,Vol-17,pp 697-706], Simulations of shaped charge penetrations into simple steel ceramic steel targets [3 layers] with AD-85 ceramic resulted in Te of 1.27 with 166mm penetration into steel and

131mm into the layered target [¼ ceramic ¾ steel target]. The ME of AD-85 should be around ~ 2 which works out to a TE of 0.9 so the approximate resistance should have been 0.97 , resulting in a **30% improvement due to layering**. At ½ & ½ it should have been 0.95 but infact it was instead 1.43 or **51% improvement in resistance @ 2CD standoff due to the layering.**

Shaped Charge resistance @ standoff
Resistance of Glass[fuzed Quartz] ¾ ½ ¼ **[steel component] [** Int.J.Impact Engng Vol-20,pp 375-386 **]**
Vs HEAT @ 2 CD standoff 1.1 1.23 1.27 0.8- 1.21- 1.28
Calculated ME/Te values should have been….. 0.93 0.86 0.8
Effective increase due to layering [8-12 layers] 18% 43% 59%

Pyrex & Steel @ 2 CD standoff 1.22 ? ? [Shock Compression of Condensed Matter ;1989 ,pp 967-969]
Calculated ME/Te values should have been….. 0.93 0.86 0.8
Effective increase due to layering [3-4 layers] 31% ? ?

Pyrex & Steel Vs HEAT @ 6 CD standoff 1.4 1.75 1.75 [Shock Compression of Condensed Matter ;1989 ,pp 967-969]
Calculated ME/Te values should have been….. 0.93 0.86 0.8
Effective increase due to layering [8-12 layers] 50% 100% 119%

Pyrex & Steel @ 5 CD standoff 1.38 ? ? [Shock Compression of Condensed Matter ;1989 ,pp 967-969]
Calculated ME/Te values should have been….. 0.93 0.86 0.8
Effective increase due to layering [3-4 layers] 48% ? ?

Shaped Charge resistance of 92% Alumina sandwiched with RHA @ standoff [Int.J.Impact Engng Vol-20,pp 375-386 **]**

Resistance of 92% Alumina [AD-92] ¾ ½ ¼ **[steel component]**
Vs HEAT @ 2 CD standoff 1.26 1.38 1.44 1.32
Calculated ME/Te values should have been….. 1.09 1.13 1.2
Effective increase due to layering [8-12 layers] 15% 22% 20%

Vs HEAT @ 6:1 standoff 1.32 1.79 1.65 1.55 1.44 @ 4:1 standoff
Calculated ME/Te values should have been….. 1.09 1.13 1.2
Effective increase due to layering [10-12 layers] 18% 58% 37%

Same target with………
plus rubber target @ 6:1 standoff 1.3 1.8 1.62
Calculated ME/Te values should have been….. 0.99 1.02 1.08
Effective increase due to layering [16-18 layers] 31% 76% 50%

plus airgap target @ 6:1 standoff 1.27 1.65 1.72
Calculated ME/Te values should have been…..
Effective increase due to layering [10-12 layers] 18% 43% 59%

Jet penetration of the following materials mounted on hard steel resulted in the Te values compared to VHS [550 BHN]
Silicate glass= 1.22
Silicon Carbide=1.49
TiVT-6 = 0.95
CopperM-1= 0.8
[Source Int.J.Impact Engng Vol 29,pp 385-390]

The resistance of VHS should be around 1.3 times the RHA standard [275 BHN], thus applying that modification to the above figures I get
Silicate glass= 1.58
Silicon Carbide=1.93
TiVT-6 = 1.23
CopperM-1= 1.04

However these are layered targets so would benefit from the 1.3 modification [5-7 multiple layers] so working backwards the base values should be …
Silicate glass= 1.21
Silicon Carbide=1.48

TiVT-6 = 0.95
CopperM-1= 0.8

Resistance of AD-97]	**¾**	**½**	**¼**	**[steel component]**
Tungsten liner @ 2:1 standoff	1.05	1.1	1.05	

DU , Tantalum or Tungsten lined shaped charges [heavy metal] seem to offer almost the same penetration into ceramic /steel targets as all steel targets ,suggesting they are hardly effected by that special armor/layering. A similar thing happens into steel /Titanium targets struck with Tantalum liner shaped charges …the resistance is less than the sum of the parts. [Sources Int. J. Impact Engng Vol 26,pp 823-830]. The common theme here is that higher density shaped charges are much less effected by lower density composite/layered special armors than traditional medium density copper shaped charge liners. It therefore may be more appropriate to apply the KE resistance rather than its HEAT resistance to these types of attacks. It is suspected that the Russian RPG-29 warhead and one of the 125mm FS-HEAT rounds feature such high density liners. Its also reported that the improved HELLFIRE-2 features a Tantalum tandem charge.

Unless other wise stated Alumina is assumed to be the 'ceramic' in modern tank armor. SiC [Silicone Carbide] was part of the XM-8 AGS & and rumored to be in the Yugoslav M84 tank ,while TiB^2[Titanium Diboride] was experimented on a Bradley development vehicle and may be in the Japanese Type 90 tank..The improved T-64 is thought to feature Kvarts , which is a Fused Quartz like material and black ceramic was reported in the T-64B and possibly other Russian tanks, this could be Alumina , as it appears black with rare earth element. See **Int.J.Impact Engng Vol-18,pp 1-22 .** Modern Chinese tanks are constructed with steel - alumina ceramic - steel sandwiches.T-80U is thought to include a large cavity with rows of ceramic cylinders [6 x 12cm] sandwiched between polyurethane type material.

By completely encasing a ceramic in metal , the shattered ceramics are forced back into the path of the oncoming jet/Rod. This is due to the fact that the shattered ceramic area is much larger diameter than the diameter of the same hole in the metal cover plate, thus trapping the fragments . Since these fragments have no where to go, they are forced back into the path of the rod/jet under pressure and double the erosion rate. It follows that - the smaller the hole in the metal- the better the results, thus since harder metal always result in smaller entry holes, they should yield better confining results and is born out by the experimental figures. Consider the following....below are a list of the effective resistance of various arrangements of steel /cermic sandwich with and with out cover plates, compared to the resistance of a reference plate of RHA. [Source: Int.J.Impact Engng Vol-19, pp 703-713]

Ceramic Steel target	**1500m/s**	**1700m/s [APFSDS striking velocity]**
Unconfined	0.90-0.91	0.98-0.99 [no support]
Radially confined	0.96-0.996	0.997-1.0 [support around the sides]
Mild steel cover plate	1.05-1.07	1.06- 1.08 [ceramic sandwiched in steel & mild steel]
HH Steel cover plate	1.03-1.13	1.13- 1.29 [ceramic sandwiched in steel & hard steel]

Result is the P/L value, the advantage advantage is
5% radial confined
13% for Mild steel cover plate
21% for Hard Steel Cover plate

In all cases the backing metal was Rc31 Type 4340 steel plus type "AD 97" ceramics and all targets were semi infinite. The ratio of ceramic to metal was 1:3, while the subscale WHA penetrator rod had a L/d of 20:1 .

Further to this Espanosa et al, have shown that the simple addition of a thin layer of graphite sandwiched inbetween the steel cover plate and the main ceramic block, results in a further increase in the erosion rate. It appears that the graphite acts as a kind of 'seal', closing off the entry hole further.This advantage may be as much as 10% increase in overall KE resistance.

In addition to this , some time in the 1990s it was discovered that if ceramics are "prestressed" inside a confined steel box this enhanced the "Dwell/interface defeat" tendency of the ceramic target . In a chinese paper ["Prestressed Ceramics and improvement of impact resistance, Bao etal , Material letters Vol 57,pp 518-524"] , it was shown that prestressing ceramics appeared to avoid the shattering of the ceramic cores in low and medium velocity impacts. In an as yet unpublished paper Int.J.Impact Engng Vo1 ? ["Modeling prestressed ceramic and its effect on ballistic performance"] , Holmquist & Johnson showed that prestressed ceramic targets offered an advantage against AP threats [over non 'prestressed' targets] to be ~ 10-20% . The threats tested were 0.7km/s steel 2.5:1 L/d rods & 1.4km/s-2.1km/s , 40:1 L/d WHA rods .

As a side note to the above, the APFSDS threat simulated was a subscale [2mm diameter] 40:1 L/d WHA penetrating rods . In a related paper it was shown that the resistance to penetration of 40:1 L/d sheathed penetrator rods was more than the resistance of the same target types [thick materials sandwiched between steel] facing 30:1 L/d rods at the same striking velocity [19th Int.Symp.of Ballistics; TB-14 pp 1151-1157]. The difference was 85% @ 1550m/s impact velocity for the Sheathed rod below the WHA penetrator rod. Penetrating efficency @ 1550m/s worked out to 71% of length for a

8mm diameter rod or 87% of the same penetrating efficency of WHA alloy penetrator. Adjusting for L/d [0.06 P/L] the difference between sheathed and monoblock at this point is 95%.

Clearly a lot more research is needed to fully explain what is happening with modern sandwich layered armors struck by shaped charges.

THE SPACED ARMOR EFFECT.

'A Hurlichs' paper "Spaced Armor" [1950] & his book "Vulnerablitiy of Armored vehicles to Ballistic Attack" [1950], both articulate a number of spaced armor tests that were conducted after WW-II with APC & HVAP ammo. These results have also been summarized in Dr Elders paper "Spaced Armor at Sea". In all these studies it was shown that a plate as thin as 1/7 th of the attacking projectiles diameter [0.14 T/d] ,was all that was needed to damage a steel projectile and reduce its penetration significantly .These effects can be generalized into the following approximate penetration losses.

Spaced plate T/d	reduction in penetration	
0.14d	10% reduction or ~ 0.4d loss	
0.17d	~ 20% reduction or ~ 0.5d loss	**[0.95d]**
0.3d	30% reduction or ~ 0.7d loss	**[1.4d]**
0.6 d	50% reduction or ~ 1.1d loss	
1.0 d	65% reduction or 1.3d loss	

This loss in penetration is measured in projectile diameters, so 0.5 d for a 100mm projectile means an additional loss of 50mm over and above the loss of penetration as a result of penetrating the spaced plate in the first place.

Thus the thicker the spaced plate the more damage it does to the penetrator. It must be understood that this effect is over and above any erosion or loss of velocity, the penetrator suffers from penetrating the spaced plate in the first place. This damage effect is attributed to the residual stress on the penetrator that can lead to shatter as well as any yaw effects it may encounter when striking the second plate .When computing this t/d ,the angle has to be included. So a t/d of 0.1 @ 60° should function like a t/d of 0.2 @ 0° [NATO angles].

There is an approximate relationship here that connects spaced plate t/d and resultant penetration loss. This is the **square route of the spaced plate t/d , times 1.3d.** So a spaced plate with a t/d of ~ 0.17 should result in SQRT 0.17 x 1.3 = 0.53d loss in penetration [roughly]. Its noticed in a number of papers on long rod penetration impacting @ 1500 to 1800m/s , that each spaced plate will reduce the amount of penetration of a projectile by about 1 projectile diameter or 1.3d per plate, provided the spaced plate is about as thick as the penetrator [See ISB-2000 TB 16, 23 & 24]. Since the penetrator tip is moving the armor material out of the way at roughly 2/3 of the speed of the rods striking velocity ,the 'spaced plate effect' is attributed to the continued erosion on the penetrator after exiting the spaced plate… until the tip and tail velocities reach equilibrium again.Thus when the penetrator exits the spaced plate the tip velocity creeps back to the striking velocity.Its as if the tip of the penetrator is acting as if there is still armor material in the way and erosion contiues until the tip and tail velocities are the same.

It was also shown that very thick spaced block also exhibited a ~ 1.3d spaced armor effect **, so once a t/d of ~ 1:1 has been reached there is no appreciable increase in this "spaced armor effect" , due to the spaced plate thickness.** However its noted in 19th ISB [2001], TB-26 that if the penetrator is made of a high strength alloy , then this reduction - due to the 'spaced plate effect'- is itself reduced to 0.9d, when the T/d is around 1:1. This difference [0.9d compared to 1.3 d], represents about 70% reduction in the 'spaced plate effect', when struck by a high strength KE shot.

In vol-22 of the Int.J.Impact Eng [pp 246-247], a semi infinite stack of RHA plates is struck by 6.5mm diameter 30:1 L/d WHA penetrators @ 1.5km/s at angles of 0°, 60°, 65° & 70°. In the tests the slanted penetration ranged from 188-194mm LOS while the Vertical penetration worked out to 160mm .Adjusting for t/d on the laminated plate reduces to 96% but the plates are harder ~ 350 BHN, thus the penetration figures should be the same…188-194mm LOS.

The difference in the solid [~ 150-158mm] to laminated penetration at angle was~ 0.5d per plate more penetration into the laminated plates compared to the solid block target [@ 70° = 64mm-51mm /4 plates] [@ 60° = 97mm-79mm /6 plates]. In these cases the plate thickness to airgap ratio [t/g] was 0.0.

In most of these test cases, the penetrator was high strength [~ 1.3GPa UTS or more] alloy, which should result in resistance of only 70% spaced plate effect or + 0.9d instead of + 1.3d , which is a - 0.4d difference.

It seems that the degree of plate thickness to airgap[t/g] controls this reduction from the "about 1 diameter per plate loss" [~ 0.9d]. If the airgap was deemed sufficient [~1.7 plate diameters or 1.7"t/g"] ,that should result in a increase in resistance of + 0.9d per plate [for high strength penetrator ;+ 1.3d for others].In the case where the airgap was less and the resultant loss in resistance was reported to be '0.7d less' or + 0.2d per plate, this featured a *“t/g” figure of ~1.0 [gap = plate thickness]. While if the gap is 0 “t/g” the resultant gain in resistance is – 0.7d [inother words 0.7d more penetration per plate than the LOS].*

So from the POV of resistance where negative is less resistance and positive is more resistance.

If t/g is 0 = - 0.5d
If t/g is 0.7 = + 0.2d
If t/g is 1.7 = + 0.9d

If we simplify the figures to t/g 1.4 boundary and work backwards from the + 0.9d additional resistance gain per spaced plate [high strength penetrator], that’s ….

0 [t/g] = 0.9- 1.4 = - 0.5d
0.7 [t/g] =0.9- 0.7 =+ 0.2d
1.4 [t/g] = 0.9 - 0 = + 0.9d

So the above suggest that where the gap is less than 1.5 plate diameters we need to use a formula ***adjustment per plate*** *d = (t/g – 0.5) . If the penetrator is not high strength add 0.4d to the above figures…so if t/g =0 it should = - 0.1d [0.0 – 0.5 + 0.4] or*

adjustment per plate *d = (t/g – 0.1) vs normal LRP.*
adjustment per plate *d = (t/g – 0.5) vs High strength LRP.*

The problem is that for a perfectily perpendicular impact this doesn’t apply. In that case the difference between laminated and block penetration is only 7mm over [153- 160 / 10plates] or - 0.1d…which is
+ 0.4d added to the above formula.More data is needed to clarify this relation ship.

Now an interesting side bar to the is the effect of yaw on this kind of impact.In the vertical impact case, a 1.0 degree projectile yaw results in a penetration of ~ 159mm on the laminated plates compared to 153mm on the vertical block…when this gets to 2 ° yaw, the laminated penetration figure is ~ 153mm while the solid vertical block figure is ~ 150mm, that’s about – 0.05d per plate loss . At 3° yaw there is no difference in penetration of solid block or laminated plates. Baced on the above tentative formula its should offer - 0.1d per plate less resistance than the LOS thickness suggests per plate…but with yaw its reduced to 0d/per plate @ ~3° yaw.

This transition is even more pronounced when the laminated plates are struck at angle…
In the 60° case solid block penetration @ 1.5km/s is 158mm while @ 1° yaw its 149- 155mm Vs solid block armor compared to 169- 175mm vs laminated target @ 60°.That’s 20mm or 10mm @ 60° over 5 plates or a perplate loss of - 0.3d. At 2° the figures are 126- 139mm for the solid block compared to 136- 174mm for the laminated target. Thus a 10- 35mm loss range or 5mm@ 60° over 4 plate [- 0.2d per plate loss] to 17mm@ 60° over 5.5 plates [- 0.5d per plate loss] .

In the paper Int.J.Impact Engng vol 28 pp 377- 390 [2003] & TB-11 19th ISB pp1123- 1132. The author of both papers [DJ Gee] ,studies the impact on insufficient airgap between plates. He identifies this as 0.7d less than the expected penetration for the two plate with limited airgap compared to the case with sufficient air gap. However his tests featured WHA vs RHA plates spaced ~ 1d apart @ 65° angle [0.7d- 1.0d] . So it appears you need more like 1 plate diameter airgap between plates to eliminate this deficiency.

The difference in spaced plate effect on high strength penetrators appears to be 70% or - 0.4d based on single source...so more data may produce better range of modifications.

If the penetrator is high strength and the plates are insufficient gap it could combined to result in 1.1 reduction in the spaced plate effect. Generally this spaced plate effect is referred to as "about one projectile diameter", but the few papers I've seen suggest ~ 1.3d per plate.So that should still leave a + 0.2d per plate adding up to ~ 1.2d increase in resistance. Here in these results there appears to be a - 0.6d over all effect or ~ - 0.1d per plate. So what it appears to mean is that there's a - 0.3d per plate effect not accounted for in the published research.

So the adjusted formula should be …

adjustment per plate *t = (T /g– 0.1) vs normal .*
adjustment per plate *t = (T /g– 0.5) vs High strength.*

*SQRT t/d * plate resistance * V [km/s] ÷ g – [0.1 normal or 0.5 high strength]*
If the spaced plate are perforated that should also add + 0.4d to [elastic perforated] + 0.8d

The above figures apply to single piece metal AP/APC /APCBC & heavy metal APFSDS ammo,but when the damage for brittle core sheathed penetrator [APDS / HVAP] is included, it appears to double the 'spaced plate effect' **[bold figures in chart above] .** Similar relationship was found between monoblock APFSDS & Sheathed APFSDS in separate studies on 10:1 L/d penetrators [See 19th ISB-2001 TB-25] and 30:1 L/d penetrators [See 19th ISB-2001 TB-23/24]. Further more steel AP with velocities approaching 1000m/s & steel APFSDS both suffer twice the damage of against spaced armor as do monoblock heavy metal penetrators. **Thus all steel above 900m/s & sheathed penetrator suffer twice as much damage as monoblock penetrators when penetrating spaced plate type armors.** In the above mentioned papers, the loss due to the 'spaced armor effect' was 3.5d for monoblock APFSDS penetrators and ~ 7.5d for sheathed 30:1 L/d APFSDS penetrators impacting ~ 1500m/s.

Several papers [See Int.J. Impact Eng Vol-5 pp 323--331{Hohler & Stilp} **&** Int.J. Impact Eng Vol 14 pp 373-385] study the impact of large air gaps on spaced plate arrangements and show very little effect of increasing the airgap on 10:1 L/d penetrators. At most these add ~ 10-20% to the amount of loss due to the 'spaced armor effect'. In the 1950s "Vulnerability of Armored Vehicles to Ballistic Attack", a yaw of about 5-7 ° is noted as normal in spaced plate impacts . Similar figures occur in the APFSDS reports mentioned above and studies of yawed impacts of APFSDS show that 10:1 L/d penetrators should only suffer ~ 0.2d additional loss over a large airgap.There are a number of papers, that seem to show that really long thin penetrators [L/d of 20:1 to 30:1] suffer adverse effects of large yaw impacts . However, this effect appears to be offset by the resistance of really long rods to yaw in the first place.

There is highly variable and considerable amount of scatter on ballistic results of spaced plate impacts, more so that the 6% Statistical standard deviation of normal KE shots [See Int.J.Impact Engng Vol-23 pp 639-649].This could amount to as much as a 30% increase in this scatter …from ± 15% to ± 20% shot to shot variation in APFSDS penetration of spaced plate armors. All the above mentioned losses in penetration measured in "d", seem to be the average results , so the above mentioned shot to shot variation is implied in all these results.

Finally in 19th ISB [2001] TB-11 and Int.J.Impact Engng Vol-26 pp 377-390, 10:1 L/d WHA rods where fired at one and two spaced plate arrays at 65° impact angle. The gap between plates was around 1 projectile diameter and the loss due to spaced plates was noted to be 0.7d less than was expected. They suggest that insufficient gap between plates was the contributing factor.

> *"The difference in perforation efficency for 0° corresponds to roughly 0.7D less erosion in the two-plate case when compared to the one-plate case.That is for a simple scaling,the predicted erosion for two single plate targets spaced far enough apart would be 0.7d more than found in the two-plate spaced target model here."[pp385]*

Since the penetrator tip is moving the armor material out of the way at 2/3 of the speed of the rods striking velocity , and this causes the continued erosion, then if the airgap between spaced plates is too small, this normalizing process doesn't occur and the amount of 'extra erosion' due to spaced plates is truncated [limited] . The Deisenroth 'Wedge appliqué' added to the LEOPARD-2 is reported to be composed of an outer 3-4cm plate a 5cm gap and a 2-3cm inner plate, this would appear to have the needed gap between plates, especially when the LOS thickness is included. But the ERA plates mounted inside Kontakt 5 boxes are less than a projectile diameter so suffer accordingly . In paper published 19th ISB , a IRA appliqué armor similar to the LEOPARD-2 wedge armor , has been tested with two 24mm thick steel plates and a 8mm elastic layer inbetween , perhaps intended for some future upgrade [LEO-2A6 ?].

Summerizing so far we can add

2x spaced plate effect if penetrator is sheathed [Steel AP above 900m/s ; HVAP; APDS & Sheathed APFSDS].
x 0.7 if the penetrator is a high strength penetrators [DM-53 & M-829A3 & L-27]
- 0.7d if multiple plates have insufficient airgap [less than 1.5 projectile diameters airgap].

PASSIVE ENERGIC ARMOR

Many new appliqué armors are added to boost the protection of modern tanks and light AFVs . These feature energetic armor s like **E**xplosive **R**eactive **A**rmor [ERA] and **I**nert **R**eactive **A**rmor [IRA] technologies to increase the effectiveness of spaced plates armors. The essential element is that the plates [often refered to as 'flyer plates'] are set in motion when struck by an attacking projectile which increases the effectiveness of the whole appliqué. Explosive Reactive Armor relies on an explosive layer sandwiched between two steel plates . When struck, the energy of the detonation propels the plates in opposite directions into the path of the penetrator. Since these flyer plates are moving at ~ 300-500m/s when they impact the APFSDS,while the rod is striking at 1400-1800m/s, the APFSDS will cut a slot through both plates and lose considerable amount of mass while also undergoing yaw and an exaggerated 'spaced plate effect'. Its been shown that this damage is much more than would be experienced if the same flyer plate was stationary.

In tests published in the Int.J.Impact Engng [**Vol 10,pp81-92** & **Vol – 14 pp 373-383**], 10:1 L/d DU penetrators suffer 1.2d additional loss against a stationary thin spaced plate [~ 1:1 T/d] @ 65° impact angle [NATO angle]. This means that, inaddition to penetrating the spaced plate , the APFSDS lost an amount equal to 1.2 times its diameter . In these tests simlar impacts where conducted with the DU APFSDS on explosive lined plates that where propelled upwards into the path of the penetrator. These resulted in 2.1 d additional loss in penetration , while impacts of plates propelled downwards result in 1.9d additional loss…. This is the amount of penetration loss, over and above the loss due to the plate them selfs, and represents 1.7 and 1.6 increase respectively in the 'spaced plate effect'. In other words if the flyer plates were 2 x 20mm thick plate exploded in opposite directions and the APFSDS projectile had a 20mm diameter , the loss would be 2 x 20mm or 40mm plus 1.7 x 1.3d [d=20mm] & 1.6 x 1.3d = + 86mm. The total resistance against a 2cm APFSDS offered should be >12cm @ 0°, if the same armor was arranged at 65° that overall resistance should amount to ~ 18cm RHAe.

Its of note that the patents of Soviet/Russian ERA like Kontakt and Kontakt 5 both feature ERA elements with the explosives underneath the steel flyer plates so these plates are propelled upwards into the APFSDS. One of the disadvantages of ERA is that once the element is expended it leaves a gap in the coverage of the appliqué. However since ERA covered AFVs, normaly only achieve coverages on the order of 50% , then the loss for each element is quite small and only represents only 1- 2% of the total profile. This means it takes a lot of impacts to dramatically change the chance of hitting exposed armor. Put another way if a tank is shooting at another tank that has ERA described above, the first time it shoots there is a 50% chance of hitting ERA and 50% chance of hitting exposed armor. With the second shot there is a 48% chance of hitting ERA and 52% chance of hitting exposed armor. After 4 hits there is an accumulated 95% of atleast one of the 4 shots hitting exposed armor. Over a large population of similar events, this means roughly every second hit is going to be on exposed armor.An example of this type of armor is on the Russian T- 90, T80UM & T-72BM tanks. Adding these heavy ERA applquies results in weight increases of ~1.5tons for these tanks , even though they only cover 50% of the front profiles of these tanks.

ERA is generally divided into heavy and light appliqués. The ERA element in both appliqué appear to feature 2- 7mm thick steel flyer plates while the heavy appliqué is further encased in thick steel box [with 25mm thick walls]. An example of the heavy ERA applique is the "Kontakt 5 ERA"on the T- 90, T80UM & T- 72BM tanks, while examples of the light ERA is the "Blazer ERA" on Israeli and American tanks or the appliqué on the export BMP- 3M and the Bradely A2/A3 models.China also makes a line of heavy ERA elements for all of their tanks and export models ,while France and several NATO countries make light ERA for some of their tanks and AFVs. Generally speaking lighter ERA can't be mounted on medium AFVs due to the impact of the retreating plate on the main body armor. This will damage the very tank its designed to protect, however some hybride light ERA have been developed with rubber backing to allow such mountings as in the case of the ERA mounted on the Bradely and the improved Israeli Zelda APC.

Similar to the effects of ERA is Inert Reactive Armor [IRA] or Non Explosive Reactive Armor [NERA] .This is an appliqué similar in design to the ERA elements , with rubber or some elastic material sandwiched between steel plates instead of the explosive sheet.The difference here is that the energetic element is a high energy rubber or elastic materials that transfers the energy of the impact through this material to the plates that bulge at speeds in the same region as ERA [100- 400m/s]. In addition the steel plates employed in IRA appear to be thicker than ERA elements and achieve AFV coverages on the order of 85- 90%. Further more damage of the bugling plate is restricted to the immediate vicinity of the impact, so a very large number of hits would have to be achieved to seriously degrade this appliqués coverage. On the whole IRA effectiveness is similar to ERA which is shown in the figures from tests and should generate about 1.3 – 1.6 times the basic 'spaced plate effects' figure for bulging plates. In ISB- 2000 TB- 23 & 24, losses due to IRA appliqué is on the order of +3.5d Vs monoblock 30:1 APFSDS while impacts of full scale sheathed penetrators achieve values of +7.5d penetration loss. Since these are essentially two plates the real advantage is + 1.8d & 3.5d per plate. Subscale tests of ERA elements show results of +2.1 - 1.9d vs 10:1 L/d monoblock penetrators & 4.2- 3.8d vs 10:1 L/d Sheathed penetrators . By point of comparison, the subscale tests of IRA elements struck by 30:1 APFSDS resulted in figures of +5d & +10d respectively or 2.5d & 5d per plate.

Like ERA, IRA can be divided into two class based on weight.Heavy & light IRA appliqués like those mounted on the Magach 7C/D & or the EAAK mounted on USMC AAVP- 7 block 2 upgrades. The heavy applique amount to ~ 4 tons increase in weight but affored 90% coverage of the front turret profile of the tank. When a similar mass heavy appliqué is added to the whole of an AFV like the Israeli SABRE and Canadian LEOPARD- 1C2, then the weight increase is on the order of 7 tons.? Lighter appliqués result in weight increase of only 1- 2 tons, even though the appliqué covers the front sides and rear of the AFV . When such an appliqué is added to the front sides and top of the entire AFV - like the Marder APC - it adds about 6 tons to the vehicles weight!These lighter appliqué , look like 1cm thick rubber layers sandwiched between two <1cm mild steel plate mounted about 4- 6 inches from the main wall at 45° angle . Since these feature a large amount of rubber ,the plate movements will be in the region of ERA flyer plates bulge at speeds about 1.6 times the base 'spaced armor effects' figures. This should offer protection in the region of +2.1 d & + 4.2d respectively over and above the resistance of the array .

FLEXING/ PERFORATED PLATES OR MESH

Lighter appliqués developed by Blohm & Voss for the LEOPARD –1 tank result in weight increase of only 700- 900kg, even though the appliqué covers the front sides and rear of the turret . When such an appliqué is added to the front sides and top of the entire AFV - like the Marder APC - it adds about 6 tons to the vehicles weight!These lighter appliqué ,as on the LEOPARD 1A1A1, look like >1cm mild steel plate sandwiched between two 1cm thick rubber layers mounted on shock absorbers , about 4 inches from the main turret wall at very sharp angle [from the front the compounded angle can reach upto 70- 75°]. Since these feature a large amount of rubber ,the plate movements will be in the region of ERA flyer plates speeds or about 1.6 times the base 'spaced armor effects' figures. This should offer protection in the region of +2.1 d & + 4.2d respectively over and above the resistance of the array [~LOS 4- 5cm RHAe from straight on].A limited type of plate movement can be achieved by mounting plain steel plates on shock absorbes like over the mantle of the LEOPARD –1A1A1 , but this is unlikely to offer more than x 1.3 times the base 'spaced armor effects' value.

The side wall appliqué armor on the LEOPARD 1A1A1 featured perforated plates which is an new addition into the arsenal of armor designers. These feature thin steel plates with holes drilled into the plate that are ~ ½ to ¾ of the diameter of the expected threat projectile. There are few studies of this appliqué in open sources , but several studies have pointed to some interesting clues about its effectivness. In a paper [see Int.J.Impact Engng –] MG type bullits where fired at the edge of a plate. Due to this being an weakened area the plates deformes and the projectile slides towards the edge, in such a yawed state, that the hard steel projectile shatters every time. If the plate is already perforated , the region immediately surrounding these holes will be also 'weakened' and like the results above, the penetrators should slide into the hole and yaw through the plates and shatter. In many respects this was already achieved by wire mesh armor mounted on WW-II German Pz- IV tanks. It was found that hard brittle core ammo [Soviet 14.5mm ATR] tended to shattered on penetration and made no damage on the main armor , spaced some distance away. There is every reason to expect the similar out come from modern projectiles.This 1000m/s Hard steel projectile [Soviet 14.5mm ATR] could penetrate 45±9mm and failed to seriously damage the 30mm backplate of the Pz- IV hull. This means the 5mm mesh canceled ~ 20- 30mm of penetration or accounted for 1.7d overall 'spaced plate effect'.A 5mm MS plate should have only accounted for 4mm erosion + 7mm [0.5d spaced plate effect].that's a 1.2d difference.

RM Ogorkiewicz in an article [Armor for Light Combat Vehicles, JIDR July 2002 pp 41- 45], report that the Mass efficency [Me] of 'spaced perforated plates' mounted ahead of aluminum armor to be ~ 12% more than a sandwich of aluminum with hard steel cover plate, when struck by high strength 14.5mm AP shot.This looks deceptive since one target is a sandwich while the other is a spaced plate armor. Technically the same thickness of hard steel spaced plate , should offer only ~ 0.6d 'spaced plate effect' compared to 1.44d for perforated plate in the same condition. Looking at the damage due to yaw of normal spaced plate, this is usually about 5- 7° and should only account for a few %reduction in penetration for a short AP type projectile. The increase is 0.5d to 1.8d [1.3d increase] .If the perforated plates is just yawing the penetrator , it should result in 15- 20% reduction or + 9mm [+0.6d @ 20- 30°]….images of the shattered penetrator as a result of the edge effects is 1- 2d loss in penetration, suggesting shattering effect is happening here. Examples of this type of armor are mounted on USMC AAVP- 7 , upgraded Italian M- 113 APC and the Israeli Zelda APC. In addition appliqué for the LEOPARD –1A1A1 feature perforated plates wrapped in elastic fibre material mounted on shock absorbers to enhance the damage and yaw effects on the attacking projectile , especially if this is a APDS or steel or sheathed APFSDS [all 100mm/115mm/125mm APDS/APFSDS etc ammo produced after 1990].

To summerize we have the base value is the **square route of the spaced plate t/d , times 1.3d.**
1.7 x basic for advancing energic plates or bulging plates
1.6 x basic for retreating energic plates or bulging plates
1.4 x basic for shock absorber plates
+ 0.8d if perforated plates
2x the spaced plate effect if penetrator is sheathed [Steel & Sheathed APDS/APFSDS].
x 0.7 if the penetrator is a high strength penetrators [DM- 53 & M- 829A3 & L- 27]
- 0.7d for each plates with insufficient airgap [less than 1.5 projectile diameters].

These test also reveal considerable variation in the results, this is also evident in spaced plate arrangements and usually results is ± 30% range between the minimum ,average and maximum penetration. See **Int.J.Impact Engng Vol- 14,pp 373- 383**

The effect on HEAT jets is similar to rod , however since the jet is already weak, the disruption can be massive. In addition , tests on 'asymetrical sandwiches' show that even impact at 'normal ' angle ,the HEAT jet is seriously disrupt ed. Thin plates offered up to 20 times the mass effectiveness while moderate plates are ~ 7- 10 times the resistance at normal impact . **Int.J.Impact Engng Vol- 23; pp 795- 802** For simple rubber steel combinations the effect is limited to about 6 times the Mass effectiveness. By comparison a simple thin to moderate spaced plate should offer ~ 2- 4 times the thickness effectiveness, while very thick plates offer ~ 1.2 increase. Some Russian studies show that the overall effect of spaced plate , including the spaced plate is to reduce the shaped charge penetration by 22- 25%, independent of standoff.

> *"The data came from a presentation by "Dan Y" the then chief engineer of Rafael's ballistic centre, at an open conference in London on Armour and Anti- Armour in September 2001.*
> *[I have hand- written the following comment on the documentation]. The engineer emphasised that both TOGA - and the Israeli supplied armour provided for the Italian VCC- 1 fitted with the enhanced mesh/spaced/slatted armour, backed with ceramic plates - are more effective in reducing the effects of an RPG than defeating it" 'Marsh' Tank Net 2004.*

Various electrical armors have been explored that appear to approach the ERA solution with an alternative source of energy, which will be repeatable is the flyer plate mechanism can be captured….for the time being these should be seen as reusable ERA type armors.

1mm thick spaced plate resulted in 0.7d additional reduction in 45mm jet penetration.
2cm spaced plate resulted in 0.5d additional reduction in a 45mm jet penetration
1.3cm spaced plate resulted in 1.0d additional reduction in a WW-II 45mm M-9 with 8 diam airgap
5.6cm spaced plates resulted in a 0.25d additional reduction in a 45mm jet penetration
3.5cm spaced plate resulted in a 0.6d additional reduction in 100mm jet penetration
7.6cm spaced plates resulted in a 0.5d additional reduction in a 105mm WW-II jet with 2 diam airgap
6cm spaced plates resulted in a 0.5d additional reduction in a 100mm jet penetration
11cm spaced plates resulted in a 0.3d additional reduction in a 105mm WW-II jet with 2 diam airgap
20cm spaced plates resulted in a 0.1d additional reduction in a 120mm jet penetration

2cm bulging plate resulted in a 0.85 d additional reduction in a 73mm jet penetration [x 1.7]
2cm chemically reactive plate resulted in a 1.3d additional reduction in a 73mm jet penetration [x 2.5]
2cm ERA/ Chemical reactive driven plate resulted in an 2.07d additional reduction in 73mm jet penetration.[x 4.1]
2cm ERA plate resulted in a 3.8d additional reduction in a 73mm jet penetration[x 7.6]
1cm ERA plate resulted in a 4.2d additional reduction in a 45mm jet penetration[x 7.9]
7cm steel pyrex plate resulted in 2.0d additional reduction in a 5cm jet penetration[x 4]

"The Vulnerability of Armored Vehicles to Ballistic Attack." A Hurlich 1950, pp 115.

"The advantage of spaced armor against the hollow charge should be its ability to start the functioning of the charge on the front plate in order that increased standoff would reduce the penetrating power of the jet and fragments. Tests of this kind were conducted using the rifle grenade AT M9A1. The M9A1 is capable of penetrating about 4 inches of solid homogeneous armor , but in the spaced armor test it was found that a ½ inch plate 14.5 inches in front of and parallel to a 1.5 inch plate would defeat this weapon."

So it should be 12mm spaced plate not 20mm and the standoff is 368mm,so that's more like 8 diameters standoff. Using Berkhoffs standoff penetration chart, that should result in about 1.5 diameters penetration into mild steel or about 1.07 diameter into RHA. I make that about 48mm . Since the spaced plate is 12.7mm thick, that should leave ~ 35mm residual penetration . But the tests show defeat of the warhead , so the spaced plate looks like its absorbing 0.8 diameter of penetration, since that's what it would take to defeat that round?

Mind you if the base plate is also included, then the spaced armor and gap only defeated 51mm instead of 87mm in total.

Thanks for pointing that out. Looking at the data you provided before on the German 46mm shaped charge vs spaced armor tests, I have 90mm reported penetration and a ¼ inch spaced plate @ 11 inches standoff to defeat this penetration. So that suggests @ 6 diameters standoff , a 6mm spaced plate reduced penetration by 90mm? The reduction in standoff should be 1.9 diameters vs mild steel or 1.4 vs RHA[64 + 6 or 70mm]. So the spaced plate absorbed 20mm additional penetration? That's + 0.44diameters.

1975 Blohm & Voss appliqué armor [Leopard 1A1A1 & Leopard –1A5]

Its reported that the Blohm & Voss appliqué armor was mounted on all the turrets of German Leopard –1 tanks from 1975 to 1977 . The front mantle add- on plate is a 4cm hard [?] steel mounted on shock absorbers ,while the front side add- on plates are ~1.3cm mild perforated steel encased with 2cm rubber also mounted on rubber buffers that probably act as shock absorbers to reduce the transmittion of KE energy to the main armor. The turret front walls accounts for about ¾ of the front turret profile ,while the inner Mantle area accounts for about ¼ of the front turret profile . Research on spaced plates show that more than one projectile diameter can be added to the relative armor resistance to cover the elastic shock wave effect continuing on the penetrator after piercing a spaced plate. This is doubled against sheathed penetrators or reduced to ¾ if the penetrator is a high strength penetrating rod [>1.1GPa]. This amount of additional resistance is increased by + 0.8d if the plates are perofated and the entire increase in resistance is doubled if the penetrator is a hard steel or sheathed penetrator [APDS or Steel/Sheathed APFSDS] .So the basic **Leopard- 1A1 front turret armor** is detailed below followed by the effect of the same turret plue the above mentioned appliqué .

¼ Base armor Mantle [10cm LOS cast (gunshield) + 10cm gap + ~3cm mild steel (outer guncradle wall)]
Against [2- 3cm] monoblock APFSDS 11.5cm+ 2.5cm or 14cm **[12cm @ 30°]**
Against [3.5- 4.2cm] sheathed APFSDS. 11cm + 6- 8cm or 17- 19cm **[15- 17cm @ 30°]**
Against a 122mm APC that's 9.8cm+ 8.8cm or ~18.6cm sloped **[~16.1cm @ 30°]**
Against a 85- 100mm APC that's 10.8cm+ 8.7cm or ~18.5cm sloped **[16.0cm @ 30°]**
Against a 10- 12cm APDS should be 12.3cm +9.7d or 22cm **[~19cm @ 30°]**
HEAT resistance should be 17/14cm+ 0.3d.

¼ Base Mantle overlap [8cm LOS cast (mantle) + 12cm gap + 10cm LOS cast (upper front turret)]
Against [2- 3cm] monoblock APFSDS 13cm+ 3- 4cm or 16- 17cm **[8- 8.5cm @ 60°]**
Against [3.5- 4.2cm] sheathed APFSDS 12cm + 9- 12cm or 21- 24cm **[~ 10- 12cm @ 60°]**
Against a 122mm APC that's 9.8cm + 12.2 or ~22cm sloped **[~11cm @ 60°]**
Against a 85- 100mm APC that's 10.4 + 10 or ~20.5cm sloped **[~10.2cm @ 60°]**
Against a 10- 12cm APDS should be 11.4cm + 16.2cm or 27.6cm **[~13.8cm @ 60°]**
HEAT resistance should be 21/18cm+ 0.3d.

½ Front turret profile:Front **s**loping walls armor [17cm LOS cast]
13cm Vs 10- 12cm APC [7cm @ 60°] ** ½ ricochet @ 0- 1km & ¾ @ 2- 3km**
14.5cm Vs 100- 122mm APDS [7.2cm @ 60°]
14.5cm Vs 4cm APFSDS [7.3cm @ 60°]
15.5cm Vs 2cm APFSDS [7.8cm @ 60°]
17cm Vs HEAT [8.5cm @ 60°]

1975- 77 applique added .

¼ Mantle with appliqué ; 5.6cm hard steel and 14cm gap plus [gunsheild + 10cm gap + outer guncradle wall]
Against [2- 3cm] monoblock APFSDS 16cm+ 2.2d or 22- 23cm [20cm @ 30°]
Against [3.5- 4.2cm] sheathed penetrators. 17cm + 4.4d or 35- 36cm [~ 31cm @ 30°]
Against a 10- 12cm APC that's 14cm+ 1.6d or ~30cm sloped [~26cm @ 30°]
Against a 10- 12cm APDS should be 14cm +4.6d or 39cm[~34cm @ 30°]
HEAT resistance should be 30/22cm+ 0.6d.

¼ overlap Mantle with Applique [sloping mantle + 12cm gap & 5.6cm steel/rubber **&** 1cm gap + upper front turret]
Against [3cm] monoblock APFSDS 17cm+ 2.8d or 25cm [13cm @ 60°]
Against [3.5- 4.2cm] sheathed penetrators. 17cm + 4.8d or 37cm [~ 19cm @ 60°]
Against a 10- 12cm APC that's 14cm+ 2.8d or ~42cm sloped [~21cm @ 60°]
Against a 10- 12cm APDS should be 17cm + 4.8d or 42cm[~21cm @ 60°]
HEAT resistance should be 27/24cm+ 0.7d

½ sloping walls with applique [10cm LOS rubber/perforated plate/rubber + 25cm LOS gap + front sloping turret walls]
Vs 10- 12cm APC ; 13cm + 3.6cm + 1.4d = 30cm [15cm @ 60°]
Vs 100- 122mm APDS ;14cm + 4cm + 3.3d = 36cm [18cm @ 60°]
Vs 3.2- 4.4cm steel/sheathed APFSDS ;15cm + 5cm + 4.2d = 38cm [19cm @ 60°]
Vs 2- 3cm monoblock APFSDS ; 15cm + 5cm + 2.0d = 25cm [13cm @ 60°]
Vs HEAT ; 34/24cm + 1.5d

1984 Kontakt ERA

Late model Soviet tanks mounted 1st Gen Kontakt armor , starting with the T- 64 and then T- 80 tanks in late 1984 and later still with T- 72B and in 1988 with the T- 72A models .A russian source reports these ERA blocks are 5 x 8 inch and

work as follows ....inside the box ,two plates lined with explosives underneath ,stacked one on top of the other , are explode outward and upward in the same direction into the path of the on coming rod or jet.
[“**Main BattleTank” pp 59,Arsenal books**].
Kontakt is thought to be 10 times as effective as RHA plates Vs shaped charges , but the ERA coverage over the front & side of Soviet tanks is reported to be only 60% ,while the glacis is about 80%.
http://www.niistali.ru./english/products/dz/dz.htm
Kontakt ERA should offer ~ 0.5cm @ angle erosion plus 0.5-1.2d [2-4cm APFSDS] & double if sheathed .So it should offer about ….

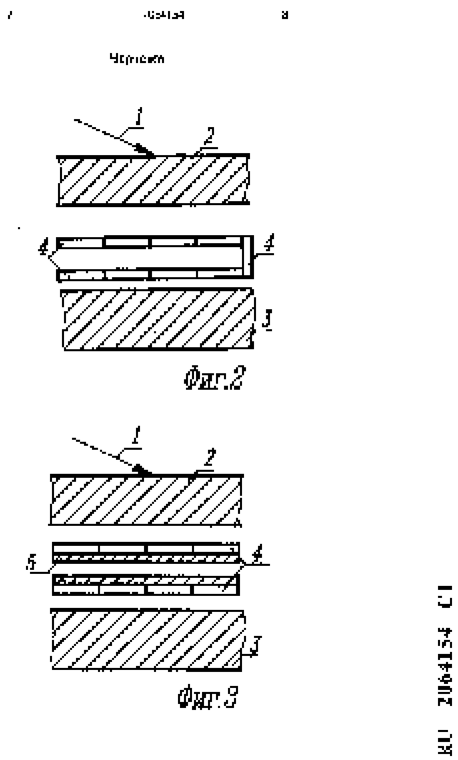
	< 30°	45°	60°	65-68 °	70°
2cm APFSDS	0.6+1cm	0.7+1.3cm	1.0+1.7cm	1.3+2cm	1.5+ 2.4cm
3cm APFSDS	0.4+ 0.5cm	0.6+0.8cm	0.8+ 1.3cm	1.0+1.6cm	1.2+2.1cm
4cm APFSDS	0.3cm	0.4cm	0.5+ 0.3cm	0.6+0.6cm	0.7+ 1cm
2cm sheathed	0.6+2cm	0.7+ 2.6cm	1.0+ 3.4cm	1.3+4	1.5+ 4.8cm
3cm sheathed	0.4+ 1cm	0.6+ 1.6cm	0.8+ 2.6cm	1.0+ 3.2cm	1.2+4.2cm
4cm sheathed	0.3cm	0.4cm	0.5+ 0.6cm	0.6+1.3cm	0.7+2.0cm

Рис. 80. Устройство и принцип действия динамической защиты.

1988 K-5 Kontakt ERA;.

By 1988 an improved version of the Kontakt ERA appeared sporting thick steel box to prevent premature detonation of the ERA elements. Armor mass of Russian tanks shows the heavy ERA adds 3 tons to the tanks mass and the frontal coverage is ½ of 3.8m² profile …amounting to 150mm steel mass or ~ 2.5 tons.So the side hull and turret ERA coverage could easly amount to 300kg per side**.**The patent for K-5 shows ERA is a 1 inch thick steel box with 2 x K-1 type ERA ‘active elements’ inside, while Steven Zalogas scale drawings of these tiles suggest 11inch x 18inch ERA elements [turret].

The outer 25mm plates hardly move at all and are fixed in place but their are 2-5 inner plates [similar to K-1] with no more than 2 Kontakt type active layers while the others are inert. It might be that ,since the ‘active’ layers are in segments them selves, they are intended to detonate seperately - move the plates - like a ‘bulging plate’- and be able to ‘do it again’ when the next projectile hits the next ‘segment’,inother wards it might be reusable! See; **Steven Zalogas “Artillery & Design Practices 1945-present”, pp122 pp124/125 pp 147 pp 436**



2x 25mm Steel plates
2 x 7mm thick ERA elements [probably 3mm steel & 4mm explosives]
separated by a 7mm spacer plate [Steel?]. Treat as one element.
- 0.7d for each plates with insufficient airgap [less than 1.5 projectile diameters].

Combined that's …
50mm x 0.9- 0.75 = 45- 37mm + 2 x 0.6d/1.2d
13mm x 0.6- 0.5= 8- 6mm + 1.5- 1.1d/[x 2 sheathed]
Total 53mm – 43mm @ angle, plus 2.7- 2.3d & 5.4- 4.6d
18- 19cm RHAe vs 2- 4cm monoblock APFSDS [@ 65°] & 16- 18cm [@ 60°]
23- 26cm RHAe vs 2- 4cm sheathed APFSDS [@ 65°] & 21- 25cm [@ 60°]

There are several techniques to defeat ERA, one is to use high strength alloys [M-829A3 ; DM-53 & possibly M-900A1] reducing "spaced armor" contribution to 70%. In addition sectioned nose of some penetrators [DM-33/53 & L-23/27/M- 426] allows partial cancellation of 'spaced armor effect', while its likely that the combination of highstrength and sectioned or spiked nose almost completely eliminates the 'spaced plate effect'.
15cm RHAe vs 120mm [L-23/DM- 33] 105mm APFSDS [IO-105 & M-900] Sectioned/spiked
13cm RHAe Vs 120mm [M-839A2] & 105mm [DM-63/M426] High strength
11cm RHAe vs 120mm [L-27/L28 /M- 839A3 & DM-53] 105mm [M-900A1?] High strength & sectioned/spiked.

If the K-5 ERA element is already spent.then modifie the overall resistance by x 80% RHA Vs APFSDS

The Glacis array looks like one thick plate [25mm?] plus two thin 15mm flyer plate mounted 2- 3 inches from the glacis with spacer bars. Its likely both inner plates have explosives underneath and act as flyer plates, but all the plates are too close together and suffer a –0.7d .The resistance should be as follows …

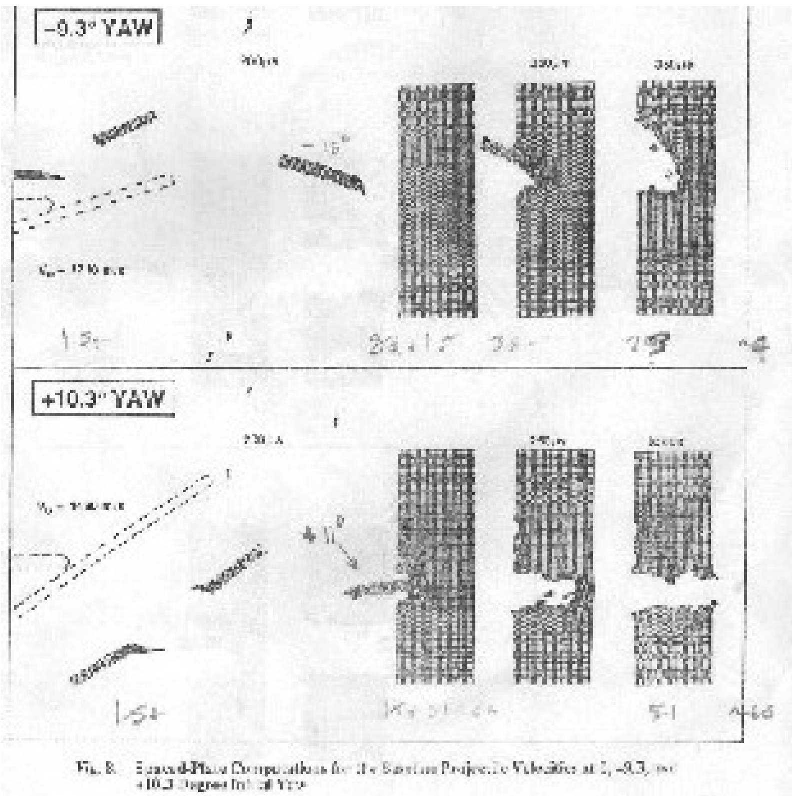
25mm x 0.9- 0.75 = 22.5- 18.8mm + 0.8d/1.6d
20mm x 0.7- 0.5= 14- 10mm + 2.8- 1.1d/5.7- 2.2d
Total 36mm – 29mm @ angle, plus 3.6- 1.9d & 7.3- 3.8d
17cm RHAe [@ 67- 68°] vs 2- 4cm monoblock APFSDS & 14- 15cm RHAe [@ 60°]
23- 25cm RHAe vs 2- 4cm sheathed APFSDS [20- 23cm RHAe @ 60°]

There are several techniques to defeat ERA, one is to use high strength alloys [DU-V in M-829A2/3] reducing "spaced armor" contribution to 70%. In addition sectioned nose of some penetrators [DM-33 & L-23/27/M- 426] allows partial [50%]or full cancellation [DM-53/L- 27]of 'spaced armor effect'.

13cm RHAe vs 120mm [L-23/DM-33] 105mm APFSDS [IO-105 & M-900] .
12cm RHAe Vs 120mm [M-839A2] & 105mm APFSDS [DM-63/M426]
11cm RHAe vs 120mm [L-27/L28 /M-839A3 & DM-53] & 105mm [M-900A1].

At 0° impact [side hull skirting plates] a similar array ismounted ...this should offer
11-12cm RHAe vs 2-4cm monoblock APFSDS
18-19cm RHAe vs 2-4cm sheathed APFSDS
10cm RHAe vs 120mm [L-23/DM-33] 105mm APFSDS [IO-105 & M-900] .
9cm RHAe Vs 120mm [M-839A2] & 105mm [DM-63/M426] APFSDS
8cm RHAe vs 120mm [L-27/L28 /M-839A3 & DM-53].
If the K-5 ERA element is already spent.then modifie the overall resistance by x 70% RHA Vs APFSDS

In Zaloga Markow & Hull's 'Soviet /Russian Artillery and Armor design practices1945-present' ,there are 3 or 4 references to K-5 effectiveness but there all different values Here are theKE resistance figures he quotes....
pp122 200mm Apfsds & 500mm HEAT == T80U
pp 147 120mm APFSDS & 500mm HEAT ===T-80U
pp 436 150-200mm APFSDS & 400-500mm HEAT ===T-80U



KAKTUS ERA.
Kaktus ERA appears to get much better coverage of Russian tanks than previous ERA. This design seems to have overcome the limitation that sympathetic detonation occurs thus eliminating the need for gap between ERA tiles . Such methods have been illustrated in Int.J.Impact Engng Vol 28 349-362 . The assumption is that the same mass of steel is used in a more space efficient arrangement with the same pattern ERA inside of steel box as Kontakt and K-5 ERAs.The Kontakt 5 ERA features ~ 15cm steel mass but covers only about ½ the turret profile which is about 1.4m² or 0.7m², while Kaktus appears to cover ¾ of the turret profile or ~ 1.0m² . Thus for the same mass, Kaktus must sport about 10.5cm steel mass or 4cm @ 68°. Given the small diameter of western ammo [~ 2cm] thinner plates will do just as well as the thicker plates on Kontakt 5.

2 x 17mm SHSteel plates
2 x 7mm thick ERA elements [probably 3mm steel & 4mm explosives]

Combined @ 70° that's ...
34mm x 1.25 x 0.85-0.7 = 36-30mm @ 70°+ 2 x 1.3d [x 2 sheathed]
6mm x 0.5-0.4= 3-2mm + 1.13- 0.65d/ [x 2 sheathed]
Total 37mm – 32mm @ angle, plus 4.8-4.4d & 8.7-7.8d

Kaktus @ 68° = 19- 22cm RHAe vs 2- 3cm WHA/DU APFSDS [13- 15cm if ERA spent]
Kaktus @ 68° = 36- 41 cm RHAe vs 3- 4cm Steel/sheathed APFSDS [23- 28cm if ERA spent]

There are several techniques to defeat ERA, one is to use high strength alloys [M-829A3 & DM-53] reducing "spaced armor" contribution to 70%. In addition sectioned nose of some penetrators [DM-33/53 & L-23/27/M- 426] allows partial or full cancellation of 'spaced armor effect'.
16cm RHAe vs 120mm [L-23/L26/DM- 33] 105mm APFSDS [IO-105 & M-900] ….. 84%
14cm RHAe Vs 120mm [M-839A2] & 105mm [DM-63/M426] APFSDS…..75%
11cm RHAe vs 120mm [L-27/L28 /M- 839A3 & DM-53]…..58%

If the K-5 ERA element is already spent.then modify the overall resistance by x 70% RHA Vs AP

The Chinese firm "Norinco" produces a line of ERA plates that are also licenced produced in Pakistan licenced
"Type- A =15mm thick reduces HEAT penetration by 70%
type- B =28mm, HEAT- 70%,kinetic rd.- 30%
Type- C- =33mm HEAT (tandeem warhead)- 70%"
Type A is probably two 7mm steel plates and 6mm explosives [HY-1]
Type B is probably two 14mm steel plates and 8mm explosives [HY-2]
Type C is probably two 16mm steel plates and 10mm explosives[HY-3]

Kanwa news agency reports HY-2 is 28mm thick by 25cm x 25cm[4.8kg] or 37.5cm x 25cm x 28mm [6.9kg]. This suggests a cross sectional density of ~ 2.8g/cc. Since we know explosives and steel are envolved these have densities of 7.8 & 1.8g/cc so given this thickness [28mm] the structure can't be steel explosive or the density would be 4.3g/cc.Traditionally the explosive thickness is similar to steel thickness and none are ever really thick [4mm steel and 3mm explosive is the thickest seen so far [Kontakt]. So clearly some airgap is included as in soviet/Russian designs. This suggest 1/3 steel ; 1/3 explosive and > 1/3 airgap, that could mean two arrays of 4mm steel and 3mm explosive underneath, just like Kontakt ERA inside of a thin aluminum box . That should offer the same resistance as Kontakt ERA.

HY-2 should offer ~ 0.5cm @ angle erosion plus 0.5- 1.2d [2-4cm APFSDS] & double if sheathed .So it should offer about ….

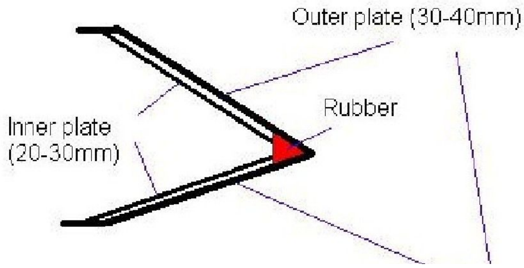
	< 30°	45°	60°	65- 68 °	70°
2cm APFSDS	0.6+1cm	0.7+1.3cm	1.0+1.7cm	1.3+2cm	1.5+ 2.4cm
3cm APFSDS	0.4+ 0.5cm	0.6+0.8cm	0.8+ 1.3cm	1.0+1.6cm	1.2+2.1cm
4cm APFSDS	0.3cm	0.4cm	0.5+ 0.3cm	0.6+0.6cm	0.7+ 1cm
3cm sheathed	0.4+ 1cm	0.6+ 1.6cm	0.8+ 2.6cm	1.0+ 3.2cm	1.2+4.2cm
4cm sheathed	0.3cm	0.4cm	0.5+ 0.6cm	0.6+1.3cm	0.7+2.0cm

However the armor reported for the Type 59D shows a two ton increase when the 50 ERA tiles will only account for ~ 300kg. One possible answer is that the ERA tiles are bolted to a 2cm steel SHS spaced plate ,similar to the arrangement on the Slovenian M-55S.

Type A at normal impact should offer 15 mm = 7mm ÷ Cos #° + 1.8d/1.5d/1.3d [2.8d/2.3d/2d @ 60- 65°] doubled if sheathed
Type C at normal impact should offer 33mm = 25mm ÷ Cos #°+ **3.5d/2.8d/2.5d [4.4d/4.1d/3.7d @ 60- 65°] doubled if sheathed**
So Type C @ 65° should offer …
[2 4cm APFSDS] 5.9cm + 8.8cm 15cm = **15 21cm RHAe**
[2 4cm sheathed APFSDS] 5.9cm+ 17.6cm 29.6cm = **23 35cm RHAe**

EARLY 1990s WEDGE ARMOR

In order to upgrade the effective resistance of the German Leopard- 2 tank in the early 1990s, an appliqué was developed for this tank to cover the front turret areas. This appliqué apparently adds 4 tons to the turret mass. The armor arrangement is reported to be two steel plates spaced 5cm apart with a 3- 4cm thick outer plate and a 2- 3cm inner plate sloped @ 60° vertical angle [horizontal angle is ~ 30°, thus the compounded angle is ~ 68°].



The whole array is mounted ~ 60-80cm ahead of the front turret wall, which was reconfigured with 3[d] gen compositie armor. The LOS thickness of the spaced armor plates amounts to ~ 13-18cm...but give the T/d compared to APFSDS threats the effective resistance should be ~ 0.9 of this thickness or about 12-16cm. Thin plates of armored steel are often thicker and standard German Armored Steel is made to hardness 430 BHN in thickness up to ~ 4cm...This would boost the resistance back up to 14-19cm RHAe. In addition there is the spaced plate effect that must be included...this should be 1.3d x two plates or 2.6d vs monoblock penetrators and 5.2d vs sheathed penetrators.The air gap of 5cm @ 68° means there is sufficient gap for the full spaced plate effect,thus the array should offer..

Vs 2cm HS/SectAPFSDS 14-19cm + 3cm ~ 17-22cm RHAe
Vs 2cm APFSDS 14-19cm + 5cm ~ 19-24cm RHAe
Vs 3cm APFSDS 14-19cm + 7-8cm ~ 21-27cm RHAe
Vs 3cm sheathed APFSDS 14-19cm + 16cm ~ 30-35cm RHAe
Vs HEAT warheads the spaced plates should offer **27-32cm plus 0.4d** [600-800mm airgap] .

Since the LEO-2A4 is already rated at 700mmm KE and 1000mm HEAT resistance, the adjusted figures including Wedge armor should be more than 70-75+22-25-35cm KE and 100+ 30/20cm + 0.4d HEAT . That's more than **90-100cm KE resistance and more than 120cm HEAT resistance**. Since the turret is rated with improved compositie armor and a spall liner , the actual resistance is going to be much higher....some german sources claim the LEO-2A5 resistance is in the region of 1000-1100mm KE resistance!

As the above diagrams indicate , these spaced plates are fixed at the base with rubber which could suggest some kind of plate movement is possible.It would be also easy to insert rubber/fibre material inbetween these plates to covert them into IRA plates.Such an increase in mass could be offset by coverting the inner steel plate into a perforated plate as this would mean ~ 2/3 of the mass....which would free up ~ 1g/cc density interlayer material. Such a change would agitate both long rod penetrators [especially brittle projectiles] and shaped charges. In this case the resistance is boosted the spaced plate effect to 1.3d + [1.4* 1.3d] + 0.8d or **18-22cm+ 3.9d vs APFSDS** and **18-22cm + 7d Vs sheathed APFSDS**. The HEAT resistance becomes **33cm + 1.0d .**

EAAK

The EAAK thickness reported in JANES is two 5mm hard steel plates 25mm apart. Thus the total thickness is 35mm @ 45° for a LOS thickness of ~ 50mm. In a paper from the RAFAEL group [who make the EAAK] "Jet Penetration into Low Density Targets"; Int.J.Impact Engng Vol- 23 , pp 585-595 [1999]. The effectiveness of low density material is examined when struck by modern particulated jets.It looks like some material with a density of rubber [1.4 g/cc] should offer a HEAT resistance of 0.38 in thin amounts [couple of inches], while in thick amounts [a foot or more] it offers about 0.3 a much resistance as RHA. In addtion it appears that theres no difference between mild steel and RHA in terms of the resistance thus if the EAAK were 'recalulated' against a modern Particulated jet warhead [late 80s on], the figures should look as follows.

10mm hard steel x 1.25 + 25mm elastiomere x 0.5 @ 45° = 36mm = about **22.5cm RHAe HEAT** resistance plus the base armor. so a **M-113/AAVP-7** side armor should have 44mm AL-5083, with this EAAK armor it should offer **25cm** resistance, **27cm** if a spall liner is included. Since the rubber does allow the plates to move , there by destablizing any AP type shot, the KE resistance to 14.5mm high strength BS-32 API should be 12.5 x 0.6 @ 45° plus 2 x 1.0d = 10.7+ 28 = **39mm plus the base armor**...so a **M-113/AAVP-7** side armor should have 44mm AL-5083, with this EAAK armor it should offer **5.2cm RHAe** resistance or complete resistance to 12.5mm API @ muzzle and against 14.5mm API @ 50m .

It looks like there are atleast two versions of the EAAK armor,one described in JANES as 2x 5mm steel plates spaced an inch apart and mounted 6 inches from the main armor wall @ 45°. Then theres the second version with 2 x 5mm plates sandwiched between ~ 5mm rubber mounted 2 inches from the main armor @ 45°. The Italian version should offer....2 x 5mm [12.5mm] + 5mm x 0.45 [2mm] @ 45o = ~ 21mm x 5.8 = **12cm RHAe HEAT armor** plus the base armor, should be ~ **15cm RHAe.The Ke resistance is boosted by 1cm erosion and 1.7cm spaced plates or 3cm all round.**

Ceramic Faced Applique

By the late 1970s attempts to increase the level of protection on basic APC type vehicles was introduced. Initially this included simple hard steel plates bolted to the hulls that were often aluminum. The synergistic effect was to increase the resistance to about the same thickness of RHA. So 44mm aluminum plus 6mm VHS bolted became about 45mm RHAe vs HMG AP ammo or a TE of 0.9. Given the base aluminum resistance of 0.33 and VHS being ~1.35 , the average value should have been only 0.58 Te [that's a 50% increase !] Even adding this thin steel plate often stressed the existing AFVs suspension and engine - transmition system to the maximum. Any further increase in expected resistance could only come from high technology or new material solutions**.**

Ballistic experiments of HMG shooting at simple Ceramic/ Kevlar type armor show a resistance of 100kg/m² to stop a 12.7mm M2AP and ~ 125kg/m² against the 14.5mm API threat . Given a ¼ Kevlar and ¾ Ceramic thickness this should mean 3.2g/cc and thickness to stop 7.62mm AP should be 15mm and 31mm to stop a 12.7mm API , while 39mm to stop 14.5mm API [Source:Structures Under Shock and Impact V,pp 673- 681] . The TE should be 1.15 vs LMG/HMG [7.62/12.7] and 1.43 vs 14.5mm . By themselves the Kevlar should only offer about 0.2 KE resistance while the Alumina ceramic [AD- 95] should result in a Te of 1.2 Vs LMG & 1.45 Vs HMG. Combined with ¾ Ceramic and ¼ Kevlar, the average TE should be 0.95 LMG and 1.14 HMG, when the experimental values are 1.2 & 1.45 respectively. The boost is 21- 26% due to this face hardened layering against LMG/HMG threats . The mass of the above mentioned appliqué would be the same as 6.3mm /11mm & 15.9mm .

LIBA composite appliqué

RMOgorkiewcz has reported the ME of 2.28 :1 for this armor subjected to HMG threats ["Armor for Light Combat Vehicles" JANES IDR; July 2002 pp41- 45] .He also reports it requires 141kg/m² to stop BS32 14.5mm API threats, and is manufactured for the USMC AAAV. French Company ARES which manufactures this armor underlicence from Israel reports the following properties for LIBA appliqué armor.

> *"Bullet- proof LIBA® add- on armour panels for LAV, AIFV and APC vehicles; trucks; helicopters; boats; civil vehicles (VIP, cash transport, police) and buildings....LIBA assures a protection level ranging from ordinary small calibres up to medium AP calibres with a weight of 2- 3 times less than its steel equivalent, with good multi- impact and shock resistance behaviour it is a real modular armour concept. It permits adaptation to all forms and dimensions, and allows for rapid and easy field reparation......ARES Protection's LIBA armour is made up of modular panels, which consist of a network of cylindrical ceramic pellets in an elastomeric matrix, glued (or not) with a fibre or metal backing...The LIBA armour panels fracture and deviate the high-hardness bullet core, then the energy is absorbed by multiple pellets and finally the pellets and bullet fragments are stopped by the backing material."*
>
> http://www.army-technology.com/contractors/armoured/ares/index.html#ares1

MEXAS

Mexas is a new German armor developed by IDB Desienroth in the early to mid 1990s . JANES A&A upgrades 2000-2001, reports that MEXAS has been marketed to a number of countries in the last decade and offer a Light; Medium and Heavy configurations. MEXAS Light is for light AFVs as small as the wiesel airborn AFV, while MEXAS Medium can be mounted on medium tanks and ICVs like the BIONIX ICV & Stryker APC. MEXAS heavy is reserved for heavy tanks like the LEO-2A5/6. JANEs reports the following capabilities associated with each class of MEXAS appliqué.

MEXAS LIGHT : All round protection from **155mm @ 15m and 7.62mm API** while the frontal protection is **14.5mm API at 60- 180° frontal arc.** Presumably the variation depends on the base AFV front and side armor. This armor adds 500- 1600kg mass depending on the coverage.This suggest a steel mass of ~ 7mm

MEXAS MEDIUM : All round protection from **155mm @ 10m range and 12.7- 14.5mm API, while RPG- 7 protection [73mm]** is listed as well for this level. This armor adds 3500kg to cover the front and side of a LEOPARD 1 tank [Austrailian prototype] and 6600kg for the Canadian LEOPARD –1 coverage front and sides.Coverage for the Stryker with MEXAS Medium is thought to weigh 3000kg to cover front/sides and rear, as well as MEXAS light for the top. 24mm steel mass. With a Mass of about 1.7g/cc that's about 10cm thickness.

MEXAS HEAVY is listed as **30mm API/APDS/APFSDS & 84mm HEAT**. This adds 4000kg just for the LEOPARD –II front and side turret coverage , while another 3000kg covers the turret roof and glacis plate as well. Approximate 50mm steel mass

All the above can be offered inconjunction with IDB Spall liner [Dyneema?]

Little is actually known about this armor or how it works but some fairly incredible claims are associated with it. Its reported that a thin armor of **7mm Hard Steel** and **23mm MEXAS** will stop **90% of all 12.7mm API @ 50m** range, this is the same as **36mm RHAe.** If the base armor is removed the **27mm RHAe = 23mm MEXAS which is a TE of 1.1 and an ME of 4.1 close to the 4.3** reported above.But if this is true then the MEXAS light **@ 15°** added to the Styker should add **27mm KE and 45mm HEAT.** In combination with the base armor that should mean **47mm KE and ~ 78mm HEAT. Most 14.5mm API** impacts should result in **45mm penetration @ 0° or 40mm° 15°.** However this is an average and some impacts may result in as much as **44- 49mm penetration @ 15°.** To go to Iraq **3mm HS** was added and the cage armor that adds 18 inches standoff to any HEAT impacts**. The 3mm** HS [added in Iraq] at angle should push the armor **to ~49mm @ 15°,** which should be enough to stop all **14.5mm API** impacts. However the cage armor results in a **2.3 diameter** reduction in the shaped charge penetration of a **73mm RPG- 7** warhead. This still leaves **2.0d residual penetration or 146mm.**

The sandwhiching of **3mm VHS ; 20mm MEXAS & 14.5mm VHS backed up by 20mm Spectra shield [spall] @ 15°** should result in a resistance of **1.5- 1.7 times the thickness or 9- 10cm maximum** shaped charge resistance. In actual instances in Iraq where RPG- 7s detonated on the cage armor, none of those RPGs penetrated the Stryker armor [upto 50 impacts in some cases], when the above suggest it should easly overmatch the base armor array. If the cage armor is treated as a spaced plate, the 18 inches standoff should reduce penetration by **2.08d [RPG- 7] or only 15cm. SO a ~30±3cm RPG- 7 falls to 15±3cm ,when the ceramic/steel resistance should only be 9- 10cm** Something else is absorbing the remaining **4- 8cm penetration?**

One explaination could be that MEXAS light has been revealed to be structured with layers of honeycomb material and slabs of some material that includes ceramic [although given an overall 1.7g/cc density this must be some special mixture]. Honey comb materials have been shown to offer more resistance due to the relative plate movement. In shaped charge tests when airgaps where introduced into the layering, the resistance **increased by about 0.15d per small airgap.** The exposed MEXAS light structure revealed 2 such airgaps that **could add 0.3d 'spaced plate effect'.** In other shaped charge tests this amount of 'spaced armor effect' has been **increased by factor of 2- 4 times, i**f plate movement can be exaggerated buy **elastic/reactive materials. Thus a "chemically reactive honeycomb"** layer could result in **3- 4 fold increase** in the **'HEAT spaced plate effect'.**This could mean the MEXAS light with +0.3d, becomes + **0.9- 1.2d or equivillent to 6- 9cm** .

This should have a similar effect on the KE resistance, but that would be offset by the insufficient airgap rules. In theory that should be **gap /diameter – 0.5d or – 0.4d per layer or –0.8d.** The bulging effect would alter this, but not sure how.It could be **4 x gap/diameter** that would reduce the resistance by only **- 0.35d .**

Thus the **MEXAS light** resistance could be said to be **1.0 Te vs KE and 2.1 Te Vs HEAT plus 1.0d**

It was also reported that the **BIONIX ICV with MEXAS protects from RPGs.**Pictures of this arrangement show a much thicker appliqué added to the glacis plate suggesting that this might infact be the MEXAS MEDIUM**.** The Bionix base frontal armor is **7mm VHS @ 70°** which is about **28mm RHAe leaving 300mm** for the Medium MEXAS to stop**.** Since this is **22mm @ 70°** that means **66mm mass ÷ 300mm or an ME of ~ 5.9:1 ,** not far from the **5.4 :1 reported.** If this is in a frontal arc [say ± 20°] that should mean **143mm resistance from the side ,** but the BIONIX offers only about 9mm steel on the side so the rest is **134mm .** Given a 6.1:1 ME that would have to mean **22mm steel or the medium MEXAS.**

Medium MEXAS is reported to be tried on the Australian LEOPARD- 1AS tanks to provide front and side immunity to RPG- 7 [N?] type threats. http://www.yaffa.com.au/defence/current/8- news9.htm. **LEO- 1A3 has 44mm LOS spaced triple hardness steel on the side turret with 7cm airgap, which should offer 90mm @ angle + 0.7d or 14cm LOS HEAT** resistance from 60° side angle**.** This in turn suggest the MEXAS medium adds the rest **or 26cm from the 60° angle [130mm from the side].** Given a mass of **22mm, that's an ME of 5.9:1,** not far from **the 5.4** reported above**. The bulk density of MEXAS appears to be around 1.7g/cc so the medium MEXAS should be about 10cm in thickness. To get the 26cm that's ~ 2 x thickness + 1.0d**

JANES claim the MEXAS heavy protects against **84mm HEAT** warhead suggests about **420- 500mm** resistance , which means the **60mm mass** has to have an **ME of 7:1 to 8.3:1.** So the previous mentioned 'generation figures' have to be seen as ball park figures.It could alternatively mean that the **500mm** is the side protection of the **LEO- 2A5** turret with MEXAS heavy**?**

COMPOSITE INTEGRAL ARMOR

This is a range of simplified light weight armors combinded with structural materials to form the basis of future generations of light weight AFVs. Such an armor has to be cheap enough to manufacture in order to replace steel and aluminum as the main structural/armor component and more effective that these as well. In addition the designs allow for special layers to be integrate into the manufacturing process ,like Radar Absorbant layers and IR signature layers etc. The USA company United Defence developed such an armor for the Advanced composite technology demonstrator and is thought to be the basis of the armor for the Future Combat System [FCS] AFVs. While the exact nature of the armor for the FCS is unknow, it should follow in the footsteps of the armor detailed below.

In the journal "Compostities part A, Vol- 34,pp635- 647" such an armor is previewed and analyised. The structure is built around fibreglas with layers of epoxy and Alumina ceramics with base thickness of 31mm ,and an bulk density of

3.1g/cc . These were developed from a multi stage manufacturing process to a single step process , presumably to reduce cost. The manufactured panels and beams feature Alumina hexagonal tiles [AD-99] with widths of 101 x 142mm and radially confined with epoxy adhesive and rubber.In a related paper [Composite part A Vol- 31,pp 823-833], it was shown that when Alumina ceramic tiles were layered with other materials and radially confined with epoxy adhesive [as opposed to polyurethane adhesive], any shattering result on the impacted tile did not transmit to the adjacent ceramic tiles.

The 31mm thick composite is similar to ~ 12mm steel in mass, but should be able to resist a NATO 7.62mm AP @ impact velocity of atleast 800m/s or about muzzle [J. Mat .Processing Tech. Vol-57,pp 141-145]. This should be the same as about 16mm RHA. In addition such an armor should resist the 12.7mmAP ball round at 550m/s [~ 800m] and 20mm FSP [155mm HE burst] , also at 550m/s . Again this should be around 16mm RHA.The composite had the following reported layers. The outer 4mm thick E glass coverlayer with epoxy adhesive attached to a single layer of 14mm thick Alumina hexagonal ceramic tiles [confined with epoxy and rubber] and glued to a 13mm thick S glass backing layer , for a total thickness of 31mm . With a bulk density of about 3.1g/cc , this should result in an thickness effectiveness of 0.52 and a mass efficency of 1.3 against the 7.62mm AP threats.

In a related paper [“Investigation of High-Velocity impact on integral armor using finite element method” ; Int.J.Impact Engng.vol-24,pp203-217] a similar armor [46mm thick and 300mm wide] with ¼ Alumina [AD-90] with ½ S glass and ¼ rubber/epoxy, was ballistically tested. It was struck by the 20mm x 23mm FSP @ 550m/s resulted in 22mm penetration into the 46mm thick array. A similar shaped hard steel [type 4340 steel] penetrator should only penetrate about ~ 28mm RHA. The thickness effectiveness works out to 1.4 and the bulk density works out to about 2.4g/cc so the ME should work out to ~ 4.4 against low velocity 20mm FSP [155mm HE simulator]. The difference in resistance with AP shot is probably explained in the blunt nose and low velocity of the threat in relation to the thicker target [IE better T/d].

In a related paper [Structures under shock & ImpactV pp 273-281], Alumina ceramic was tested with backing layers of Kevlar [almost as much resistance as fibre glass but at 2/3 density]. In these tests it was shown that 30mm thickness of Kevlar/Alumina stopped all 7.62mm AP and would provide ballistic resistance to 12.7mm AP shots, similar to the results in “J. Mat .Processing Tech. Vol-57,pp 141-145” , mentioned above . The 46 mm thickness would provide complete resistance to 12.7mm API and ballistic resistance to 14.5mm API shells at 200m range.

In theory this type of armor should offer about twice its thickness in shaped charge resistance, so the following approximations can be made about the FCS basic armor.

31mm top/bottom @ 90°[~ 12.2mm steel same as M-113] = **~ 6cm HEAT & ~3cm KE**
Resist all 7.62mm tungsten AP and ballistic limit to 12.7mm API. From 30° down angle should be immune to 12.7mm API and to 14.5mm API @ 60° down angle @ 50m range [90° = horizontal] .

46mm side /rear @ 0° [15mm steel , same as M-113] **= ~ 9cm HEAT & 5cm KE.** Resist all 12.7mm tungsten AP and ballistic limit to 14.5mm API. From 30° side angle should be immune to 14.5mm API.

46mm frontal @ ~ 65° [30mm LOS steel mass] = **18cm HEAT & 9cm KE**. Should resist all 30mm AP and APDS ammo, while 30mm APFSDS should get ballistic limit penetration @ 1km. From 30° side angle should be immune to 30mm APFSDS.

This APC , with an internal volume similar to the M-113, should mean 12-13 tons base weight, while an ICV with volume similar to MTLV or a light 105mm gun tank, should weight about 16 tons. The outer armor is reported to be reinforced with “Electromagnetic Armor” that’s demonstrated the ability to defeat an RPG-7 [~ 300mm penetration]. This should add **2cm + 4.5d HEAT and ~ 2cm KE** to the above figures, which should give an allround resistance to 14.5mm API & RPG-7L and frontal resistance to 25/30mm APFSDS and RPG-7RV/RPG-29.

Electro Magnetic armor.

http://www.copybook.com/publications/article.asp?pubID=15&catID=96&artID=451
It shows a 'resusable ERA' type capability for a couple of tons weight increase [~2000-2500kg?] that offeres the same protection as 10-20 tons. Thats a ME of 5-10:1...almost as good as ERA.

The picture shows a modified warrior with what looks like 4-5" thick array cover 'most' of the side hull.I've seen similar picture of the Bradely with multiple side by side penetration holes on the same type Electric armor? Presumably...to cover the side hull. To cover the entire hull all round is going to be possibly 50% heavier. Covering a turret allround will make it heavier still. Assuming the electrical capacitor is ¼ of the overall mass and the rest is the armorplate, that should result in about 13-14mm steel or two ¼ inch steel plates separated by ~ 4” gap. The plates are electrically charged and the passage of the copper shaped charge jets ‘short curicts the electric charge and disperses the jet flow at the same time. This may not have much effect against short rod AP/APDS type autocannon type penetrators. In that case it may well still act as ‘spaced armor’.That should add about ~ 1cm + 1.0d or ~ 2cm. Simply going on the cases sited about RPG-7 defeat suggest ~ 4.5d reduction in penetration plus 2cm.

So the "DSTL" will develope the above armor to ½ the thickness and possibly ¾ the weight, over the next 20 years ...I take that to mean ~ 2" & 800-1000kg weight , for the side hull coverage.

AMAP Protection System

IBD unveiled its new Advanced Modular Armor Protection (AMAP) composite armor concept, follow-on to their combat proven Modular Expandable Armor System (MEXAS) protection, which has provided basic protection suite for over 12,500 combat vehicles worldwide, AMAP, utilizes ultra-fine powders made from nano-particle ceramics to create thinner, lighter but tougher ceramic modules. AMAP is already utilized for a number of new applications including the protection kits for the Italian army's MLV, the Norwegian CV-9030 and Swedish CV-9040 armored vehicles. New add-on armor suits are on development for Patria's 8x8 AMV IFV and command vehicles, scheduled for deliveries to the Finnish and Polish armies.
http://www.defense-update.com/products/a/amap.htm

In a paper "Numerical modeling of the impact behavior of new particulate-loaded composite Materials" Comp Struct Vol-61,pp-151-159. This material is 1/30th the cost of pressed quality ceramic and less than 1/2 the cost of RHA, so its dirt cheap!

Reference penetration into Aluminum 2017 was 42mm which offers atleast 41% of the resistance of RHA by thickness when struck by 7.62mm AP [WC core] shots. Against that the composite using long alumina grains at 50% volume, resulted in Areal density of 45g/cm² with a residual penetration of 8mm into aluminum. Since this material is 80% of the density of ceramic and then mixed down with less than 1/4 resin [vinylester], the mass ends up being about 2.5g/cc.

Thats the same as 25mm thickness compared to 42mm 2017 or a Te of ~1.65 compared to this aluminum. Converting to RHA it should be a Te of 0.68 for this composite/aluminum plate target. The mass effectiveness becomes ~ 2.1:1. Extending the graph to zero residual penetration, yeilds a Areal density of ~70g/cm², which works out to a theoretical thickness of 27mm/42mm by aluminum or 0.64 Te compared to RHA and a ME of ~2:1. Since ALuminum is over twice the cost of RHA then the combination of this particale composite/vinylester/Aluminum should be the same cost of RHA but offers twice as much protection.

This would be the minimum protection level. If the same armor was sandwiched with steel the overall resistance of the sandwhich should be 30% over the bulk TE. In addition the HEAT resistance should be roughly 2.0 times the thickness of this composite.

MEXAS has layers of honeycomb structures sandwich between blocks of some composite material.When honeycomb structures are used as interlayers between plates their resistance is about 40% of the thickness of RHA even though the density is merely a fraction of g/cc. That must be how this armor achieves such high resistance at only 1.7g/cc bulk density. THe big problem with MEXAS is cost, its 2.5 times the cost of a perforated steel plate which [since its machined] is more expensive than Hard Steel which in turn are generally twice the cost of simple RHA plate.

KHAFJI Armor moduls found in some Iraqie tanks in 1991.

Here are the details regarding Khafji Armor (Turret Box):

Box=6.9mm steel plate
Box face=405mm tall (front)
Box Back=565mm tall (back)
Box Depth=495mm (top)
Armor Composition=six arrays (five tri-plates and one bi-plate)
1st Array (Outer)=14.7mm aluminum, 4.0mm rubber, 4.7mm steel
2nd Array=4.0mm rubber, 10.3mm aluminum, 4.7mm steel
3rd-4th-5th Arrays=10.3mm aluminum, 4.0mm rubber, 4.7mm steel
6th Array=10.3mm aluminum, 4.0mm rubber
1st Air Gap (Between Outer Box layer and 1st Array)=4.8mm air
Other Air Gaps (Between Following Arrays)=24.6mm

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LAYERING- -

Test of AP shots on various Aluminum Steel combinations has revealed that if the less dense layer is on top, the array offers **as much as 15%** more resistance than the other way around. Tests on APFSDS seem to show this same effect. **Test on ceramic with backing plates show resistance** changes with the backing material **. The Ceramic/Aluminum**, **offering much less resistance than the same Ceramic mounted on RHA. In addition the same ceramic mounted on tungsten plate offers more resistance still**. In the case of aluminum ,this is less dense than the ceramic and thus it fits into the above model. The case of the Tungsten backing is of note due to the possibility that this might be a key to DU armor effectiveness.

Tungsten offers a Te of 1.44 compared to RHA. But when the ceramic was mounted on Tungsten , the resistance of the ceramic increased by 33% over the resistance offered by the Tungsten plate. Looking at it numerically the 1 part ceramic + 2 parts RHA offered 88% of RHA ,making the ceramic 'Te' only 0.75. The 1 part Ceramic +1 part Tungsten target was 1.16 times RHA. But it should have offered an average of 97% resistance making the combination 20% better. **This implies that the backing material increases the resistance of all the components of the array**. See; **Int.J.Impact Engng Vol-23; pp 771-782**

Another way to increase the effectiveness of the ceramic /steel target - is to confine [encase] the ceramic in steel . Tests of APFSDS impact ,have shown that a mild steel cover plate mounted on top of a Ceramic Steel target ,will increase the overall target resistance by 18% ,while SHS cover plate increases the resistance by 25%.This occures because the shatter zone of the ceramic is much larger than the hole created in the steel cover plate. **As the ceramic shatters it has to go somewhere and would normally flow out ward away from the crater. With the steel cover plate in the way the ceramic material is forced back into the path of the on coming rod there by doubling the erosion rate.** In addition its also been show that if a thin Graphite layer is inserted between the coverplate and ceramic this increasesd the erosion rate further, possibly acting like a 'seal' and boosting resistance by an additional 5-10%.

If the backing material in a Steel - Ceramic - steel target is SHS instead of RHA the resistance of the target as a whole goes up again..A ¼ ceramic ¾ SHS target offered 20% more resistance than an all SHS target. In the test the SHS was BHN 420 and when adjusted to RHA means a further 23% increase , or 1.5 times . The numerical value should have been only 1.1,thus the increase was 36% . In the case of a ¼ SHS + ¾ Alumina target, the value should be 1.05 , but the real value is 1.31 or a 25% increase. **These changes apply to the whole armor arrangement just like heavlier and ligher backing materials. Its likely the secret to the generations of DU armor may be in the impact of high density and high hardness backing materials**. SEE **Int J Impact Engng Vol 17 pp 409-418. Int J Impact Engng Vol 19 pp 703-713.1997**

Simplified Mass effectivness model for modern tank armor.

The mass efficencey [Me] of modern armors are rated in numerous ballistics papers published in engineering journals around the world. Two of the best sources are the "International Journal of Impact Engineering" and the annual "International Symposium on Ballistics". By applying some of the lessons above to these data sets, a simple model can be erected to approximate the effective resistance of modern armor to APFSDS attacks, even if the exact details of the armor arrangement are unknown.Rolf Hilmes in his 1987 "Main Battle Tanks-developments in design since 1945", reports the 'Me' [Mass efficency] of early sandwich armors to be between 1.2 to 1.4 RHAe [Rolled Homogenous Armor equivilent]. What this means is that if you had 10cm of steel in a certain area of a tank design [like the side or rear turret armor], and used a contempory sandwich armor instead, it should result in a level of protection equivilent to 12-14cm of RHA. The variation [1.2 to 1.4] is due to the proportion of steel to ceramics. If this is ¼ ceramic and ¾ Steel, then the 'Me' is ~ 1.2, while if the ratio is ¾ ceramics and ¼ steel , then the 'Me' is 1.4 x RHAe.

These early armors featured simple Alumina ceramic which was about the same cost as Aluminum and hard steel [double the cost of RHA], which where already in common use of tanks designed in the 1970s. This basic Alumina ceramic was the cheapest at 85% theoretical density and was also featured prominently in contemporary ballisitics research of the 1980s.In a semi infinitie target of Alumina ceramics [85%], which is also refered to as AD-85, the expected resistance is ~ 82% of RHA. This means is that 10cm of AD-85 should offer a resistance equal to 8.2cm RHAe . This works out to a 'Me' of 1.9 . Thus 1.9 [Me] x 3.4g/cc [density of alumina ceramic] = 6.46 ÷ 7.83 [density of RHA]= 0.82 of RHAe.

First Generation Composite
[AD-85 /RHA]
¾ = 1.3
½ = 1.1
¼ = 1.0

What this means is that a tank armor with a sandwich of 3 parts RHA & 1 part AD-85 should offer a resistance ~ 1.0 times its mass.....in other words if it had a multilayerd armor equivillent to 40cm steel mass, it would still offer only 40cm RHAe , it doesn't offer any advantage against APFSDS threats, however it would increase shaped charge resistance. So the Chieftian tank front turret is designed with ~ 40-45cm Steel mass through the front turret. In its production form, cast armor was used which offers a resistance of 95% of RHAe. Taking into account T/d & d/W [see below] the resistance is **~ 37-38cm RHAe** [45-40 x 0.95 (cast) x 0.9-97 (t/d & W/d)]. If the same tank was redesigned with a sandwich of ¾ RHA & ¼ AD-85 , it should offer a KE resistance of **42cm RHAe**. [42cm x 1.0 (Me)].

When this type of sandwiched is layered with a steel cover plate , the overall resistance of the array is boosted by 18% or 25% if the coverplates are Semi hardened steel [BHN > 400]. If the coverplates are simple aluminum plate there is little apparent increase in KE resistance. Further if the cover plates are substantial thickness [3 times the projectile diameter or more], then these figures for cover plates go up ~ 5% respectively.

This means the above example of a ¾ steel & ¼ AD-85 changes to a resistance of 1.18 Me or 1.25 if the coverplate is SHS.If the coverplate was thick RHA that should mean 1.23 Me. So a Chieftain tank remade with such an arrangement should offer **52cm RHAe** against APFSDS.

If the rear metal plate in the sandwich is Semi harded steel [SHS] , then the overall resistance is boosted by ~7% , while if the rear metal plate is aluminum , the resistance is reduced to ¾ of the original value [lack of support]. If the backing metal plate includes some dense layer like Tungsten or DU metal, the overall resistance of the armor package is boosted a further ~ 20%.

So in the above mentioned case , if SHS is used as both the coverplate and back plate, the Me becomes 1.34....In the case of the Chieftain with SHS steel /Alumina should offer ~ **56cm RHAe** against APFSDS threats. Like wise a Chieftain tank remaid with ¾ AD-85 & ¼ SHS should offer ~ **73cm RHAe** [42cm x 1.3 (Me) x 1.25 (SHS coverplate) x 1.07 (SHS back plate)].

More modern armors and research feature more advanced ceramic armors like 'AD-99' and 'Silicon Carbide' [5-10 times the cost of RHA]. These feature a semi infinite resistance of ~1.05 RHAe offering 'Me' of 2.2 ….compared to 0.82 RHAe for 'AD-85'.Other more advanced ceramics are available that are lighter , like Boron Carbide which offers a resistance of ~ 0.89 RHAe [density 2.5 g/cc] or 'Me' of 2.7 and heavier like Titanium Diboride [density 4.5 g/cc] which offers a resistance of 1.2 times RHAe[2.1 Me] . But these are hughly expensive [20-40 times the cost of RHA], so are not likely to be in use in current armor designs.The most advanced [and most expensive] ceramic armor available is the Swedish "Syndia diamond composite" armor [@ 4.5g/cc] ,which appears to offer a resistance of 2.0 RHAe [Me of 3.5 : 1] , when subjected to APFSDS attack. If this armor was sandwiched with ¾ Syndia & ¼ SHS, the Me should become 4.0. However breakthroughs in construction technquies could open the doors to the use of these advanced type armors in the future AFV designs.If this happens a light 20 ton ICV could reach allround protection levels of 8cm RHAe and frontal armor protection levels ~18cm RHAe, while a 35 ton tank should reach 100-110cm RHAe front turret protection levels and side turret resistance of 60cm RHAe.

Second Generation compositie
[AD-95 /RHA] IJIE Vol26, pp 337 [open face sandwich @ 60°with d/w ratio of 28:1 & t/d of 3:1]
¾ = 1.4
½ = 1.2
¼ = 1.1

[AD-95 /Al-7xxx] IJIE Vol26, pp 337
¾ = 1.3
½ = 1.4
¼ = 1.4

Third Generation Composite
AD-98-99 /RHA
SI = 2.25 [2.1÷ 0.95(d/w)]
¾ = 1.9 [1.8 ÷ 0.95]
½ = 1.7 [1.57 ÷ 0.95]
¼ = 1.2 [1.15 ÷ 0.95]
{Source Adv Comp-93; pp 141-146} Me = 2.2 in 4:1 t/d ; 1.57 in moderate amounts [½ AD-98 & ½ RHA] and 0.56 in thin amounts [1.5 t/d = x 0.5] ratio was and d/w of 20:1[x 0.95]

[AD-97 /SHS] [IJIE Vol-17,pp 411-415] {10:1 L/d WHA APFSDS shot at radially confined target with d/w ratio of 17:1 - 31:1 & t/d of 3.5:1}

	d/w 17:1	26:1	31:1	
¾ = 1.8	1.62		1.7	[÷ 0.97 (d/w) ÷ 0.95 (t/d) = 1.76-1.85 Me theoretical]
½ = 1.6	1.47		1.52	[÷ 0.97 (d/w) ÷ 0.95 (t/d) = 1.6 Me theoretical]
¼ = 1.5	1.5		1. 47	[÷ 0.97 (d/w) ÷ 0.95 (t/d) = 1.59 Me theoretical]
Converted to the RHA standard [÷ 1.07 hard backing] ÷1.05 [radial confinement]				
¾ = 1.5	1.35		1.41	[÷ 0.97 (d/w) ÷ 0.95 (t/d) = 1.53 Me theoretical]
½ = 1.4	1.36		1.37	[÷ 0.97 (d/w) ÷ 0.95 (t/d) = 1.48 Me theoretical]
¼ = 1.25	1.3		1.27	[÷ 0.97 (d/w) ÷ 0.95 (t/d) = 1.38 Me theoretical]

[IJIE Vol23, pp 575]…..½ AD-97 ½ RHA with RHA coverplate = Me of 1.53-1.61 and a multi layered armor with 23-28:1 d/W ratio & t/d of
5:1 that's Me of 1.47-1.55 x 1.18 [RHA coverplate effect] x 0.98 [d/W] x 0.9 [t/d] = 1.53-1.61 Me .

[SiC /Al-7xxx] IJIE Vol26, pp 337
SI = ?

¾ = 1.8
½ = 1.75
¼ = 1.5

[SiC /RHA] ISB-2001 –TB-07 pp 1094]
SI = 3.0
¾ = 2.0
½ = 1.5
¼ = 1.2

The construction of large armors for tanks requires the fabrication of really large ceramic blocks which are very expensive. One alternative is to use a number of thinner ceramic tiles , but this practice reduces 'Me' by > 3% . In addition the sheer mass involved in these inserts is so weight limited , that often lower density materials have to be included as 'interlayers' in the sandwich layers to bring the whole armor mass into line with the AFV limitations. This - as one would expect- reduces the 'Me' of the armor further to 95%-80% respectively.These figures are included in the T/d & Lc values.

The ratio of diameter of penetrator to ceramic tile width [d/W] also plays an important part in overall ceramic/steel resistance. If this ratio is ~ 12-14 :1 the resistance should be 85-90% below the above mentioned figures , but really small ceramic cylinders , which are thought to be used in the armor of the T-80U tank [T-80A featured them and T-80A was prototype for T-80U] may offer only 50% of the ME .These cylinders had a d/W ratio of only 2-3 :1 and their resistance should be ~ 50-60% of the 'Me' for a sandwich of the similar construction reported above.

So the above mentioned hypothetical Chieftain tank remaid with ¾ AD-85 & ¼ SHS armor array, should actually offer ~ **61cm RHAe** [42cm x 1.3 (Me) x 1.25 (SHS coverplate) x 1.1 (SHS back plate) x 0.9(t/d) x 0.9 (d/W)].....If this case had a back plate with DU armor , then the resistance should be ~ **73cm RHAe** [x 1.2].

Studies of multilayered armors show that the coverplate helps to boost the resistance of the overall armor package due to the fact that the shattered ceramic materials always generate a larger crater than the sandwiching steel plates. If there is a coverplate , then this will tend to trap the ceramic fragments and plough them into the path of the oncoming penetrator, thereby doubling the erosion levels.These studies have also shown that the simple addition of a thin graphite layer between the cermic and the cover plate , tends to creat a much smaller hole, resulting in a kind of 'seal'. This has been tentatively shown to boost the overall resistance of the armor package by ~ 10%.

Shaped charge resistance is harder to gauge for the simple reason that with every paper published on shaped charges penetration, there are 10 papers published on kinetic energy penetrators, thus we know a lot more about KE , than we know about shaped charge. What has been shown is that is broadly similar to high velocity APFFSDS penetration and that layering of dissimilar materials leads to a 1.2 increase in resistance while many multiple layers of dissimilar materials leads to ~ 1.35 increase in resistance. If DU armor is included in the backing plate this overall increase should go up ~ 10% in a steel/WHA sandwich to 20% and for a Steel /WHA/Ti sandwhich [4.5g/cc] or 23% for a steel/WHA/Aluminum sandwich [2.8g/cc]. SO the lower the density cavity the more the heavy layer benfites the target as whole [maybe 1.5 g/cc is 25% increase]. RHA with a hardness of ~ 270-280 BHN has a resistance value of 1.0 and relative to this value the following materials have resistance values of……

Aluminum 5xxx 0.5 Te & 1.42 Me
Aluminum 7xxx 0.6 Te & 1.7 Me
Aluminum 2xxx 0.7 Te & 1.9 Me
Mild steel [BHN 180] 0.8 Te & Me 0.8 cheap
SHS [BHN 400-480] 1.2-1.25 Te & Me 1.2-1.25
VHS [BHN >500] 1.3-1.35 Te & Me 1.3-1.35
Plexiglas 0.7 Te & 4.5 Me
FRP [1.0g/cc] 0.5 Te & Me 3.9 [dyneema Spectra shield]
Kevlar [1.4g/cc] 0.5 Te & Me 2.7 [expensive]
Steltexolite [1.7-1.8g/cc] Te 0.5 & Me 2.0-2.2
GRP [2.5g/cc] 0.6 Te & Me 1.8 [V expensive]
Titanium 1.0 Te & Me of 1.7-1.8 [costs twenty times as much as RHA]
Sandbar [1.8g/cc] = Te 0.5 & Me 2.2 cheap
Glass/ Quartz [2.6g/cc] = Te 0.76 & Me 2.3 relatively cheap [1.2 reported for a steel/glass target; could be 1+ [3 x 0.76] ÷ 4 x 1.35= 1.11]
Ceramic
AD-85 [3.4g/cc] = Te 1.0 & Me 2.3
AD-90-92 [3.6g/cc] = Te 1.4 & Me 2.9
AD-95-97 [3.8g/cc] = Te 1.6 & Me 3.4…costs three times as much as RHA?
AD-98-99 [3.9-4.0g/cc] = Te 1.8 & Me 3.6…costs three times as much as RHA?
B4C [2.5g/cc] Te 1.0 & Me 3.1…costs twenty times as much as RHA
SiC [3.2 g/cc] = Te 1.2 & Me 2.9…costs ten times as much as RHA [1.5 reported for a steel/SiC target; could be 1+ [3 x 1.2] ÷ 4 x 1.35=1.55]
TiB^2 [4.5g/cc] = Te 1.7 & Me 3.0…costs 40 times as much as RHA?

Unless other wize stated above , all materials are expected to cost twice as much as RHA to include in armor design.

Chieftain Challenger –1 Challenger - 2

Armed with these basics we can now look at some modern armors by basing on previous generations and extrapolating to the next generation. For example if a tank with the armor of the chieftain tank where made out of ¾ AD-85 ceramic steel- interlayer sandwich with hard steel cover plate , we would end up with…..

The Chieftain tank front armor is reported to be 195mm cast armor @ 60°. In truth there is also a horizontal angle of ~ 30°, bringing the LOS thickness to be penetrated to ~ 42cm cast steel. Since the resistance of cast armor is 95% of RHA and the lateral confintement & T/d figure should be ~ 90-97% , this results in an effective resistance of **37± 8cm [APDS] & 38± 10cm [APFSDS] RHAe through the front turret.**The HEAT resistance should be Me 1.0 x 42cm = **42cm RHA from straight on and 31cm RHAe from 30° off angle**…reported resistance is 400mm HEAT resistance. This means a near side APFSDS hit would offer 38-10cm = 28cm RHAe , while a hit straight on would offer 38cm RHAe and a farside hit should result in a resistance of 38 + 10 = 48cm RHAe.

If this tank was to made out of a steel ceramic interlayer sandwich, the front turret 42cm steel would become {x 1.3 [Me] x 1.25[coverplate] x x 0.8-0.7[d/W & t/d] } = **54±14cm RHAe [2cm APFSDS] to 48±12cm RHAe [4cm APFSDS] .** The HEAT resistance should be Me 1.77 x [1.0 + 1.0 + 0.6 x 1.2 ÷ 3 x 7.85 ÷ 4.7] x 42cm = **74±16cm RHAe.**

In 1986 a version of the Chieftain was fielded to bridge the gap between the slow Challenger tank production and the increasingly obsolete Chieftain tank. This was achieved by adding “Stillbrew” appliqué armor to the turret front plus a liner inside. This appliqué was thought to be a ceramic steel sandwich possibly with an air gap, but it appears to be just a steel rubber appliqué that’s applied directly to the cast turret.The turret steel mass went up by >11 cm across most of the frontal turret profile, while the steel rubber layers on top of the cast armor offered a ME of ~ 1.0. The appliqué by its self should have a ME of ~ 1.27 resulting in a KE resistance + 14cm or ~ **52±13 cm RHAe,** while the HEAT ME should be 1.38 over all [42 + 18 + 2 x 1.2] or **74±16cm RHAe.**So the simple addition of Stillbrew appliqué brought it up to Chobham armor levels.

Challenger –1

The Challenger tank turret is roughly 21tons with a volume of ~ 4.2m^3 compared to 14 tons and volume of 3.5m^3 for the Chieftain. While the turret profile of the Challenger is 2.0m² compared to 1.9m² for the Chieftain .So all things being equal, a Challenger front turret should result in 1.15 increase in steel mass or 50cm steel mass base. Since this tank came out in mid 80s its assumed to use second gen ceramic /interlayer arrangement , with a density of ~ 4.9g/cc, which is considered the optimum for defeating Shaped charge warheads. This could be a ½ steel & ½ composite with SHS[¾ rubber/AD-90]Cast= 50cm x 1.39 [me] x1.25 [coverplate] x 0.8-0.7[d/W & t/d 2cm-4cm APFSDS] **= 69± 13cm RHAe [2cm APFSDS] & 61cm ± 11cm RHAe [4cm APFSDS]**. The HEAT resistance should be Me 1.86 x [1.07 + (1.4 +0.5* 3 ÷4] x 1.3 ÷ 3 x 7.83 ÷ 4.9] x 50cm = **93± 12cm RHA** …IDR article reports the resistance tobe ‘about 1000mm HEAT’ region, but a figure of 800mm has also been quoted. **.** It just so happens an engineer leaked that the **Challenger –1 armor was ~ 620mm KE** resistance shortly after the tank first entered service...but another source suggests 500mm KE resistance. If this were consistant with a early-80s threat projectiles the 36-38mm diameter BM-26/29 125mm APFSDS would be the threat, so the resistance of 62cm sounds close…however a figure of 500mm KE resistance has also been quoted. If this follows amerian practice the armor should be measured from the 30° off angle or 49-56cm KE and 81cm HEAT, not far of the 500mm KE and ~ 800mm HEAT resistance.

Challenger –2

Challenger 2 turret is thought to be 23 tons but the front turret profile looks to be ~10% less than Challenger - 1, so the front turret armor mass is probably ~60cm steel masss. The armor is reported to be Dorchester [much improved armor rumored to feature DU armor suspended in some elastic medium?].DU ceramic exists that offeres a resistance of 2.67 times RHAe for a mass of 11g/cc [Uranium Oxide 99.7% density or UO^2-100]. This resulted in a 'Te' of 1.9 for a ½ DU-100/RHA sandwich or a 'Me' of 1.53. But theChallenger 2 cross sectional density is only ~ 5.9g/cc , requiring a modified arrangement of Semi hardened steel [SHS] /Graphite/UO^2-100/Cast [1.1/0.4/2.7÷3 *7.84÷5.9]=ME 1.7. This should be 60cm x 1.7 [Me] x 1.37[SHS cover/graphite] x 0.7-0.6 [d/W & t/d 2cm-4cm APFSDS]**= 98 ± 13cm RHAe [2cm APFSDS] & 84± 11cm RHAe [4cm APFSDS] .**The HEAT resistance should be Me 2.75 x [1.12 + 1.9 + 0. 6] ÷ 3 x 1.8[multilayered DU] x 7.84 ÷ 5.9] x 60cm = **165 ± 21cm RHAe.**

No figures have been published for the Challenger-2 armor protection level, but it has been reported that Charm-3 APFSDS was fired repeatedly at a C-2 front turret armor at combat ranges and this armor was shown to be resistant to multiple impacts. The Charm –3 APFSDS is supposed to do a ballistic penetration of > 700mm @ 2km range. Since the standard deviation of penetration results is a theoretical ± 15% range , the maximum expected slanted Charm-3 APFSDS penetration should be **~81cm RHAe.** Since the claimed resistance was in 'the frontal arc' this also applies to a 30° off impact, suggesting the resistance from straight on is at least **89cm RHAe**. Since the resistance was repeatedly shown this suggests front turret resistance from straight on must be >5% higher or **> 94cm RHAe.** Going on the above figures the resistance against a 25mm Charm-3 should be **95cm RHAe**, just enough to resist repeated Charm-3 impacts in a 30° arc . ...reported shaped charge resistance is unknown at this point.

LEOPARD –1A1 LEOPARD –2 LEOPARD –2A4 LEOPARD 2A5/A6

The frontal armor thickness of the **LEOPARD-1A1** turret is reported to be LOS thickness of ~ 6cm cast armor @ angle.The armor mass over the mantle area [½ of the front turret profile], is ~10cm LOS plus 10cm airgap and 3cm outer gun cradle wall thickness [spaced armor?], while the front sloping walls are ~6cm @ 70° x 30° [~ 17cm LOS] for a ~ 16 cm average front turret steel mass. This effective resistance amounts to 0.90 –0.95 [APDS- 2cm APFSDS T/d & W/d] x 0.95[cast Me] or **14-16cm RHAe** over ½ the front turret [APC/APDS/BM-6&9]and **11cm plus 1.0-2.0d spaced plate effect** or **16-19cm RHAe** [BM6&9/APC]over the mantle- ¼ of the front turret profile and where the two overlap [¼ front turret] its 13-14+2-4d = **20-36cm RHAe** . Thus the average **KE** resistance should be **16-22 cm±9cm RHAe**. The HEAT resistance should be ~ **18 cm RHAe** over ½ the profile and across the mantle & overlap area the armor mass is either solid 25cm cast or spaced armor 13cm . With the airgap include that should add 5-10cm bringing the shaped charge resistance upto **19-25cm RHAe .** Thus from straight on the AVERAGE **HEAT** resistance should be **22/18 ± 10cm RHAe** The "±" is from 30° off angle near side /farside hit , so a near side hit would be 7-12cm RHAe HEAT, while a farside hit would be 27-32cm RHAe HEAT.

The addition of the appliqué armor on the turret of the LEO-1A1A1 and A5 models , starting in 1975, boosted the resistance considerably. The increased mass is ~ 20cm average across the front turret. Since these are thin perforated steel plates wrapped in rubber and mounted on rubber buffers [KEshock absorbers] they have enhanced ability to yaw and damage rods [especially brittle ones], and thus double the 'spaced armor' effect to 2.7d/5.4d. The erosion of the appliqué its self is ~ 4cm RHAe plus 5- 10cm [2-4cm APFSDS] ; or plus 17-18cm [3.2-3.8cm sheathed APFSDS] or + 19-20cm [4-4.2cm sheathed APFSDS]. Combined with the base armor the effective resistance should be roughly **.....**

½ Mantle & overlap with appliqué

Against [2-3cm] monoblock APFSDS 16-17cm+ 2.2-2.8d = [20cm @ 30°] or [13cm @ 60°]
Against [3.5-4.2cm] sheathed penetrators. 17cm + 4.4d –4.8d = [~ 31cm @ 30°] or [~ 19cm @ 60°]
Against a 10-12cm APC that's 14cm+ 1.6-2.8d = [~26cm @ 30°] or [~21cm @ 60°]
Against a 10-12cm APDS should be 14-17cm +4.6-4.8d = [~34cm @ 30°] or [~21cm @ 60°]
HEAT resistance should be @ 30° = 26/19cm+ 0.6d or @ 60° = 13/12cm+ 0.7d

½ Sloping walls with applique

Vs 10-12cm APC ; 13cm + 3.6cm + 1.4d = [15cm @ 60° ± 7cm]
Vs 100-122mm APDS ;14cm + 4cm + 3.3d = [18cm @ 60° ± 8cm]
Vs 3.2- 4.4cm steel/sheathed APFSDS ;15cm + 5cm + 4.2d = [19cm @ 60° ± 9cm]
Vs 2-3cm monoblock APFSDS ; 15cm + 5cm + 2.0d = [13cm @ 60°± 7cm]

Vs HEAT 1st Gen HEAT/ 2nd Gen HEAT @ 60° = 17/12cm + 1.5d ± 15cm

LEOPARD –2

Starting in 1979 through 1985, the first of ~ 1600 **LEOPARD-2s** were manufactured for the German army and progressively brought up to the A2 configuration through 1984-87. This 55 ton tank featured an advance 'hunter killer' digital FCS with Thermal sight mated to 120mm smoothbore gun firing new APFSDS ammunition. JANES and Osprey both report the 'turret is multi layered armor while the hull is advanced spaced armor'. But a german sources [Spielberger], reports all the LEO-2 armor includes spaced armor .The conversion from **LEOPARD-1A1A1 to LEOPARD-2** results in a weight increase [9-12 tons turret but the volume also increased from 4.2 to 4.5m^3 ….1.24 mass times] and a smaller front turret profile [2.1-1.6m² …1.36 times], this results in a LEO-2 front turret potential armor mass increase of 1.7 times the leo-1 mass of x 22cm = 37cm steel mass. The front turret has a reported 830mm LOS thickness , with estimated 62cm insert. The average insert mass should be [22cm/62cm] 2.85g/cc . The presence of an airgap should reduce the insert package to ~ 50cm LOS thickness and the density to 3.6-3.0g/cc [22/50]. This suggests a 1/3 AD-85 & 2/3 aluminum structure with SHS outerplates [overall Me 1.25], but no coverplate effect? RM Ogorkiewcz previewed such an armor in a 1976 IDR article .The LEOPARD-1A3 turret features Semi hardness & multi hardness steel s and its likely that LEO-2 has similar armor.This should result in atleast a 25-80% increase in steel resistance and at least 12 % increase overall due to "hardness steel backing" .Thus the 'Me' should be 37.2 cm x 1.5 [Me] x 0.85 –0.79 [2cm –4cm d/W & t/d] x 1.12 [SHS Hard Backing] = **57-53cm RHAe** . Including the 'spaced plate effect' , which should add 1.3/2.6d or 2.6 cm upto 11cm.This should result in a resistance of ~ 53-49cm + 2.6-11cm or **56 ± 8cm RHAe Vs 2cm APFSDS to 60± 6cm RHAe Vs 4cm sheathed APFSDS**. The HEAT resistance should be Me 1.87 x [2*1.3 + 5 * (1.0 + 1.1÷3) x 1.2 ÷ 7 x 7.85 ÷ 4.4] x 37.2cm = ~70cm RHAe.But there is an airgap to include that should add 5-10cm bringing the shaped charge resistance upto **70±10 + 0.7d RHAe [RPG 7 to 125mm Heat]**… resistance is said to be around 700mm HEAT..but other sources claim 850mm, both figures apply if the 700mm is the RPG-7 from a frontal arc figure and the 850mm is from 125mm HEAT from straight on .

LEOPARD –2A4

In 1986-1987 a batch of 520 LEOPARD 2 tanks were produced as the **LEOPARD 2A4,** which is thought to feature more advanced second generation composite armor , but the tanks mass has not changed.After this, all the previous batches of LEO-2s where brought up to the LEOPARD-2A4 standard with the last being delivered in march 1992 at which point there were 2,125 LEOPARD-2A4 in German inventory. Its likely heavier ceramic is achieved by replacing aluminum interlayer with a lighter material……which probably means a ¾ AD-97 & ¼ Plexiglas sandwich layer inserts with SHS spaced plate & THS back plate. This should change the front turret calculation to 37.2cm x 1.95[Me] x 0.85 –0.78 [2cm –4cm d/W & t/d] x 1.12 [SHS Hard Backing] = **69-63cm** + 'spaced armor effect' +2.6 -11cm = **70± 8cm RHAe [Vs 2cm APFSDS] to 74± 7cm RHAe [Vs 4cm sheathed APFSDS].** FAS.Org and Krauss Maffie representatives have both reported the front turret resistance of the **LEO-2A4 @ 700mm KE & 1000mm HEAT resistance .** The HEAT resistance should be Me 2.37 x [2 * 1.2 + 5* [3*1.2 + 0.7÷4] x 1.2 ÷ 7 =1.33 x 7.83 ÷ 4.4] x 37.2cm = 88cm RHAe.But there is an airgap to include that should add 6-10cm bringing the shaped charge resistance upto **100-105± 11cm RHAe [RPG-7 –150mm HEAT]**… resistance is said to be 1000mm HEAT .

LEOPARD 2A5/A6

In the mid 1990s the first of a batch of 225 Leopards were produce in an improved configuration designated as the **LEOPARD-2A5** , this featured an advance appliqué armor added to the front turret that also boosted the tanks weight to 59 tons. It is reported by JANES, the LEO-2A5 also features 3rd generation composite armor in a redesigned front turret armor that includes a wedge appliqué armor and a spall inner liner in the turret as well as special armor inserts inside the hull armor. The LEO-2A5 turret is assumed to have solid turret without airgap plus the wedge appliqué. The tank mass goes up 4 ton increase with the wedge appliqué and a spall liner installed. Over the area covered the wedge accounts for ~ 3 tons ,leaving 1 ton for a front turret redesign plus a 5cm thick spall liner and new side skirts are installedThe extra armor mass is the same as 13cm steel and the area is ~ 12m² and a 5cm Dyneema layer would account for 6cm leaving 3cm/m² on the front turret.. The front turret armor is changed from 37.2cm steel to 40cm steel over the whole thickness [83cm].Minus 18cm base plates that leaves leaves a 2.66g/cc insert which suggests 2/3 AD-97 & 1/3 Dyneema layered structure with no airgap within the turret. The appliqué has been shown to be a 4cm outer spaced plate and 5cm airgap followed by a 3cm inner spaced plate @ ~ 68°[compounded] , mounted ~ 80cm from the front turret wall.The basic calculation is changed to 40.2cm x 1.89 [Me] x 0.75 –0.65 [2cm –4cm d/W & t/d] x 1.4 [HS coverplate & THS Hard Backing] = **79-69cm RHAe .**A spall liner is included that adds 2-4cm liners., which are known to reduce kill by 10-20% **.** The appliqué armor is ~ 18.4cm LOS thickness plus 2.6d 'spaced armor effect' [79+21-25cm APFSDS] **or 101-102± 13cm RHAe RHAe [2cm APFSDS & HS APFSDS].** Against an older sheathed penetrator [BM-32/42] that's + 5.2d or 69cm + 35cm = **104± 14cm RHAe.** Some German sources claim the resistance of the LEO-2A5 front turret to be in the region of **1000-1100mm KE resistance.** The HEAT resistance should be Me 3.1 x [1.2 + 1.6*2 + 0.6÷4] x 1.2 ÷ 5 =1.2 x 7.85 ÷ 3.8] x 40cm = 124cm RHAe**.** In addition the liner and wedge armor should increase the HEAT resistance by ~22+12-10cm to **156cm ± 20cm RHAe** …shaped charge resistance has never been reported.

The LEOPARD-2A6/A7 armor is unknow so it could be at the A5 level, but if were to be improved to the threat of the M-829A3 ,then several solutions are possible. Exchanging a few mm steel mass in the 'wedge applique', will allow the airgap between plates to be filled with elasitic materials that will boost the "spaced armor effect" . Further the two one inch plates can be replaced with 3 plates if two of the three plates are perforated. With 2.5 HS + 2.5ms ep + 2.5 msep @ 68° = 2.8+ 1.8 + 1.8 ÷ 0.38 plus 0.64d + 1.6d +1.6d =16.8 cm + 3.9d = 85-74cm + 25-41cm ~ 110-116cm RHAe . The shaped charge effects would be 4 times the effective resistance of the wedge or 4 x 18 = 71cm +120cm [base] …or **110± 14cm RHAe KE & 190± 23cm RHAe HEAT**…if this wedge armor is retro fitted to the existing fleet of LEO-2A4 that would result in around **97± 13cm RHAe KE and 175± 20cm RHAe HEAT**

M-60è M-1è M-1A1èM-1A1HAèM-1A2èM-1A2SEP

As of the year 2000, its reported that the USArmy has
1174 x M1A2 SEP
1535 x M1A1D
780 x M1A1HA
2053 x M1A1 M-1A1D [similar to M-1A2]
2094 x M1 (with a 105 gun)
M-1A1D has same armor as M-1A1HA, but with FCS/Ti fitt similar to M-1A2, while M-1 are in the NG as reserves and to be sold off.

M-60

The **M-60A1** front turret thickness is reported to be 25-26cm LOS cast steel with a turret weight of 16 tons and profile of 2m² and a 5m^3 volume. The front turret resistance should work out to 26cm x 0.97[t/d & d/w] x 0.95 [Me cast] , but the turret is thought to be made of lower hardness flawed cast materials bring the resistance down 90% to ~**21± 8cm RHAe**, while the shaped charge resistance should be **25± 9cm RHAe**. Against large caliber 100-122mm APC type warheads, the total turret resistance should be ~ 75% of LOS thickness or **~ 19cm RHAe** from straight on and **~12cm RHAe** from 30° off angle. This mean't the basic 100mm & 122mm APC round should penetrate the front quarter turret @ 2km range , while the T-10 /IT-122 long 122mm APC could penetrate @ 3.5km from 30° off angle, but to penetrate from straight they had to close to ~ 1km range. The M-60A3 included a new cast turret that solved the flaw and low hardness problem , resulting in a resistance of **~ 24± 9cm RHAe vs APFSDS and 26± 10cm RHAe Vs Shaped charges.** Late model M-60 tanks , fielded in ODS also featured blazer ERA appliqué …this covers atleast 50% of the tank profile and over the front turret it increases resistance to **26± 10cm RHAe Vs APFSDS and 51± 18cm RHAe Vs HEAT.**

M-1

2094 x 105mm gun **M-1s** were produced in the early 1980s and are now in the NG units. This turret featured **a** front turret with 2.1m² front profile and weights 19 tons with a volume of 4m^3 , thus the conversion from M-60 to M-1, the steel mass should be ~ 1.18 x 1.27 x 0.95 x 26cm= 36.5cm steel mass.The first generation turret is most likely a ¾ AD-85 /interlayer/RHA sandwich with a coverplate[3.8g/cc & 2.2g/cc]. This should result in a calulation of; 36.5cm x 1.3 [Me] x 1.18[coverplate] x 0..8/0.7/0.6 [d/W & t/d 2cm /4cm /6cm APDS] }= **45± 5cm RHAe RHAe [2cmAPFSDS] & 39± 4cm RHAe [4cm APFSDS] 33± 3cm RHAe [APDS] .** The M-1 armor was reported as 350mm KE resistance for the CFE talks in 1990s , but USA armor is usually rated from 30° off angles so the actual resistance from straight on should be 10 % higher or **38.5cm RHAe.** The HEAT resistance should be Me 1.95x [1 x 1.0 + 3 x (1.0+ 0.4 ÷2) x 1.35 ÷ 4 x 7.83 ÷ 3.76] x 36.5cm = **78cm RHA from straight on & 70cm from 30° off angle** …reported resistance is 700mm HEAT resistance.

M-1A1

M-1A1 & M-1IP turret was redesigned to accommodate the 120mm gun and went from 4 to 5.5m^3 internal volume and 2053 were produced in the mid 1980s and are now being converted to M-1A1D with improved electronics/FCS/Ammo. The profile increased to 2.2m², but the weight went up to ~ 23 tons. Thus the transition from M-1 to M-1A1 turret results in a steel mass of 30.7cm [36.5cm x 0.73 x 1.21 x 0.95]. This is assumed to be a second generation more mass efficient composite, with ~ 2/3 Plexiglas & 1/3 AD-97 ceramic insert .Thus the calculation is adjusted to 30.7cm x 1.8 [Me] x 1.18[coverplate] x 0.75/0.65 [d/W & t/d ; 2cm /4cm] = **49 ± 5cm RHAe [2cmAPFSDS] & 42.4± 4cm RHAe [4cm APFSDS] .** The M-1A1 armor was reported as 400mm KE resistance for the CFE talks in 1990s , which is @ 30° frontal arc so the actual resistance from straight on should be 10% higher or **44cm RHAe.** The HEAT resistance should be Me 3.16 x [1 x 1.0 + 2 x (0.75)+ 1.4 x 1.37 ÷ 4 x 7.83 ÷ 3.5] x 30.7cm = **97± 10cm RHAe** …reported resistance is around 1000mm HEAT max [IDR].

M-1A1HA

Roughly 2300 Abrams where produced in the late 1980s as the **M-1A1HA** and are now under conversion to the **M-1A1D.** This armor is famous for the adoption of DU armor into the array. Studies on armor show that heavy dense backing layers boost the overall multilayered armor protection in much the same way cover plates boost the resistance. Studies show this boost is 20% for Tungsten [and assumed DU] armor backing. Production of DU armor is reported to be in thin 10mm rolled plates that are sandwiched between steel plates, so the DU layer is assumed to be included in the rear plate. The tank weight went up 3.5 tons and its assumed that's all in the turret mass in the frontal arc, resulting in a mass increase of ~6.4cm steel mass to 37.1cm steel. Since the DU armor is assumed to be the sandwiched in the steel backing plate, this should increase the steel mass to 21cm ,leaving a slightlyheavier insert density alowing for more or heavier ceramic to be included [2.1g/cc = 1/3 AD-99 & 2/3 Plexiglas?]. The erosion of the DU plate the adjusted calculation is …37.1cm x 1.8 [Me] x 1.18[coverplate] x 0.75/0.65 [d/W & t/d ; 2cm /4cm] x 1.2 [heavy back plate]= **71cm RHAe ± 7cm [2cmAPFSDS] & 61cm ± 6cm [4cm APFSDS], this could be against 32mm diameter BM-32APFSDS. The M-1A1HA armor was reportes as 600mm KE resistance for the CFE talks in the 1990s, but this will be a frontal arc figure so the resistance from straight on should be 10% higher or 66cm RHAe.** The HEAT resistance should be Me 3.6 x [1.1 + 2 x (0.75)+ 1.6 x 1.6 ÷ 4 x 7.83 ÷ 3.7] x 37.1cm = **134± 13cm RHAe** … resistance is said to be around 1300mm HEAT max .

M-1A2

1200 Abrams are being produced or converted from earlier models to the **M-1A2** configuration in the late **1990s. These featured improved FCS system and Ti sights along with improved ammo [M-829A2] and 2nd gen DU turret armor.** Its been reported that in the late 80s the M-1A1HA was tested with DU APFSDS type penetrator [M-829A1 APFSDS?] and a Hellfire type ATGM . It was found to be vulnerable to repeated impacts of both of these warheads at combat ranges[?]. An improved armor package was needed to meet future 125mm APFSDS threats into the next century. Three generations of DU armor have been identified and its assumed M-1A2 features the second variant of this DU armor.Some sources report the tank weight in the region of 63 metric tons resulting in a further 2 ton increase in turret mass, bringing the theoretical front turret armor mass to ~ 44.1cm steel. Given the DU armor in the HA configuration that suggests the mass increase went into better insert density ...[3.2g/cc] . This could support a package of 2/3 AD-99 1/3 Kevlar, but 2nd Gen DU armor is assumed .One way to boost the overall resistance is to harden the backing plate to boost the overall resistance by 7%. DU metal can be heat treated upto Rc60 , so this is assumed to be done. In addition resent open source research included graphite sealing layer after the cover plate that further boosts resistance by 10%[?] . If I redo the calculation for the M-1A1HA with hard backing modifier ,I get…..44.1cm x 1.64 [Me] x 1.3[RHA & Graphite coverplate] x 0.8/0.7 [d/W & t/d ; 2cm /4cm] x 1.28 [heavy hard back plate] = **96± 9cm RHAe [2cmAPFSDS] & 84± 8cm RHAe [4cm APFSDS].** Some sources claim the M-1A2 armor is 800mm KE resistance, which is from 30° off angles, so straight on should be 10% higher or **88cm RHAe. One explaination could be that the reference penetrator is no longer a 4cm APFSDS but the more contemporary 3.2cm BM-32/42APFSDS...against this threat the M-1A2 should offer ~88.5±9cm RHAe.** The HEAT resistance should be Me 3.46 x [1.22 + 2 x (1.6)+ 0.5 x 1.62 ÷ 4 x 7.83 ÷ 4.5] x 44.1cm = **152± 15cm RHAe** shaped charge resistance is not rated.

M-1A2SEP

The 1200 x M-1A2s are currently being converted to the **M-1A2SEP** digital tank **These featured improved digital C3C electronics and FCS , with improved ammo [M-829A3] and 3rd gen DU turret armor**. By the mid 90s the US must have decided that the ever increasing L/d of modern APFSDS would make even the M-1A2 vulnerable to increasing APFSDS penetration, so a further increase in armor resistance was needed.This lead to the third generation of DU armor to be fielded. It has been rumored that the English 'Dorchester armor' was tested in the US with the view to possibly adopting it in the M-1 tanks. Tests with this Dorchester armor has shown that 12 inches of this armor resisted penetration of the M-829 APFSDS round. Since this round gets a penetration 55cm @ combat range that's a considerable resistance[on the order of 1.8 Te]. The only modern ceramic armor that can get this level of resistance is DU ceramic in 87 and 100% densities [9.5 g/cc & 11.0 g/cc respectively] , by itself a Me of 1.5 & 1.9 , but such a package would imply thicker interlayer to offset massive weight increase, thus adjusting the Me . The modified calculation becomes 44.1cm x 1.8 [Me] x 1.3 [RHA & Graphite coverplate] x 0.75/0.65 [d/W & t/d ; 2cm /4cm] x 1.28 [heavy & hard backing] = **99± 10cm RHAe [2cm APFSDS] & 92± 9cm RHAe [3cm APFSDS] & 86 ± 9cm RHAe [4cm APFSDS.** The HEAT resistance should be Me 3.96 x [1.22 + 2 x (1.9)+ 0.6 x 1.62 ÷ 4 x 7.83 ÷ 4.5] x 44.1cm = **174cm ± 17cm RHAe** …shaped charge resistance is not rated.

T-62 T-64[T-72] T-64B [T-72A] T-64U [T-72MP?]

The front armor mass of the T-62 is 17-26cm LOS steel [average 21cm] and the weight growth between T-62 and T-64A is 36.3-36.7 tons or an 1 %increase in armor mass. The tank volume has been reduced from 12.5 m^3 in T-62 to 10.4 m^3 on T-64 or 20% increase in density, and the front armor profile of the T-62 is 4m² while T-64 is about 3.76 m² for a 6% increase in density . Thus a total potential of ~28% increase in armor mass .The new average works out to 26.95cm steel mass over the T-64front armor, but the upper front turret and lower front hull [40% of the profile] have 20cm LOS thickness of steel, leaving ~ 31.6cm average steel mass over the glacis and the front turret.The glacis is reported to be 80mm steel + 105mm steltexolite [1.7 g/cc] and 20mm back steel plate@ 68°, this is a mass of 122mm steel[32.2cm], while the above prediction is 120mm steel mass. The average front turret thickness is 50cm [40cm near the gun and 60cm @ the turret corners] and examination of the armor layout shows roughly 40% steel & 60% aluminum, leading to a average density of 4.75g/cc or ~ 30.3cm steel mass. Such a turret arrangement should offer an mass effectiveness of 1.0 against APFSDS x 1.18 [confinement] x 0.92 [t/d & Lc]. So the effective turret resistance should be 34cm RHAe…with the armor **near the gun being 28cm and the turret corners being 40.8cm RHAe**.The claimed maximum resistance is 41cm KE resistance. HEAT resistance should be 1.07 Me x 1.2 [layering] x 31.6= **41cm average add up to 33cm @ gun mantle and 49cm @ turret corners**.

T-64B[T-72A]. This was a late 70s upgrade to the T-64 design including ATGM and FCS improvements along with ammo improvements [BM-22-29 etc]. Total weight growth between T-64A and T-64B is 38.6 tons to 40.3 tons or an 4 % increase in armor mass while the vehicle dimentions and therefor volume look the same as the T-64A, thus the adjusted armor mass should be 269mm T-64 frontal armor x 1.04= 280mm average frontal armor …..[x 10] 2800– 4x 200mm 2000/6 = ~33.3cm Steel mass on the T-64B glacis and fron t turret…but the glacis is know to have changed to 6cm steel 10.5cm Steltexolite and 5cm steel back plate @ 68° or ~35cm Steel mass,this leaves 31.7cm steel mass for the front turret. The average distribution 40/60 steel/insert leading to ~ 3.0g/cc insert density[12/30] . A 'black ceramic' mounted on steltexolite has been mentioned in relation to this armor and this could be Alumina since it can be very dark grey and 3.5g/cc [Boron Nitrite or Boron Carbide are black but horribly expensive].The turret armor is reported to feature Corrundum [alumina]which is usually a grinding material that is maunfactured cheaply in 'pelete' form, similar to "Chernosem"[Sand] . Russian test on various KEP Vs sand show that the longer the penetrator the more damage it suffers as it penetrates sand at higher and higher velocity. There is a melt temp that effects steel penetrators more than Tungsten but also suggests that HEAT warheads should suffer more too. This amounts to about 13% of RHAe @ 1.8km/s 10% of RHAe @ 1.6km/s and 12% of RHAe @ 1.8km/s[Int.J.Impact Engng. Vol26, pp675-681]…. So to a first approximation Te of sand looks like ~ 0.12. Since alumina offers about ½ more resistance than glass , I will assume the alumina ceramic peletes perform ½ better than sand…or Te of ~ 0.18. The claimed maximum resistance is the same as T-64A , or 41cm KE resistance. So that's 60-40 alumina/cast armor that should offer a 1.0 Me against APFSDS x 1.18 [confinement] x 0.92 [t/d & Lc]. HEAT resistance should be 1.24 Me x 1.2 [layering] x 31.7= **47cm** .

near the gun being = 28cm RHAe & 38cm HEAT
Average mid turret =34cm RHAe & 47cm HEAT
The turret corners =41.3cm RHAe & 56cm HEAT

Kontakt ERA was later added [1988] that covered about ½ of the front turret and boosted resistance by **2-3cm Vs APFSDS and 30-40cm Vs HEAT** warheads

	½ front turret	**½ front turret with Kontakt ERA**
near the gun being	**= 28cm RHAe & 38cm HEAT**	**31cm RHAe & 68cm HEAT**
Average mid turret	**=34cm RHAe & 47cm HEAT**	**38cm RHAe & 90cm HEAT**
The turret corners	**=41.3cm RHAe & 56cm HEAT**	**45cm RHAe & 96cm HEAT**

From a 30° near side hit treat all of the armor as **"average mid turret"** values.
Percentage of coverage is reduced by 2% with each hit so after 15 hits, coverage is ¼ Kontakt & ¾ exposed armor.

T-64U [T-72MP?] was a upgrade to the basic T-64 model replacing FCS and Sights with modern versions [more digital and passive Imaging sight, now thermal?] plus the latest ammo [BM-42/BM-42M?]. Included was an upgrade in the armor…in addition to steltexolite over the rear half of the tank turret, the interior and appliqué armor was replaced with energetic armors [T-72B type internal ? and K-5 external].

The addition of the appliqué armor on the turret of these tanks boosts the resistance considerably. Following the T-72B formula, these should be rubber sandwiched between an aluminum & Mild steel plates, with up to 4 arrays along any give LOS through the front turret. K-5 should add 18-19cm KE resisance [11-13cm Vs High strength] & 40-50cm HEAT resistance.

	½ front turret	½ front turret with K-5 ERA
2cm high strength APFSDS	= 24cm + 10.9cm= **35 47cm [Average 41 ± 6cm]**	plusERA K5 = **47 59cm [Average 53± 6cm]**
2cm APFSDS	= 24cm + 15.6= **40 52cm [Average 46 ± 6cm]**	plusERA K5 = **58 70cm [Average 64± 6cm]**
3cm APFSDS	= 23.4cm + 18.5= **41 54cm [Average 47± 6cm]**	plus ERA + K5 = **60 73cm [Average 66± 6cm]**
3.5cm sheathed	= 23cm + 37.5 = **60 72cm [Average 66± 5cm]**	plus ERA + K5 = **84 96cm [Average 90±6cm]**
HEAT	11.7 + 4.8 + 17cm x 1.2= **40 49cm HEAT[Average 45± 5cm]**	plus ERA + 50cm =**90 99cm [95±5cm]**

From 30° off angle treat all hits as the 'average' value.
Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 4 of above values, except 3.5cm Sheathed, in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 26cm.

T-62 T-72B T-72BM T-90 T-90M

Transitioning from T-62 to T-72B is a little difficult since the armor distribution appears to be quite different in the T-72.Going from T-62 to T-72B we get the front armor mass of the T-62 is 17-26cm LOS steel [average 21cm] and the weight growth between T-62 and T-72B is 36.3-44.6 tons or an 22 %increase in armor mass. The tank volume has been reduced from 12.5 m^3 in T-62 to 11.0 m^3 on T-72 or 12% increase in density, and the front armor profile of the T-62 is 4m² while T-72 is about 3.76 m² for a 6% increase in density . Thus a total potential of ~48% increase in armor mass .The new average works out to 31cm steel mass over the T-72B front armor, but the upper front turret and lower front hull [40% of the profile] have 22cm LOS thickness of steel, leaving ~ 37.7cm average steel mass over the glacis and the front turret.The glacis is reported to be 80mm steel + 105mm steltexolite [1.85 g/cc] and 50mm back steel plate@ 68°.This is a mass of 150mm steel @68° [39.2cm LOS], while the front turret is reported to be 38cm cast and a ~ 10cm steel mass insert.Clearly something is different here!The reported side &rear hull armor of the T-64/T72/T-80 appears to be the same , while the rear turret mass is probably the same too. But there should be an increase from the 38 ton T-64 to 44 ton T-72B of about 15% or a cm all round.Given that profile, the steel mass redistributed to the T-72B front should amount to about 3cm steel mass increase over the front. The adjusted calulation becomes ~42cm over the heavy armored 60% of the frontal profile. If the glacis is limited to 39cm steel mass then the turret can support ~46cm steel mass So like T-64 , the area around the mantle is probably a lot less armor than the 815mm main section.The T-72B appeared with the Kontakt ERA almost from the start and the internal array effectiveness is similar to T-64U armor and should be rubber sandwiched between an aluminum &Mild steel plates plus spacers, with up to 4 arrays along any give LOS through the front turret. Kontakt is at low angle and should only add ~2cm KE resisance & 30cm HEAT resistance.

T-72B [2/3 front turret profile]
Spaced plate effect on HEAT should be only around 1.05 times the TE/LOS figure, however this is a energetic armor and in theory its spaced plate increase should be a lot more. If there was sufficient airgap this would be the case , but like KE figures the gap is insufficient.Looking at it another way, thin spaced plates offer ~ 3 times their Te/LOS effectiveness but thick plates only offer 20% to 5% improvement in their Te/LOS. When compared to energetic armors this is doubled to ~ 6 times and 40% - 1 0% improvement, respectively.

½ front turret ½ front turret with Kontakt ERA
2cm high strength APFSDS = 39.7cm + 4.6cm= **42 - 44 - 48cm [Average 45 ± 3cm]** plusERA = **44 - 46 - 51cm [Average 47 ± 4cm]**
2cm APFSDS = 39.7cm + 6.6= **43-46-50cm [Average 46± 4cm]** plusERA = 46cm = **45-49-53cm [Average 49± 4cm]**
3cm APFSDS= 39.3cm + 9.7= **46-49-53cm [Average 49± 4cm]** plus ERA =49cm = **48-51-56cm [Average 52± 4cm]**
3.5cm sheathed = 37.5cm + 19.5= **46-57-61cm [Average 54± 8cm]** plus ERA = 57 = **48-59-63cm [Average 56±6cm]**
HEAT 8.6 + 3.2+ 38cm x 1.1= **50-55-60cm HEAT[Average 58± 4cm]** plus ERA = 55cm + 27-30cm =**80-82-93cm [85±6cm]**
Percentage of coverage is reduced by 2% with each hit so after 15 hits, coverage is ¼ Kontakt & ¾ exposed armor.
From 30° off angle treat all hits as the 'average' value.

T-72BM is the late 80s improvement to the T-72B with Kontakt –5 ERA and FCS improvements , plus passive night sight with improved ammo [BM32/42]. K-5 should add 18-19cm KE resisance [11-13cm Vs High strength] &40-50cm HEAT resistance.

½ front turret ½ front turret with K-5 ERA
2cm HS/Sect APFSDS = 39.7cm + 4.6cm= **42 - 44 - 48cm [Average 45 ± 3cm]** plusERA K5 = **54 - 58 - 60cm [Average 57 ± 3cm]**
2cm APFSDS = 39.7cm + 6.6= **43-46-50cm [Average 46± 4cm]** plusERA K5 = **61-64-68cm [Average 64± 4cm]**
3cm APFSDS = 39.3cm + 9.7= **46-49-53cm [Average 49± 4cm]** plus ERA + K5 = **64-67-71cm [Average 67± 4cm]**
3.5cm sheathed = 37.5cm + 19.5= **46-57-61cm [Average 54± 8cm]** plus ERA + K5 = **74-81-88cm [Average 81± 8cm]**
HEAT 8.6 + 3.2+ 38cm x 1.1=**50-55-60cm HEAT[Average 58± 4cm]** plus ERA = 55cm + 50cm = **100-105-110cm [105±5cm]**
From 30° off angle treat all hits as the 'average' value.
Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 4 of above values, except 3.5cm Sheathed, in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 26cm.

T-90 is the 1990s evolution of the T-72B with Kontakt 5 ERA and FCS improvements and passive night sight with improved ammo [BM42M]. The spaced energetic array is thought to be a evolution of the T-72B armor which could be improved with thinner mild steel plate plate and more space between plates, allowing full 'spaced plate effect'. The K-5 should add 18-19cm KE resisance [11-13cm Vs High strength &24cm Vs sheathed] &40-50cm HEAT resistance. Its assumed the T-90 insert is based on the T-72B array of aluminum/rubber/Mild steel but with enlarged airgaps to fully exploite the "spaced plate effect" . The T-90 is about 10% heavier than T-72B leading to an assumed average steel armor mass of 50cm [compared to 45.7cm on the T-72B]….. but the proportion of 'upper front turret' to front turret on the T-90 looks to be less than ¼ of the front turret profile ,compared to 1/3 on the T-72B.If the T-90 weight increase is just the same armor level but with better armor coverage, then 4/5 of the profile should be the 53cm steel mass , while the upper front turret [1/5 profile] should be 38cm steel mass. Given the increased angle of the upper front turret [78°] this suggest a sandwich with 8cm Steltexolite plus 5cm cast & 5cm linner material @ 78°. Reworking the T-72B insert density to try and make it more efficent, by rearranged to afford more airgap for more efficient 'spaced plate effect'. The array could feature 4cm aluminum back plate and multiple arrays [4-5] of 10mm Mild Steel + 6mm rubber + 3mm Mild Steel sandwich and 43mm airgap @ 55°followed by the next array. This allows enough airgap for the full 'spaced armor effect'.

½ front turret ½ front turret with K-5 ERA

2cm HS/Sect APFSDS = 39.7cm + 10.9cm= **42 - 51 - 55cm [Average 49 ± 7cm]** plus K-5 ERA = **54- 63 - 67cm [Average 61 ± 6cm]**

2cm APFSDS = 39.7cm + 15.6= **46 - 55- 60cm [Average 53± 7cm]** plus K-5 ERA = **61 - 73- 78cm [Average 70± 8cm]**

3cm APFSDS = 39.3cm + 18.5= **46- 58- 63cm [Average 55± 8cm]** plus K-5 ERA = **64- 76- 81cm [Average 73± 8cm]**

3.5cm sheathed = 37.5cm + 37.5= **46- 75- 81cm [Average 67± 14cm]** plus K-5 ERA = **74- 99- 105cm [Average 92± 13cm]**

HEAT 11.7 + 2.4+ 38cm x 1.2=**60- 62- 69cm HEAT[Average 64± 5cm]** plus K-5 ERA = 64cm + 50cm =**110- 114- 119cm** [**114±5cm]**

From 30° off angle treat all hits as the 'average' value.

Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 4 of above values, except 3.5cm Sheathed, in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 26cm.

Similarly the hull armor should be up 10% compared to T-72B levels [40.7+ 27.6cm] 75cm, this suggest the glacis could be 3cm SHS+6cm RHA+10.5cm rubber with 2 cm mild steel +5cm back Steel plate @ 68° .The lower hull should be 10cm steel + 2cm dozerblade @ 65° plus hinged skirting plate .

T-90 M Vladimir [welded turret]

Recently [~ 2000] a version of the T-90 has appeared with the cast turret replaced by a welded turret, which has been sold to India in 2004. The dimenions of this turet are unknow at this point as is the weight of this version of the tank. The Chinese made a similar conversion from cast to welded turrets about 10-15 years ago and culmated in the narrow Type 98 welded turret which should feature 70- 80cm KE resistance . Its noticed the welded turret armor is nearly vertical which is usually done to mount ceramics multilayered armor, as in the west , and resembles the T-84 welded turret. T-80 U has a armor mass of about 60cm steel but the Vladimir turret could be denser if the turret is narrower or heavier weight, however if propotion of 'top turret to main armor ratio' is balance along a western model , the mass should fall back to ~52cm ,so any increase in mass will probably bring the overall front turret mass to 60cm armor mass over 90cm LOS . If we assume a western model [mostly insert] this figure is right in the middle with an average density of 5.2g/cc].If we try 1/3 steel + 2/3 ceramic/polyurethan layers [or STEF Steltexolite] we get 7.85 + 2x 4g/cc÷3 =5.3g/cc ..using a Corrundum as ¾ AD-97 [4g/cc] + ¼ STEF [1.85g/cc].Going on an improvement over the T-80 ceramic cylinder type layers we could end up with about 3 layers of tiles [15x 12cm] & interlayers.

KE 60cm x Me 1.45 x 0.61- 0.46 [Lc & t/d] x 1.27 [thick SHS Confinement] = **67cm- 55cm ± 8 [2cm –3.2cm APFSDS]..**
HEAT 60cm x me 1.73 x 1.35 = 140cm plus ERA 50- 57cm= **140cm- 190cm- 197cm [HEAT]** .

¼ front turret	¾ front turret with K-5 ERA	¾ front turret with Kactus ERA
2cm HS/Sect APFSDS = **67± 9 cm**	plus + K5 = **79± 11 cm**	plus + Kactus = **80cm**
2cm APFSDS = **67± 9 cm**	plus + K5 = **85± 13 cm**	plus + Kactus = **86cm**
3cm APFSDS = **59± 8 cm**	plus + K5 = **77± 12 cm**	plus + Kactus = **81cm**
3.2cm sheathed = **55± 8 cm**	plus + K5 = **79± 14 cm**	plus + Kactus = **91cm**
HEAT = **140cm**	plus + K5 ERA =**190cm**	plus + Kactus =**197cm**

If more than 6 hits on the front turret then 'K-5/Kactus covered areas' are considered "reduced" and should have the KE resistance reduced by 4cm [7cm if sheathed APFSDS], while the HEAT resistance should go down 26cm.

T-62 T-80 T-80B T-80U T-80UM

The front armor mass of the T-62 is 17- 26cm LOS steel [average 21cm] and the weight growth between T-62 and T-80 is 36.3- 42 tons or an 16 % increase in armor mass. The tank volume has been reduced from 12.5 m^3 in T-62 to 11.1 m^3 on T-80 or 11% increase in density, and the front armor profile of the T-62 is 4m² while T-80 is about 3.76 m² for a 6% increase in density . Thus a total potential of ~29% increase in armor mass same as the transition from T-62 to T-64. It is reported that the armor was not any better than T-64 level protection so the same armor is assumed to be in the T-80 tank as in the T-64 tank [IE Aluminum - Cast turret].Thats 26.95cm steel mass over the T-80front armor, but the upper front turret and lower front hull [40% of the profile] have 20cm LOS thickness of steel, leaving ~ 31.6cm average steel mass over the glacis and the front turret.The glacis becomes 80mm steel + 105mm steltexolite [1.7 g/cc] and 20mm back steel plate@ 68°, this is a mass of 122mm steel @ 68°[32.2cm LOS], while the above prediction is 120mm steel mass @ 68°. The average front turret thickness is 50cm [40cm near the gun and 60cm @ the turret corners] and examination of the armor layout shows roughly 40% steel & 60% aluminum, leading to a average density of 4.75g/cc or ~ 30.3cm steel mass. Such a turret arrangement should offer an mass effectiveness of 1.0 against APFSDS x

1.18 [confinement] x 0.92 [t/d & Lc]. So the effective turret resistance should be 34cm RHAe…with the armor **near the gun being 28cm and the turret corners being 40.8cm RHAe**.The claimed maximum resistance is 410mm KE resistance. HEAT resistance should be 1.07 Me x 1.2 [layering] x 31.6= **41cm average add up to 33cm @ gun mantle and 49cm @ turret corners**.

T-80B. This was a late 70s upgrade to the T-80 design including ATGM and FCS improvements along with ammo improvements [BM-22-29 etc] and a completely redesigned turret with much thicker armor [maximum reaching ~ 800-900mm LOS thickness]. Total weight growth between T-80 and T-80B is 1 % increase in armor mass while the turret dimentions and therefor volume & Mass look the same as the T-72B, thus the adjusted armor mass should be same as the T-64B ~37cm. Steel mass on the T-64B glacis and fron t turret…but the glacis is know to have changed to 6cm steel 10.5cm Steltexolite and 5cm steel back plate @ 68° or ~35cm Steel mass.This leaves 38cm steel mass for the front turret. The average distribution 80/38 thickness /mass leading to ~ 3.7g/cc overall density .The ceramic is reported to be the same Combination K ceramic on the T-64B which leads to roughly 2/3 ceramic sand & 1/3 cast.Again cast is 95% resistance and this combination K is probably 0.18 resistance. So that's 80-53 alumina/cast armor that should offer a 1.0 Me against APFSDS x 1.25 [thick confinement] x 0.92 [t/d & Lc]. The T-80B claimed maximum resistance is 500mm KE resistance. HEAT resistance should be 1.24 Me x 1.2 [layering] x 38cm= **56cm average ……**.So the effective turret resistance should be

near the gun being = 35cm RHAe & 45cm HEAT
Average mid turret =44cm RHAe & 56cm HEAT
The turret corners =49.5cm RHAe & 64cm HEAT

Kontakt ERA was later added [1984] that covered about 2/3 of the front turret and boosted resistance by **2-3cm Vs APFSDS and 30-40cm Vs HEAT** warheads

	½ front turret	**½ front turret with Kontakt ERA**
near the gun being	**= 35cm RHAe & 45cm HEAT**	**37cm RHAe & 75cm HEAT**
Average mid turret	**=44cm RHAe & 56cm HEAT**	**47cm RHAe & 90cm HEAT**
The turret corners	**=49.5cm RHAe & 64cm HEAT**	**52cm RHAe & 104cm HEAT**

From a 30° near side hit treat all of the armor as **"average mid turret"** values.
Percentage of coverage is reduced by 2% with each hit so after 15 hits, coverage is ¼ Kontakt & ¾ exposed armor.

T-80UM

In the late 1980s a version of the T-80 has appeared with a heavier cast turret and Kontakt 5 ERA. The turret appears to be similar in volume to T-72B and T-80B, but the armor arrangement is reported to be cast turret with ceramic cylinders layered in polyurthen. T-80 U has a armor mass of about 60cm, over 80-110 cm LOS for a average density of ~5g/cc. The T-80A prototype turret revealed 800-1100mm LOS thickness maximum with ½ cast and ½ insert, which should be 1.6g/cc or ½ polyurthen & ½ Alumina 85, with a thin back plate of aluminum.

½ front turret ½ front turret with K-5 ERA
2cm HS/Sect APFSDS = 80.3 x 0.57= **41-46 -55cm [Average 48 ± 7cm]** plus K-5 ERA = **53-58 -67cm [Average 60 ± 7cm]**
2cm APFSDS = 80.3 x 0.57= **41-46-55cm [Average 48 ± 7cm]** plus K-5 ERA = **59-64-73cm [Average 66± 7cm]**
3cm APFSDS = 80.3 x 0.53= **40-43-51cm [Average 45 ± 6cm]** plus K-5 ERA = **59-61-70cm [Average 64± 6cm]**
3.5cm sheathed = 80.3 x 0.5= **39-41-50cm [Average 44 ± 6cm]** plus K-5 ERA = **63-65-74cm [Average 68± 6cm]**
HEAT 60cm x me 1.2 x 1.35 = 97cm =**65-97-125cm HEAT[Average 96± 29cm]** plus K-5 ERA = 64cm + 50cm =**110-150-175cm [145±30cm]**

From 30° off angle treat all hits as the 'average' value.
Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 4 of above values, except 3.5cm Sheathed, in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 26cm.

Similarly the hull armor should be up 10% compared to T-72B levels [40.7+ 27.6cm] 75cm, this suggest the glacis could be 3cm SHS+6cm RHA+10.5cm rubber with 2 cm mild steel +5cm back Steel plate @ 68° .The lower hull should be 10cm steel + 2cm dozerblade @ 65° plus hinged skirting plate .

- - - - - Notes & Sources :- - - - - -

The accuracy of estiamtes is ofcourse always going to be in question, because we don't know the exact composition, thickness and effectiveness of every Tank armor[debates still rage today as to the true protection levels of fered by WW-II tanks]. Generally the older the tank the more accurate the estimate. Tanks from the 70s or older should be with a %or two of the actusl value , while tanks produced in the 90s may be as much as ± 10% of the estimated value . All effective measure of armors used the Thickness Effectiveness or 'Te'. This is the effective resistance the armor offers relative to RHA Rc-27 plate [usually Type 4340 steel] . All measurments are taken from scale drawings in '**Abrams' [** Hunnicutt] & **"Soviet/Russian Armor and Artillery Design Practices: 1945 to Present."** [Zaloga], and various **Osprey booklets** on each tank . The exception are the glasis armor thickness and composition and layout of front turret of the T-80A &T-72 & T72A, which were obtained from numerous discussions on the "**Tankers Net**" with Sebastian Balos ;Vasiliy Fofanov & Col Mourakhovsky . The performance of materials are derived from numerous papers from the **Int.J.Impact Engng; Int.J. Solids & Structures ; Int.J. Mech. Sci. ; Journal of Applied Physics ; J of Battle field Technology and The Int. Symp.on Ballistics.** Other information is obtained from **JANES ARMOR & ARTILLERY 1995/95 & 2002/2003 ; Rheinmetall Handbook on Weaponary[1982] ; JANES Armor and Artillery Upgrades 2000- 2001. THE TANK,** Christopher Chant ; the "**Main Battle Tank"[**Russian] ;the **Patent for Kontatk - 5** armor[in Russian from Vasiliy Fofanov] and articles in **International Defence Review** by R.M. Ogorkiewczs and others. **Information on Chinese and Indian tanks came from the Chinese Military forum from Richard Que and others in the Chinese Military Forum [internet] , inaddtion to the sources stated above.**

Tank volumes

Steve Zaloga
Mike: regarding the notes from yesterday at internal hull volume.
I checked the Safanov
book, and it does have internal hull volumes for the T-64, T-72
and T-80, but not for the
earlier types. I have the last (1983 edition) tech manual for the
T-55 (Tank T-55 tekhnicheskoe opisanie i instruktsiya po
eksplutatsii) and
although it has a lot of detailed
data, it lacks any volumetrics. The internal volume data for the
newer types in cubic meters
(Hull + turret) are:
T-80U= 9.2+1.93
T-72B= 9.186+1.846
T-64BV= 8.7+1.7
M1= 17+4
M60A3=13+5
Cheers! Steve

	(mass/volume)	density"
T-90	46.5 - 11.04	4.21
T-80U	46 - 11.13	4.13
T-64B	42.4 - 10.4	4.07
M1A2	63.1- 21	3.0
M60A3	51 - 18	2.83
Leo2A4	55.2 - 19.4	2.84
Leo1A5	42.5 - 18.2	2.33
Chieftain	55 - 17,1	3.21
Amx30B2	37 - 12.8	2.89

Rolf Hilmes'
lists M60A1 at 18.41 2.0m² turret profile
M-60A2 16.8m^3
XM-803 17.8m^3
M48 at 17.7
M47 at 15
T55 at 11.3
T62 at 12.5
T64 at 11.5
Type 85 2.3- 0.48 h 3.45 w 6.733 HL 42. 3
T-72B 2.19- 0.49 h 3.59 w 6.86 HL 41.9 1%
11.03 = ~ 11.15 m^3 for Type 85 tank.

OK in Bob G Chieftain book he reports on a tiny one man ,15 ton tank destroyer, that features 250mm LOS thickness RHA through the front glacis while the all round protection is between 14 & 25mm.In other words if you reduce the volume enough and are willing to scrap armor of the flanks and rear, it all can be piled up on the frontal armor.This is how Russian tanks usually end up with similar armor masses to Western tanks @ much reduced volume. COmpare M-60 to T-62

M-60A1 51 tons & 18m^3 or ~ 2.8tons /m^3 density.
T-62 36 tons & 12.5m^3 or ~ 2.9 tons/m^3 density.

So to a first approximation, M-60A1 and T-62 should have similar armor mass levels,but the distribution is alittle different.

T-62 has ~ 204mm Glacis and 173mm Lower front hull , while front turret is ~ 265mm cast LOS thickness.By comparison M-60A1 is ~ 256mm front turret thickness while the glacis is 250mm while the lower front hull is 193-250mm. So the Turrets have similar protection levels while the M-60 front hull looks to be better.
Looking at the flanks T-62 side turret armor is 150mm LOS thicknes while M-60A1 is ~ 160mm LOS...where there is a difference is that the side hull of the M-60A1 is only 48-53mm thick, while T-62 is 80mm thick.

However to a first approximation there in the same ball park

Simple Armor mass comparisons

Type 98 production @ 52 tons & 11.6 m^3 volume = 4.5 tons/m^3 [Me 1.3 = 5.8]
T-90 @ 50 tons & 11m^3 volume = 4.5 tons/m^3 [Me-1.2 =5.4]
T-80U & T-90S @ 46 tons & 11.1 m^3 volume = 4.15 tons/m^3 [Me 1.1= 4.6]
Type -90/88C @ 49 tons & 12m^3 volume = 4.1 tons/m^3 [Me-1.2 = 4.9]
T-64B @ 42.4 tons & 10.4^3 volume = 4.1 tons/m^3 [Me-1.05=4.3]
T-72B @ 44.5 tons & 11.0 m^3 volume = 4.0 tons/m^3[Me- 1.05 = 4.2]
Type 88 @ 42 tons & 12 m^3 volume = 3.5 tons/m^3 [Me 1.2= 4.2]
Chieftain @ 55 tons & 17.1m^3 volume = 3.2 tons/m^3 [Me-0.9= 2.9]
Challenger-2 @ 62.5 tons & ~ 19.5m^3 volume = 3.2 tons/m^3 [Me-2 = 6.4]
Challenger-1 @ 62 tons & ~ 20m^3 volume = 3.1 tons/M^3 [Me-1.5-1.6= 5.0]
Leclerc @ 54 tons & ~17.5m^5 volume = 3.1 tons/m^3 [Me-2.1 =6.5]
AMX-30B2 @ 37tons & 12.8 m^3 volume = 2.9 tons/m^3 [Me-0.95= 2.75]
T-62 @ 36 tons & 12.5m^3 or ~ 2.9 tons/m^3 density. [Me-0.9 = 2.6]
M-60A1 @ 51 tons & 18m^3 or ~ 2.8tons /m^3 density. [Me-0.85=2.4]
Merk-III & IV 65 tons & ~23m^3 volume =2.8 tons/m^
LEO-2A5 @ 59 tons & 19.4m^3 volume = 3 tons/m^3[Me- 2.11= 6.4]
LEO-2A4 @ 55 tons & 19.4m^3 volume = 2.8 tons/m^3[Me- 1.8= 5.0]
M-1A2 @ 63 tons & 23m^3 volume = 2.75 tons/m^3 [Me- 2= 5.5]
LEO-2A1 @ 55 tons & 19.4m^3 volume = 2.8 tons/m^3[Me- 1.3-1.5= 3.6-4.2]
M-1A1HA @ 61.5 tons & 23m^3 volume = 2.7 tons/m^3 [Me-1.5= 4.0]
Merk-1 & II @ 63 tons & ~23m^3 volume = 2.7tons/m^3
M-1A1 @ 58 tons & 23m^3 volume = 2.5 tons/m^3 [Me-1.4 = 3.5]
M-1 @ 54 tons & 21m^3 volume = 2.6 tons/m^3 [Me-1.2 = 3.1]
Leo1A1A1 @ 42.5 tons & 18.2 m^3 volume or 2.33 tons/m^3 [Me-1.4-1.6 =3.3- 3.7]
Leo1A5 @ 42.5 tons & 18.2 m^3 volume or 2.33 tons/m^3 [Me-1.6-1.9=3.7-4.4]

So this clearly shows that [all other things being equal]the potential is for Chieftain Challenger & Leclerc to have more protection than M-1 or LEO-2 tanks. Since we know Chieftain tank doesn't have the modern armor its obviously not in the same league [just there as a reference point].Clearly the Russian tanks come out on top assuming all other variable being equal….but there not. A study of the armor shows T-64/72 with a ME of ~ 1.0-1.05 and T-72B/T-80B with the same Me but more armor mass , while the T-80U/T-90 generation has more armor mass still but an improved ME of ~ 1.1-1.17 . When you factor in the heavy Kontakt ERA the overall ME jumps to Western counter parts like the M-1 had a Me of 1.1 while the M-1A1 is improved to ~ 1.4 as is the basic LEO-2A1. The Improved M-1A1HA and the Challenger –1 have Me of 1.5 to 1.6, while the LEO-2 A4 ME is ~ 1.7 to 1.8Me . The M-1A2 and Challenger 2 have a ME of 2.0 and the Leclerc and LEO-2A5 have Me of 2.1.

Leclerc @ 54 tons & ~17.5m^5 volume = 3.1 tons/m^3 [Me-2.1 =6.5]
LEO-2A5 @ 59 tons & 19.4m^3 volume = 3 tons/m^3[Me- 2.11= 6.4]
Challenger-2 @ 62.5 tons & ~ 19.5m^3 volume = 3.2 tons/m^3 [Me-2 = 6.4]
Type 98 production @ 54 tons & 11.6 m^3 volume = 4.5 tons/m^3 [Me 1.3 = 5.8]
M-1A2 @ 63 tons & 23m^3 volume = 2.75 tons/m^3 [Me- 2= 5.5]
T-90 @ 50 tons & 11m^3 volume = 4.5 tons/m^3 [Me-1.2 =5.4]
Challenger-1 @ 62 tons & ~ 20m^3 volume = 3.1 tons/M^3 [Me-1.5-1.6= 5.0]
LEO-2A4 @ 55 tons & 19.4m^3 volume = 2.8 tons/m^3[Me- 1.8= 5.0]
Type -90/88C @ 49 tons & 12m^3 volume = 4.1 tons/m^3 [Me-1.0-1.2 = 4.1-4.9]
T-80U & T-90S @ 46 tons & 11.1 m^3 volume = 4.15 tons/m^3 [Me 1.0- 1.1= 4.1-4.6]
M-1A1HA @ 61.5 tons & 23m^3 volume = 2.7 tons/m^3 [Me-1.5-1.6= 4.0-4.3]
T-64B @ 42.4 tons & 10.4^3 volume = 4.1 tons/m^3 [Me-0.85-1.05=3.5-4.3]
LEO-2A1 @ 55 tons & 19.4m^3 volume = 2.8 tons/m^3[Me- 1.3-1.5= 3.6-4.2]
T-72B @ 44.5 tons & 11.0 m^3 volume = 4.0 tons/m^3[Me- 0.85-1.05 =3.5- 4.2]
Type 88 @ 42 tons & 12 m^3 volume = 3.5 tons/m^3 [Me 1.0-1.2= 3.5-4.2]
M-1A1 @ 58 tons & 23m^3 volume = 2.5 tons/m^3 [Me-1.4-1.45 = 3.5-3.6]

Leo1A5 @ 42.5 tons & 18.2 m^3 volume or 2.33 tons/m^3 [Me-1.0-1.9=2.3-4.4]
M-1 @ 54 tons & 21m^3 volume = 2.6 tons/m^3 [Me--1.3-1.2 = 3.3-3.1]
Chieftain @ 55 tons & 17.1m^3 volume = 3.22 tons/m^3 [Me-0.95= 3.0]
Leo1A1A1 @ 42.5 tons & 18.2 m^3 volume or 2.33 tons/m^3 [Me-1.0-1.6 =2.3- 3.7]
AMX-30B2 @ 37tons & 12.8 m^3 volume = 2.9 tons/m^3 [Me-0.9= 2.6]
T-62 @ 36 tons & 12.5m^3 or ~ 2.9 tons/m^3 density. [Me-0.85 = 2.46]
M-60A1 @ 51 tons & 18m^3 or ~ 2.8tons /m^3 density. [Me-0.75-0.85=2.1-2.4]
Leo1A1 @ 40.5 tons & 18.2 m^3 volume or 2.2 tons/m^3 [Me-0.9-1.15 =2.0-2.5]
Merk-III & IV 65 tons & ~23m^3 volume =2.8 tons/m^3
Merk-1 & II @ 63 tons & ~23m^3 volume = 2.7tons/m^3

When it comes to LEO-2 Vs M-1A1 we have to note that LEO-2 front turret is ~ 1.6m² profile , while M-1A1 front turret strikes a profile of ~ 2.2m² . Buy comparison the Challenger front turret is ~ 2m², and the C-2 front turret is 1.9m². So the narrowness of the LEO-2 turret is its saving grace!It means that for the same armor mass it can theoretically have [1.27 x 1.13] 43% more armor mass than M-1A1.M-1A1 front turret protection is in the 45cm region leading to ~ 64cm for the LEO-2A4 front turret.But german tanks are known to focus armor mass on the front turret at the expence of the front hull [LEO-1 has ~ LOS thickness of 13cm front hull steel , compared to ~ 20cm steel on the front turret]. If this patern is continued with LEO-2 [and I understand that it has] and the LEO-1 is used as the base line, the armor density of the LEO-2 front turret reaches ~ 34-37cm steel armor mass. Compare this to 30cm steel mass [1.3 time M-60A1 256mm LOS] for the M-1A1 front turret.

Rhilmes MBT pp 44-45
Leo-1 = 11 ton turret
LEO-2 = 16 ton turret 4.5 m^3 volume & 1.57 m² profile [3.55 tons/m^3] [1.07 x 1.27]
MBT-70 = 19.1 ton turret
T54 = 24% = turret 8,600kg
M-48= 23% =turret 10,900 kg
Tiger = 22% ; turret = 13,100kg
Panther = 19% turret = 8,500kg
T-62 = 25% turret = 10,000kg
Leo-1 = 25% turret = 10,250kg [11 tons reported] 4.2m^3 volume & 2.0m² profile [2.6ton/m^3] [1.36x 1.21]64%
M-60A1 = 31%, turret = 16,300kg 5m^3 volume & 2.0m² turret profile [3.3 ton/m^3]
Leo-1A4 = 26%, turret = 11,000kg
AMX-32 = 29% turret = 12,500kg
MBT-70= 37.5% , turret = 19,400kg
LEO-2 = 31% , turret = 17,000kg [16 tons reported...must mean empty weight] 4.5m^3 volume & 1.57m² profile [3.55 tons/m^3]
M-1 = 35% , turret = 19,090kg & 4m^3 volume = 4.75m tons/m^3 & 2.1m²[1.44 x 0.97] 357mm steel x 1.2Me= 44cm RHAe
M-1A1 21 tons 2.22m² profile and 5.5m^3 volume = 4.2 tons/m^3 [0.9 x 1.27 m-60] 293mm steel x 1.5 Me = 44cm RHAe

Chinese Tanks ;

http://www.china-defense.com/forum/index.php?showtopic=2076

3500 Type-59
300 Type-79 (this is Type-69 with 105mm main gun and Marconi f/c, there are no basic Type-69 left in PLA service)
around 1000 Type-88 (incorrectly known as Type-80)
around 1500 Type-96
around 200 Type-98/99
around 1500 Type-62/-63/-63A light tanks

http://www.sinodefence.com/army/default.asp

The armor is read as follows .....

Shot from straight on ; The first number is the resistance in and around the mantle area, while the number after the symbol is the resistance at the extreme turret corners from straight on.The value in brackets is the average mid turret range along with the average distibution of hits. So a 3cm APFSDS can expect to encounter 22-40cm of armor with the average being ~ 31cm .

From a ± 30° off angle, the value in brackets is used, so going on the 3cm APFSDS , from a 30° off angle hit the turret corners should be 31cm .

 Type T-88A & B Also known as Type –80 [Approximate]

http://www.sinodefence.com/army/tank/type88.asp

This tank is a development of the Type 59-79 tanks [reported below] , after China turned away from the soviets to the west. Its obvious that the M-60 tank influenced this design evolution. Its assumed the internal volume is about the same as the T-62 @ about 12.5m^3 . It is reported on tbe Chinese Military Forum that Chinese tanks use HY-80 RHA [~ 220BHN] . JANES Armor & Artillery 1997/98 has a detailed interior drawing of the Type 85/III side profile revealing front and rear armor as well as top and bottom armor. The hull of the type 85 is based on the Type 80 without composite armor and is assumed to be the same basic layout. In addition the turret is cast with no special armor and appears to be the similar turret on the Type 69-79 with the 105mm gun but about 6-7cm longer which is assumed to be more armor, infact the armor thickness quality and effectivenes is reminisant of the M-60 turret armor.Armor with a hardness of 220 is penetration should be 8-10 %easier.Based on 12.5m^3 volume and 39 tons compared to 36tons of T-62, this suggests 17% heavier armor than T-62 or 30cm front turret steel mass, but a composite insert is reported with ~ 18cm thickness making the whole thickness ~ 45cm LOS . The front hull has a mass of 22cm armor, however the Type 88 lower hull is only 8cm @ 50° [13cm LOS], this leaves 31cm LOS thickness for the glacis or 11.8cm @ 67°.

The hull length is 6.34m x 3.37m

Glacis ~ 12cm RHA @ 68° LOS [31cm ~240 BHN]
Lower hull ~ 8cm @ 50° [13cm ~ 240 RHA]
Front turret ~ 45cm LOS Cast armor/insert [Steltexolite?] ~240 BHN
Turret sides 175mm @ 30° Cast armor ~240 BHN
Top turret ~ 5cm cast @ 240 BHN .
Rear turret ~75mm @ 0 @ 240 BHN
Rear hull 35mm & 20mm plates with ~ 2 meter thick engine space armor.
Side Hull should be similar to T-72 or 60mm RHA plus rubberized side skirts about 25mm thick.

** Turret front** The effective thickness is 26cm cast [0.95] and [0.92] for hardness or 0.87. the weakened zone [0.88-98]. armor.It should look like this. The 18cm Composite should be something like ST-1 should offer 0.35 KE and 0.5 HEAT resistance for a total of ....6.3+22.6 x 1.23 [thick confinement] = 35cm RHAe and 25.1+10.8 x 1.2= 43cm
/ 45cm LOS cast/ST-1 x 0.87[Cast & Hardness] 0.35/0.5 [ST-1] x 0.95 [t/d & Lc] = **34cm KE & 43cm HEAT**
/ 45cm LOS cast/ST-1 x 0.87[Cast & Hardness] 0.35/0.5 [ST-1] x 0.9 [t/d & Lc] = **32cm KE & 43cm HEAT**
[45cm LOS cast/ST-1 x 0.87[Cast & Hardness] 0.35/0.5 [ST-1] x 0.8 [t/d & Lc] = **28cm KE & 43cm HEAT**
\45cm LOS cast/ST-1 x 0.87[Cast & Hardness] 0.35/0.5 [ST-1] x 0.9 [t/d & Lc] = **32cm KE & 43cm HEAT**
\ 45cm LOS cast/ST-1 x 0.87[Cast & Hardness] 0.35/0.5 [ST-1] x 0.95 [t/d & Lc] = **34cm KE & 43cm HEAT**

ERA is some times mounted on the turret , Norinco type C should add [2 4cm APFSDS] 3.7cm + 6.6cm 9.2cm = **10 13cm RHAe** [2 4cm sheathed APFSDS] 3.7cm+ 13.2cm 18.4cm = **17 22cm RHAe.** HEAT values are +50cm **.**

Type 88 A/B with ERA but no compositie add on armor.

	½ armor exposed		½ armor with C-ERA 2cmAPFSDS-4cm SHeathed
/ 27cm LOS cast	**25-26cm KE & 29cm HEAT**	plus C-ERA	**35-48cm KE & 80cm HEAT**
/ 29cm LOS cast	**24cm KE & 29cm HEAT**	plus C-ERA	**34-46cm KE & 80cm HEAT**
[~31cm LOS cast	**23 cm KE & 29cm HEAT**		**23 cm KE & 29cm HEAT**
\29cm LOS cast	**24cm KE & 29cm HEAT**	plus C-ERA	**34-46cm KE & 80cm HEAT**
\ 27cm LOS cast	**25-26cm KE & 29cm HEAT**	plus C-ERA	**35-48cm KE & 80cm HEAT**

Type 88 A/B with ERA and compositie add on armor.

	½ armor exposed		½ armor with C-ERA 2cmAPFSDS-4cm SHeathed
/ 45cm LOS cast/ST-1	**34cm KE & 43cm HEAT**	plus C-ERA	**44-56cm KE & 93cm HEAT**
/ 45cm LOS cast/ST-1	**32cm KE & 43cm HEAT**	plus C-ERA	**42-54cm KE & 93cm HEAT**
[45cm LOS cast/ST-1	**28cm KE & 43cm HEAT**		
\45cm LOS cast/ST-1	**32cm KE & 43cm HEAT**	plus C-ERA	**42-54cm KE & 93cm HEAT**
\ 45cm LOS cast/ST-1	**34cm KE & 43cm HEAT**	plus C-ERA	**44-56cm KE & 93cm HEAT**

Side turret 175mm x 0.87[Cast& Hardness] x 0.98 [t/d & Lc] = **15cm KE & 17-18cm HEAT** . In the side and rear turret are mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor , this may amount to an additonal **~13-25cm HEAT armor**..Additionally ERA can be mounted around the front side of the turret, that should boost the armor to **27cm[21-33] KE & 57cm [36-78] HEAT**.

Rear turret ~75mm LOS Cast x 0.87[Cast & Hardness] x 0.88 [t/d & Lc] **6cm KE & 8cm HEAT**. In the side and rear turret are mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor , this may amount to an additonal **~13-25cm** HEAT armor

 Hull Glacis is 12cm @ 68° probably 240 BHN RHA for a resistance of **27cm KE & 30cm HEAT** ERA is some times mounted on the glacis adding Norinco type C over ¾ of the glacis that should add [2 4cm APFSDS] 3.7cm + 6.6cm 9.2cm = **37 40cm RHAe** [2 4cm sheathed APFSDS] 3.7cm+ 13.2cm 18.4cm = **44 49cm RHAe** and **80cm HEAT** resistance.

 Lower hull is 8cm @ 50° = LOS thickness ÷ 0.64 or **13cm** **LOS armor, KE/HEAT**

 The side hull Should be like the T-72 and about 6cm thick with the lower side hull around the wheels is probably only 2cm thick just like on the T-54-62 tanks The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional **6-7cm KE and ~ 20cm HEAT** armor. The side hull has 2.5cm thick rubber side skirts. The erosion will be 3 x 2.5cm x 0.2/0.3 + 600 mm standoff , which should result in 1.5cm + 4cm hull plate x 1.2[YAW] & 5-10cm from standoff, that's ….**. 6-7cm KE & 12-17cm HEAT.**

** Rear hull** 20mm with ~ 2 meter thick spaced armor [engine] & 20mm plate, 4x 1.2 [large YAW] ~ **5cm KE & 44cm HEAT** but diesel fuel tanks mounted there could offer 0.1 to 0.15 Te resistance to APFSDS and 0.34 resistance to HEAT. The HEAT armor should range from additional 3-4cm to as much as 18cm HEATarmor.

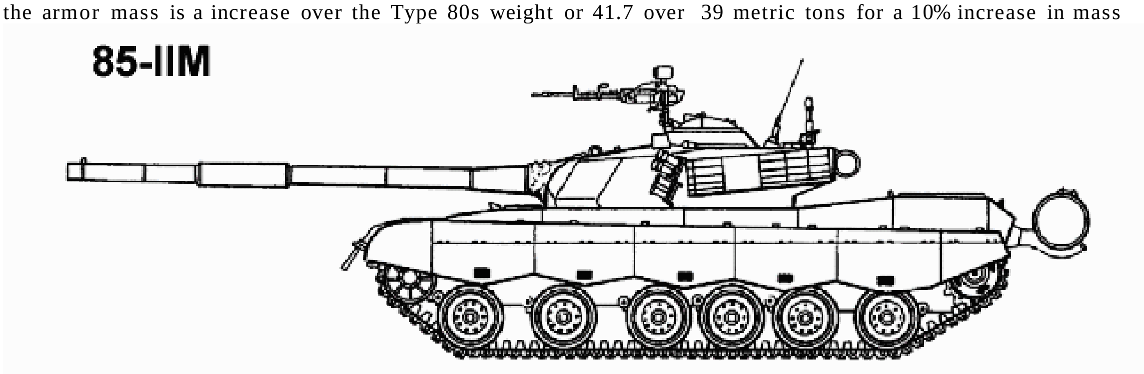
Top tank armor; is in three sections , the rear 1/3 [turret & engine deck] looks like just **~ 2cm RHA** , while the top turret & front hull deck seems to be **~ 5cm** thick. The front 1/3 turret and all the glacis is quite thick and may offer ~ **14cm KE & HEAT**

Bottom tank armor ; seems quite thin with may be 2 x RHA plates 1-2cm thick each . Inaddition there should be 10-20cm gap between the plates . The resistance is probably **~ 4-5cm KE ;** while the standoff in the plates plus the 'ground clearance' should offer a standoff of 55-65cm leading to ~ 5-10cm increase in HEAT protection for a value of **11-16cm HEAT**

 Type 88C Also known as Type 85-I/II/III [Approximate]

It is reported on tbe Chinese Military Forum that the Type 85-98 tanks use HY-80 RHA [~ 240BHN] plus 'Alumina' ceramic armor. JANES Armor & Artillery 1997/98 has a detailed interior drawing of the Type 88C [85/III] side profile revealing front and rear armor as well as top and bottom armor. The Type 85 II & III have about the same weight and protection. From these drawings I estimate the following armor thickness.
Glacis ~ 21cm @ 68°[7cm rear plate RHA and 14cm front plate/layer] ~ 57cm LOS
Lower hull ~ 8cm @ 50° [seems to be the same material as glacis rear plate RHA?]
Front upper turret ~ 48-50mm @ ~80° = 279mm LOS
Front turret ~ 65cm LOS in 4 layers with ~ 25cm insert [ceramic?] followed by a ~ 14cm LOS segment [Steltexolite?], sandwiched inbetween steel plates.
Top turret ~ 45mm
Rear turret ~35mm & 20mm plates and ~ 40cm spaced armor.
Rear hull 35mm & 20mm plates with ~ 2 meter thick engine space armor.
Side Hull should be similar to T-72 or 60mm RHA plus rubberized side skirts about 25mm thick.
Side turret 18cm[?] ,plus 'storage basket'

Armor mass : The internal volume of the Type 85 tanks looks @ $12m^3$ while the Type-80 volume is about $12.5 m^3$ and the armor mass is a increase over the Type 80s weight or 41.7 over 39 metric tons for a 10% increase in mass



** Turret front**
. **I estimate the Type 88C front turret profile is $1.25m^2$ which is a 12% denser armor than T-88B/A .** Thus the armor mass increase over Type 80 should be 24% , thus the Type-85 front turret should be 30cm x 1.24 = 37cm over a ~65 cm LOS thickness. That's 4.5 g/cm^3 .and the insert is reported to be 390mm thick leaving 26cm Steel.This leaves a

insert density of ~ 2.2g/cc which leaves the possibility of 2/3 Steltexolite [ST-1?] and 1/3 Alumina insert which has also been reported. The effective 'Te' should be
RHA = 26 cm x 0.95 [hardness] x 0.99/0.97/0.94/0.92 [T/d]= 24.4/24.2/23.7/23.2cm & 25cm
ST-1 = 26cm [0.35/0.5] x 0.92/0.9/0.85/0.8 [T/d]= 6.7/6.5/6.4/6.2cm & 13cm
Alumina = 13cm [0.82/1.0] x 0.92/0.9/0.85/0.8 [T/d]= 10.5/10.3/10/9.8cm & 13cm
multipliers HEAT 1.2 times & 1.23times[thick coverplate] 0.8 [W/d]
KE resistance should look like …..
2cm APFSDS 24.4cm + 6.7 cm +10.5 x 1.23 x 0.8 = **40.5cm RHAe**
3cm APFSDS 24.2cm + 6.5 cm +10.3 x 1.23 x 0.8 = **40cm RHAe**
3cm APFSDS 24.2cm + 6.5 cm +10.3 x 1.23 x 0.8 = **40cm RHAe**
HEAT resistance should look like [25 + 13 +13cm] x 1.2 = **61cm HEAT**

Front turret armor looks like 40cm KE and 61cm HEAT resistance

Norinco Type C ERA is some times mounted on the turret adding **13±6cm KE & 41 ± 21cm HEAT, but the coverage is only ~ 60%.** and should look as follows.

This should bring the front turret armor up to 53±6cm KE and 112cm ±21cm HEAT

 Upper front turret accounts for about 1/5 of the turret profile and looks like 48-50 mm HY-100 @ ~ 80° or **~28 cm KE and 28 cm HEAT** armor. ERA is also included sometimes in the array , Norinco **Type A ERA** at normal impact should offer 15mm x 1.7 = 25mm or 17±8mm ÷ Cos 80° , this should boost the armor by ~ 15±4cm KE & 42±14cm HEAT to **43±4cm KE and 70±14cm .**

** Side turret** Looks like 18cm thick plates that's probably RHA with 35-40cm Storage baskets mounted external to the side of the turret. Going from the T-80 armor mass that's 17.2cm LOS x 1.1 = ~ 19cm . Thus if we use the 19cm as RHA we get
19cm KE & HEAT resistance plus another 5-15cm HEAT resistance due to the baggage.This results in a resistance of about

19x 0.95 [hardness] = 18cm KE/HEAT plus 0-2cm KE/10-20cm HEAT = **18-20cm KE & 20-35cm HEAT**

Rear turret ~35mm & 20mm plates and ~ 40cm spaced armor= 5x 1.2 [large YAW] ~ **7cm KE & 32cm/15cm HEAT [1st Gen / 2nd Gen HEAT] .** Plus storage ands say 0-2cm KE & 5-15cm HEAT. Leading to about **7-9cm KE & 37-47cm / 20-30cm HEAT [1st Gen / 2nd Gen HEAT]**

 Hull Glacis is 21cm @ 68° thick –T-64 like glacis - with probably 105mm Steltexolite STEF [0.41 KE and 0.7 HEAT] thus the glacis should offer [148 ÷ 0.37 =] **~ 40m KE** & [178 ÷ 0.37=] >**48cm HEAT** armor. ERA is some times mounted on the glacis adding **~ 2cm KE & 40cm HEAT**, or the new Norinco K-5 type ERA which should boost the armor by **12 ± 5cm KE & 37 ±18cm HEAT** but the coverage is ~60- 80%..This should lead to **49±9 KE & 76cm ± 27 HEAT**

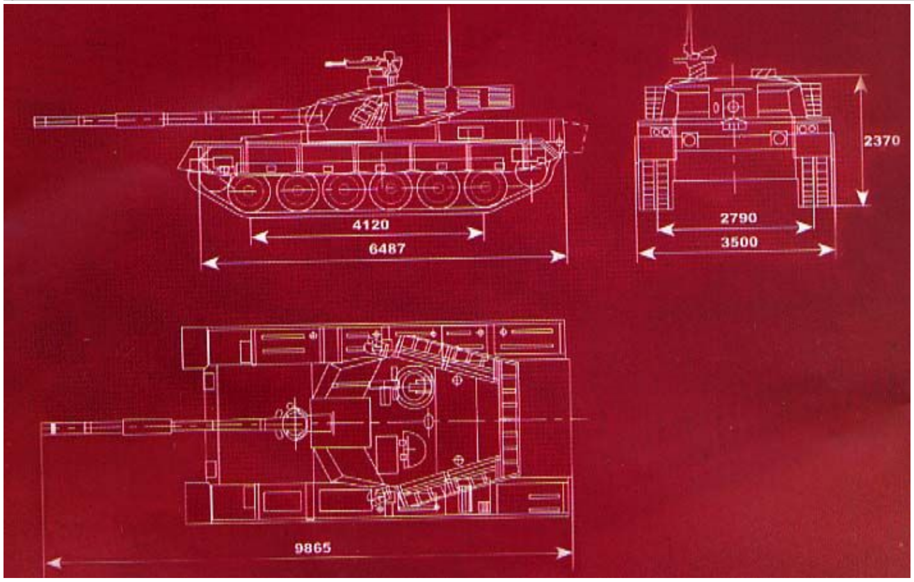
Lower hull is 8cm @ 50° = LOS thickness ÷ 0.64 or **13cm** LOS armor, KE/HEAT

The side hull is 6cm thick but the lower side hull around the wheels is probably only 2cm thick just like on the T-54-62 tanks The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional **6-7cm KE and ~ 20cm HEAT** armor. The side hull has 2.5cm thick rubber side skirts that probably have steel mesh included . The erosion will be 7 x 25mm + 600 mm standoff ..which should result in 20cm + 4cm hull plate & 5-10cm from standoff, that's …**..5-7cm KE & 29-34cm HEAT.** If the side skirts are only Rubber , as in T-59 then the addition should result in only about **6cm KE and 20-25cm HEAT resistance.**

** Rear hull** 35mm & 20mm plates with ~ 2 meter thick spaced armor. 5x 1.2 [large YAW] ~ **7cm KE & 44cm HEAT** but diesel fuel tanks mounted ther could offer 0.1 to 0.15 Te resistance to APFSDS and 0.34 resistance to HEAT. The HEAT armor should range from additional 3-4cm to as much as 18cm HEATarmor.

Top tank armor; is in three sections , the rear 1/3 [turret & engine deck] looks like just **~ 2cm RHA** , while the top turret & front hull deck seems to be **~ 5cm** thick. The front 1/3 turret and all the glacis is quite thick and may offer ~ **17cm KE & 20cm HEAT**

Bottom tank armor ; seems quite thin with may be 2 x RHA plates 1-2cm thick each . Inaddition there should be 10-20cm gap between the plates . The resistance is probably **~ 4-5cm KE ;** while the standoff in the plates plus the 'ground clearance' should offer a standoff of 55-65cm leading to ~ 5-10cm increase in HEAT protection for a value of **11-16cm HEAT**



MBT- 2000 Also know as AL Khalid & Type 90 [Tentative]

> *Nothing new -- but there are some details concerning the armor protection. The frontal protection consist of multi- layer steel and non- metallic composite armor. HY- 80 steel is used for side and other protections. Al- Kalid's turrent is about 10 ton lighter than M1A2. [BTW, I read from another magazine article that Al- Kalid's armor mass may actually be greater than type- 98 due to the superior/more compact arrangement of the engine so lengthened hull is not required.] The price of the tank without gun and fire control is about $541k USD. 55% of the parts are new. 20% of the parts are common with type- 85- AP. 15% of the parts are common with type- 69, and 10% of the parts are common with type- 59. Al- Khalid claimed to have autotracker, hunter/killer capability, and 3rd generation thermal imager from European source.*

Built as a export version of the T- 85- III [or T- 88C] in cooperation with Pakistan , where it is know as the Al Khalid. It is reported on tbe Chinese Military Forum that the Type 85- 98 tanks use HY- 80 RHA [~ 220BHN] plus Alumina ceramic armor and that the front turret armor is based on the ukramian T- 84 armor arrangement that's been reported by Janes to consist of 6 layers on the front turretand 5 layers on the side turret. JANES Armor & Artillery 1997/98 reports the Al Khalid has turret thickness of 600mm and hull thickness of 450- 470mm and the above drawings seem to confirm the turret thickness. Source on the Chinese Military Forum reported the maximum KE armor of the *'88C at 650mm [Type 85- III or Type 90]"* and a HongKong paper reported harder steel is used in this tank ....given the use of HY- 80 plate, the 'hard steel' is probably HY- 120 [BHN- 270].The MBT- 2000 is 48,000 Kg and appears to have a internal volume of ~ 12.6m^3 compared to 41,700 Kg for the Type 85III leading to the assumption that the MBT- 2000 has 20% more armor mass. **I estimate the Type 90 front turret profile is 1.25m²** From this assumption and the Type- 85 measurements, I estimate the following armor thickness. Chinese magazine has reported the insert thickness to be 390mm thick .

Front Hull ~47- 45cm LOS @ 35- 45°
Front upper turret ~ 48- 50mm @ 80° ~ 27- 28cm LOS
Front turret ~ 70cm LOS with a 39cm insert & 21cm @ 25° x 20°
Top turret ~ 45mm
Rear turret ~35mm & 20mm plates and ~ 40cm spaced armor.
Rear hull 35mm & 20mm plates with ~ 2 meter thick spaced armor.
Side Hull should be similar to T- 72 or 60mm RHA plus rubberized side skirts about 25mm thick.
Side turret same as Type 85- III?

Turret front Armor mass : Its assumed the same internal volume as the Type 85 tanks and the armor mass is a increase over the Type 80s weight or 49 over 41.7 metric tons for a 18% increase in mass. The T- 85 front turret armor mass is 31.8cm x 1.2= 38.2cm steel armor mass plus the similar increase over the side and rear turrets +7 cm steel to over 45cm steel across a ~65 cm LOS thickness with 43cm LOS insert. That's ~ 5.2 g/cm ³ leading to an assumed insert density of 3.9g/ cm ³ or Alumina [97%] . If this is true the inserts are 43cm thick [LOS] AD- 97,while the steel is HY- 120 RHA . The effective resistance should be......

RHA = 22 cm x 1/1 [Te] x 0.96 /0.98[t/d] = 21.1 / 21.6 cm & 22cm
AD-92 = 43 cm x 0.9/1.54 [Te] x 0.9/0.94 [t/d] = 38.7 / 40.4cm & 66.2cm
multipliers HEAT x 1.2 [layers] and KE x 1.2 [confinement] x 0.8 [Lc] x 1.05 [backing]
KE resistance should look like [21.1 / 21.6 + 38.7 / 40.4] x 1.2 x 0.8 = 57.4cm /59.5cm KE
HEAT resistance should look like [22 + 66.2cm] x 1.2 = 105.6cm HEAT

Front turret armor looks like 57.4cm [2.5cm APFSDS] 59.5cm [2cm APFSDS] and 105.6 cm HEAT resistance when the reported resistance is 645mm KE . Pak istan discovered that Chinese had overrated penetration estimates by 94-90% , since the same rating system would be used to assess armor resistance, it could be that the 645mm quoted figure is actually 606mm-580mm. From a 30° off angle the turret should offer ~ 53-55cm KE resistance to a 25mm-20mm diameter APFSDS.

Norinco Type A ERA is some times mounted on the turret that's similar to Kontakt ERA . This should add 15mm x 1.7 = 25mm or 17±8mm ÷ Cos 30° = + 2cm ±1cm KE resistance & 15 ± 5cm HEAT, **but the coverage is only ~** 2/3 of the profile , and should bring the front turret armor up to ~ **59±2cm [2.5cm APFSDS] ~61±2cm [2cm APFSDS] and ~116cm ±10cm HEAT** .There is also the option to upgrade to Type B or C Norinco ERA the should boost the armor values by **4±2cm & 5±2cm KE at angle [so @ 65° that's +10±3cm & +12±4cm**].

 Upper front turret accounts for about 1/5 of the turret profile and looks like 48-50 mm HY-120 @ ~ 80° or **~31 cm KE and 31 cm HEAT** armor. ERA is also included sometimes in the array , Norinco **Type A ERA** at normal impact should offer 15mm x 1.7 = 25mm or 17±8mm ÷ Cos 80° , this should boost the armor by **~** 15±4cm KE & 42±14cm HEAT to **46±4cm KE and 73±14cm .**

** Side turret** Looks like 18-20cm thick plates that's probably RHA with 35-40cm Storage baskets mounted external to the side of the turret. Going from the T-80 armor mass that's 17.2cm LOS x 1.1 = ~ 19cm . Thus if we use the 19cm as RHA we get
21cm KE & HEAT resistance plus another 5-15cm HEAT resistance due to the baggage.This results in a resistance of about

19x 1.1 [hardness] = 21cm KE/HEAT plus 0-2cm KE/5-15cm HEAT[baggage] = **21-23 KE & 27-36cm HEAT** .

Rear turret ~35mm & 20mm plates and ~ 40cm spaced armor= 55mm x 1.3 [large YAW] ~ **7cm KE & 32cm/15cm HEAT [1st Gen / 2nd Gen HEAT] .** Plus storage ands say 0-2cm KE & 5-15cm HEAT. Leading to about **7-9cm KE & 37-47cm / 20-30cm HEAT [1st Gen / 2nd Gen HEAT]**

Hull TheType-85 hull has an armor mass of 127.8 mm steel ÷ 0.37 ~ 345mm armor mass , while the lower hull is only 8cm @ 50° = LOS thickness ÷ 0.64 or 13cm LOS armor . Thus the average hull armor mass is ~27.3cm steel, times the mass increase from Type 85-III to MBT-2000 which is 18% , this equals ~ 32cm armor mass .The front hull thickness looks like ~47@ 35 & 45cm @ 45° for a LOS of 57-64cm That's 28/60 = 3.66g/cc average density on the glacis and , which in turn suggests a layered structure with say 1/3 RHA[HY-120] plus 2/3 Steltexolite, leading to the following figures……

Glacis & Hull 45cm with 1/3 RHA [HY-120]& 2/3 Steltexolite .thus this is
RHA 20cm x 1.05[Te] + 0.96/0.98 [t/d] = 20.2/20.6 cm KE & 21cm HEAT
40cm STEF [0.41 / 0.6] Te x 0.9/0.94 [T/d] = 14.8/15.4 cm KE & 24cm HEAT
Multiples = x 1.2 HEAT [layering] & x 1.25 [hvyConfinment] x 1.04 [backing]
KE= [20.2/20.6 + 14.8/15.4 cm] x 1.04 x 1.2 = **43.6cm [3cm APFSDS] & 45.4cm [2cm APFSDS]**
HEAT = [21 cm + 24cm] x 1.2= **54cm HEAT.**

Norinco **Type A ERA** is available that should boost the glacis armor by 15mm x 1.7 = 25mm or 17±8mm ÷ Cos 35-45° , this should boost the armor by **~ 2-3cm±1cm KE & 18-20cm ±8cm HEAT**, but the coverage is only ~ 2/3 of the profile , thus the effective resistance for the hull should be **~ 45-47±2cm KE & 67± 13cm HEAT.**

REST OF THE ARMOR IS THE SAME AS TYPE 85-III

Type 98 [Tentative]

http://www.sinodefence.com/army/tank/type98.asp

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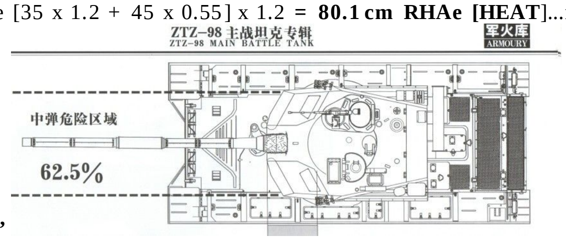
The armor plate of the Type - 98 exists from steel, aluminum, insoles from ceramics and synthesis-fibers. In order to increase the effect against force-projectiles, an DU armor plate is moglich. The entire protection-concept is held very modular, also under skirmish-conditions can renew the armor plate or is exchanged. Additionally, also a reactive-armor plate can, like the Russian

Kontakt-5 is installed" [CMF] At 2km = 700mm for kinetic round, 800mm HEAT,this w/o the DU armour.report from the article.a/ add- on armour,weight increases by 0.7ton.protection increase to 830mm for knetic round. and 1,060mm for HEAT.w/ additional layer of ERZ,-protection for kinetic rd. and HEAT rd. reaches 1000mm~1200mm . **Kamfpanzer Web site**

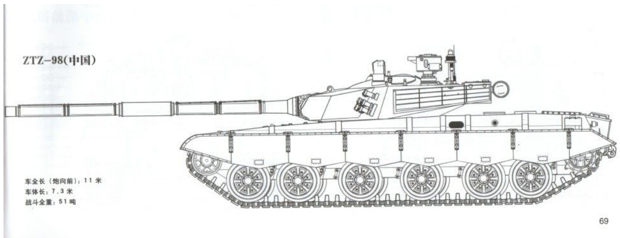
"according to the magazine,the laminated armour for glacis plate are steel(80mm) -fibre glass-HB strenght steel-fibre glass-base armour= total 220mm the turrent was fitted (2 row?) of ceramic tiles.- protection 700mm(kinetic round) at 2000 meter range." "The gun tube undergoes redesign,designated as ZPT-98,this is a conmplete new 125mm/50 calibre smooth borne gun,it uses high tensil strenght PCr Ni3 NoV steel to manufacure .life span at 700 round.her muzzle energy is 45% higher than the Russian 2A46M-1 125mm tank gun and offer 25% more accurate.some report that muzzle energy for ZPT-98 are 12.7,. type-98 at $1.9 million per copy,happen to be the most expensive tank ever produced in China"

The difference is in the volume of the tank and its weight modified by the profile.Sov designs are 2/3 volumne of western tanks , so the T-80 is 11.3 m^3, while the Chieftain is 17m^3 and the T-98 is about 13 m^3, or 1.3 times . Factoring in tbe weight 49/55 x 0.89 x 1.3= 45cm armor mass . The Type 98 turret is the narrowest I've ever seen, and its reported to use DU armor. Examining scale drawings [crude] it looks like 650mm thickness across the front turret , which is the same as the Type 85 III turret. I assumed the rolled plate was a 'HY120' type plate and DU armor - as has been reported. Finally I assume Alumina-99[%] These combined to reach ~ 83cm KE armor when the reported figure is 845mm . Adding 'Norinco K-5' type ERA boost this to 96 ± 6cm KE armor after laterial confiment is factored in.

Type 90 has 63cm thickness and 70cm LOS through the front with a 39cm thick insert [leaving 24cm steel].Thats a steel mass of a ~40.9cm steel and a straight LOS through the front should be ~ 45.4cm Steel mass....But the Type 98 turret is narrower concentrating more armor mass to the front...I estimate the Type 90 front turret profile is 1.25m^2 and the Type 98 turret profile to be ~ 1.1m^2 . For the same Turret mass thats 13-14% increase in mass to ~ 51.5cm steel mass. The approximate ME of such an armor is likely to be 1.6 @ 0° and 1.33@ 60°., thus the 51.5cm steel mass should translate into about 1.45 x 51.5 x 0.95 [t/d & L/c] = 70.9cm RHAe. The armor is reported to be a simple steel aluminum thick layered armor .If the actual front turret LOS armor was 36cm steel and 43cm Aluminum the Te could be [35 x 1.2 + 45 x 0.41] x 0.95 [T/d & Lc] x 1.23[hard cover & Backing] **= 70.6 cm RHAe [APFSDS].** The shaped charge resistance of the above arrangement should be [35 x 1.2 + 45 x 0.55] x 1.2 **= 80.1 cm RHAe [HEAT]**...not far off the quoted figures of " **700mm KE & 800mm HEAT"**



I estimate the Type 98 turret to be 1.6m^3 volume while the hull is ~ 10m^3 volume. The tank is reported to weight In at 52 meteric tons.



Its reported on tbe Chinese Military Forum that the Type 85- 98 tanks use HY- 80 RHA [~ 240BHN] plus ceramic armor. JANES Armor & Artillery 1997/98 has a detailed interior drawing of the Type 85/III side profile revealing front and rear armor as well as top and bottom armor and a HongKong paper reported harder steel is used in this tank ….given the use of HY- 80 plate ‘hard steel’ is probably HY- 120 [Te 1.1].Its also been reported an experimental Type 96 was built with DU armor [second generation DU ?] and it appears the T- 96/8 turret is narrower than the MBT- 2000 turret by about 12% which may explain how the heavier DU armor is integrated. The MBT- 2000 front turret profile looks like 0.47m x 2.11m = 0.99m² , with a 12% narrower turret this leads to a 0.47 x 1.86m = 0.87m². There is an appliqué that is added to the front turret which is said to add 0.7 tons to the tank mass. This should lead to a 700 ÷ 1.1 = 636/7850kg mass = 8cm steel mass.The reported armor increase of the ‘none DU version’ of the Type- 98, goes from 700mm KE to 830mm KE resistance with this applique.The appliqué thickness looks like ~30cm thick, which suggests a cross sectional density of ~ 2.1g/cc….so the construction must include spaced armor and/or some light weight materials in a sandwich construction with steel outer plates. Whats more likely is a simple spaced steel armor 8.1cm mass which given the angles probably works out to ~ 5cm SHS@ 45 x 30°?…this should add 9.6+1.3d or 12.5cm plus 70cm or 82.5cm ,when the reported resistance is 83cm KE.The HEAT resistance should be ~ 24cm plus the base armor 80cm , or 104cm HEAT…the reported resistance is 108cm.if the above spaced plate is adjusted to 9cm LOS thickness or 6cm SHS@ 45 x 30° we get….
2cm HSAPFSDS 70.6cm+ 10.8 + 2cm to 83.4cm KE
2.5cm APFSDS 70.6cm+ 10.7 + 3.2cm to 84.5cm KE
Precision shaped charge = 80.1cm + 9 x 3 = 107cm HEAT
Add heavy ‘Type C ERA’ can also be added to this bringing the resistance threat upto
2cm HSAPFSDS 70.6cm+ 10.8 + 2cm + 3.3cm + 8.8 to 96cm KE.
2.5cm APFSDS 70.6cm + 10.7 + 3.2cm + 3.3cm + 11 to 99cm KE
Precision shaped charge = 80cm + [9 x 3 + 4.4 x 10] x 0.67 = 48cm = ~ 128cm HEAT

	¼ glacis	¾ Glacis with Type C ERA
2cm HSAPFSDS	**83.4cm ± 10cm**	**96cm ± 12cm**
2.5cm APFSDS	**84.5cm ± 11cm**	**99cm ± 13cm**
Precision shaped charge =	**107cm ± 14cm**	**~ 128cm ± 17cm HEAT**

Multiple hits will reduce ERA coverage so after 7 hits it should be considered ½ with ERA & ½ without ERA .

Turret front Armor mass : The Type 98 front turret is narrower than MBT- 2000 front turret [66% of the tank width while 74% for the MBT- 2000 width] about , 12% narrower which will lead to a denser front turret armor. In addition the Type 98 weight has gone up to 54 tons over the 49 tons of the MBT- 2000 tank again leading to 10% denser armor over all. Combined the front turret of the Type 98 should have ~ 24% heavier armor mass over MBT- 2000 front turret , with an armor mass of 47.4cm [38.2cm MBT- 2000 x 1.24] over a ~65cm LOS thickness. That’s 5.7g/cm ³ leading to an assumed ¾ insert composed of mostly Alumina [99%] plus Steltexolite [STEF?] and backed up by steel encased DU armor. By Steel mass this should be 19.4cm[ceramic] + 2.8cm[Steltexolite interlayers] + 7cm [RHA cover]+ 18cm [10cm Steel /DU/ Steel] or RHA = 47cm . The hard steel encased DU backing should boost the armor by 1.27 times due to heavy and hard backing, while the 49cm thick inserts have 3 parts AD- 99 & 1 part STEF, while the steel is HY- 120 RHA . The low cost alternative is the steel- Alumina- steel armor which should boast 7cm SHS /48cm Alumina 85 and 10cm RHA back plate .The effective ‘Te’ should be……

7 cm SHS x 1.2 [hardness] x 0.98/0.96/0.94/0.92[T/d] = 7.5 /7.4/7.2/7cm & 8.4cm
36 cm AD- 99 x 1.1 /2.0 [Te] x 0.98/0.96/0.94/0.92 [T/d] = 30.1cm/ 72 cm
12 cm STEF x 0.4/0.6 [Te] x 0.98/0.96/0.94/0.92 [T/d] = 4.8 cm /7.2 cm
10cm RHA/DU/RHA x 1.23/1.23 [Te] x 0.98/0.96/0.94/0.92 [T/d] = 12.3/12.3cm
multipliers HEAT x 1.2 [layers] and KE x 1.27[Heavy hard backing] x 1.2 [coverplate] x 0.8/ [Lc confinement]

HEAT resistance should look like [7.7cm + 72cm+ 7.2cm + 12.3cm] x 1.2 = 119cm HEAT

Front turret armor looks like 84cm KE and 119 cm HEAT resistance and its reported the “WZ123 [Type 96] has 845mm KE armor.”

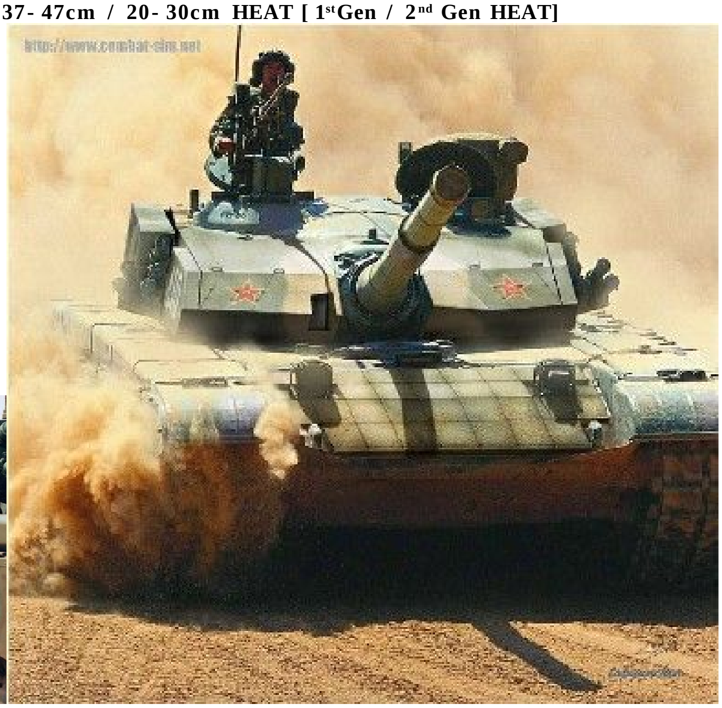
Low cost model should be ……
8 cm RHA x 1.1 [340 BHN hardness] x 0.98/0.96/0.94/0.92[T/d] = 7.5 /7.4/7.2/7cm & 8.4cm
43 cm AD- 85 x 0.8 /0.95 [Te] x 0.95 x 0.8 [T/d & Lc] = 30.1cm/ 45.6 cm

12cm RHA x 1.0/1.0 [Te] = 12/12cm
multipliers HEAT x 1.2 [layers] and x 1.2 [coverplate] x 0.8/ [Lc confinement]

HEAT resistance should look like [8.4cm + 45.6cm + 10cm] x 1.2 = 77cm HEAT
Norinco Type C ERA is some times mounted on the turret adding **13±6cm KE & 41 ± 21cm HEAT,** but the coverage is only **~ 60%.** and should look as follows**. KE resistance about 94± 10cm KE and HEAT resistance about 150± 31cm** .

Side turret Looks like ~20cm thick with 35-40cm Storage baskets mounted external to the side of the turret. Going from the T-85 armor mass that's 19cm LOS x 1.10 = 21cm~ over a 20cm thickness suggesting a material heavier than steel is used [8.25 g/cc] . Thus if we use the 21cm steel mass and think of a layered structure that could be ceramic and DU armor so the layering might be 13.2g/cc [DU-RHA] + 4g/cc [AD99] + 7.85[RHA] ÷ 3= 8.35 g/cc ….that suggests about 7cm SHS + 7cm AD-99 + 7cm SHS-DU =
7cm SHS x 1.1/1.1 [Te] = 7.7/7.7cm
7cm AD-99 x 1.1/2.0 [Te] x 0.95 [T/d] x 0.8 [Lc] = 5.8 / 14cm
7cm S-DU-S x 1.23/1.23 [te] = 8.6/8.6cm
Multiples HEAT x 1.2 [layering] & KE x 1.27 [dense hard backing] x 1.2 [confinement]
KE resistance = [7.7 + 5.8+ 8.6] x 1.27 x 1.2 = 33.7cm
HEAT resistane = [7.7+14+8.6] x 1.2 = 36.3cm
Plus baggage = 0-2cm KE/5-15cm HEAT = **34-35cm KE & 36-51cm HEAT**

Rear turret Probably the same as Type 90 tank …..~35mm & 20mm plates and ~ 40cm spaced armor= 55mm x 1.3 [large YAW] ~ **7cm KE & 32cm/15cm HEAT [1st Gen / 2nd Gen HEAT] .** Plus storage ands say 0-2cm KE & 5-15cm HEAT. Leading to about **7-9cm KE & 37-47cm / 20-30cm HEAT [1st Gen / 2nd Gen HEAT]**



Hull TheType-98 hull has an armor mass 10% higher than the 32cm on the MBT-2000 leading to ~ 35.6 cm steel mass or 13.5cm steel @ 68°. The thickness is reported to be 220mm @ 68° or 58cm and is reported to be constructed with 8cm steel outer plate followed by Steltexolite with steel and a ?steel back plate. This is reminicant of the T-80U armor . If we assume 8cm steel plus 8 cm steltexolite with 2cm mild steel and 4cm steel back plate we have 22cm @ 68°….. . Thus the thick layers are rubber and the thin plates are metal , in this case it could be 2 x 1cm MS [7.8/cc] plus 8cm of Steltexolite [1.7g/cc] = 2.72g/cc or 8cm STEF [1.85g/cc] & 2cm MS = 3.0g/cc.
.In addition ¾ of the glacis is covered in Type C ERA that adds ~ **+14-15cm KE protection [2cm-4cm APFSDS]** and **23-24cm [Sheathed APFSDS] +50 cm HEAT** armor .

8cm RHA x 1.0/1.0 [Te] x 0.97/0.95/0.9 [t/d] = 7.8/7.6/7.2/ & 8cm [HEAT]
10 cm STEF /MS/ STEF x 0.5/ 0.6 [Te] x 0.7/0.6/0.55 [T/d] = 3.5/3/2.75cm & 6cm
3cm SHS x 1.2/1.2 [Te] x 0.9/0.88/0.85 [t/d] = 3.2/3.1/3.0cm & 3.6cm [HEAT]
Modifiers x 1.2 [HEAT] & KE x 1.26 [RHA confinement] ÷ 0.38 [Cos of glacis]

¼ glacis **¾ Glacis with Type C ERA**

2cm APFSDS = 14.5 x 1.26 ÷ 0.38 = **48cm** **¾ with Type C ERA = 63cm**
3cm APFSDS = 13.7 x 1.26 ÷ 0.38 = **45cm** **¾ with Type C ERA = 63cm**
3.5cm Sheathed = 12.95 x 1.26 ÷ 0.38 = **43cm** **¾ with Type C ERA = 63cm**
[HEAT] = 17.6 x 1.2 [layering] ÷ 0.38 = **56cm** **¾ with Type C ERA = 130cm**
Multiple hits will reduce ERA coverage so after 7 hits it should be considered ½ with ERA & ½ without ERA .

REST OF THE ARMOR IS THE SAME AS TYPE 85- III

Longer APFSDS have been tested that are said to be inconjunction with this design. These look to be longer than the 70cm limit imposted on the Russian 125mm autoloader licence produced for Chinese tanks. However its been resently noted that the Russians have developed a fleet wide upgrade programe for their tank fleet refered to as RELICT. One of the features of this programe is a modification to the auto loader to facilitate longer rounds. This modification has been described to be quite simiple suggesting that perhaps the Chinese could have already instituted such a modification too.

Its also been suggested the Type 98 features a turret bustleAuto loader [perhaps for overlong APFSDS projectiles?]. The type 98 bustle cavity is minimum of 1.4m wide by 1.2m long and 0.4m tall. A comparison with bustle autoloaders developed for 105; 120 & 140mm APFSDS, reveals the following capacities.

105mm AGS ; 16 rounds with 1.7m width , 1.2m length and 0.5m height. Type 98 bustle autoloader could carry 2/3 or ~10 rounds.
120mm Leclerc; 22 rounds with 2.4m width ; 1.4m length and 0.5m height. Type 98 bustle autoloader could carry ½ or ~10 rounds.
140mm AL ; 16 rounds with 2.0m width ; 2.4m length and 0.6m height. Type 98 bustle autoloader could carry ¼ or ~4 rounds.

Since the 105 and 120 are single rounds and complete rounds of 1 meter length [140 is two piece its actually storing 8 larger rounds]. Since the the soviet designed Ammo is two piece with lengths of 0.7m and 0.4m, then both parts could fit into the bustle loader or even a one piece 125mm APFSDS round with a length of 1m ? This should allow ~ 10 x overlong 125mm APFSDS rounds with inflight projectile lenghts of 75- 80cm and penetrator lengths of ~75- 78cm. Given current improved propellant technology this allows a 4.5kg DUV penetrator to grow to a length of 2 x 78cm or 39:1 L/d ,with MV of 1.83km/s and 0.05km/s/km Vloss.This would results in a modified Andersons formula estimated penetration of 1.044 V - 0.92 * 1.2 * 1.2 x 78cm plus 1.3d .This inturn suggest a maximum of….

1.43 x 78 = 111cm + 2.0cm or 113cm penetration @ 0° & 57cm @ 60° at muzzle .
1.27 x 78 = 99cm + 2.0cm or 101cm penetration @ 0° & 51cm @ 60° at 2000m range.

SOVIET & RUSSIAN TANKS

T- 54/55 & Type 59/69& 79 [Accurate]

The back bone of all communist armies this tank is the most produced tank in the modern world . Its reported in JANES to have cast turret armor and Rolled hull armor . The plate hardness is reported [by Vasiliy Fofanov] to be…. *"cast turret 270- 286 HB ; rolled hull 290- 300 HB and rolled top turret 330- 370 HB The data is for T- 54, but consequent models can hardly be expected to be worse."* . JANES reports the plate thickness to be **…..**

Glacis = 97mm @ 58°
Lower hull = 99mm @ 55°
Hull sides = 79mm …20mm around the wheels]
Hull rear = 46mm @0°
Hull roof = 33mm
Hull floor = 20mm

Turret front = 203mm @ 0° x 30° ranging to 170mm @ 50°[½ with 24cm LOS thickness and ½ with 26cm LOS thickness
Turret roof 39mm @ 79°
Turret sides = 150mm @ 0° x 30°
Turret Rear = 64mm @ 30° x 30°

[3/10 th front turret profile] MANTLE is about 20cm @ 30° or 23cm LOS 270BHN cast armor. The cast reduction [0.95] and the weakened zone .Free edge effect is 0.88 [APFSDS] , while its 0.8 for APDS & APC . The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.96[120mmAPC] & 1.0 [90mm APC] 1.0 [APDS/APFSDS]
Vs 120mm AP = **16.8cm LOS or 14.5cm @ 30°**
Vs 90mm AP = **17.5cm LOS or 15.1cm @ 30°**
Vs APDS/APFSDS = **18cm LOS or 15.5cm @ 30°**
Vs HEAT = **23cm LOS or 20cm @ 30°**

[½ front turret profile] main sloping walls is ~17cm @ 45° or 12cm @ 60° ~ 24 cm LOS , 270BHN cast armor. The cast reduction [0.95] and the free edge effect is 0.98 [APFSDS] , while its 0.94 for APDS. For APC its 0.95. The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.90[120mmAPC] & 0.96 [90mm APC] 1.0 [APDS/APFSDS] It should look like this. …... …..
Vs 120mm AP = **19.6cm LOS or 13.7cm @ 45°**
Vs 90mm AP = **21cm LOS or 14.7cm @ 45°**
Vs APDS = **21.4cm LOS or 15cm @ 45°**
Vs APFSDS = **22.3cm LOS or 15.6cm @ 45°**
Vs HEAT = **24cm LOS or 17cm @ 45°**

[1/5 th front turret profile] Upper front turret = 39mm @ 79°= LOS thickness 205mm x 0.95 [cast] x T/d [0.75/0.85/0.88/0.92/0.94] **=**
Vs APC **=** 15.0cm LOS or **3.9cm @ 75° ** ricochet **** [120mm APC = * ¾ ricochet *]
Vs APDS **=** 16.1cm LOS or **4.1cm @ 75°** ** ½ ricochet ** [L-52/L16 APDS (WHA) = * ¼ ricochet*]
Steel/Sheathed APFSDS = 17.0cm LOS or **4.4cm @ 75° * ¼ steel APFSDS ricochet ***
2-3cm APFSDS **=** 18.0cm LOS or **4.6cm @ 75°**
Vs HEAT = 20cm LOS or **5.2cm @ 75° ** old warheads may ricochet ****

Side turret 150mm @ x 30° to 12cm @ 45°= 17cm LOS x 0.95[cast & t/d]
Vs APC **=** 15.5cm LOS or **13.4cm @ 30°**
Vs APDS& APFSDS = 16.1cm LOS or **14cm @ 30°**
Vs HEAT = 17.3cm LOS or **15cm @ 30°**

Rear turret ~64mm Cast @ 30° = 74mm x 0.95 = ~ 7cm
7cm KE & 7cm HEAT or 6cm @ 30°

If [50cm thick] storage boxes installed ½ profile becomes.
Vs API/APDS = 7+0.8 =7.8cm or **6.7cm @ 30°**
Vs HEAT 7 + 0.2 + 19/7 + 0.7d **or 23/12cm @ 30° + 0.7d**

[½ Front Hull profile] Glacis is 98mm @ 58° ~ 290-300 BHN RHA = LOS thickness 185mm x 1.05 [hardness] = 194mm . The T/d is of 0.88/0.92/0.94/0.96/0.98….
Vs APC **=** 17cm LOS or **8.5cm @ 60°**
Vs APDS & 4cm APFSDS = 18cm LOS or **9cm @ 60°**
Vs 2-3cm APFSDS & HEAT = 19cm LOS or **9.5cm @ 60°**

[½ Front Hull profile] Lower hull JANES reports 99cm @ 55° ~ 290-300 BHN RHA = LOS thickness of 172mm , x t/d [0.88/0.92/0.94/0.96/0.98]….
Vs APC **=** 15cm LOS or **7.5cm @ 60°**
Vs APDS & 4cm APFSDS = 16cm LOS or **8cm @ 60°**
Vs 2-3cm APFSDS & HEAT = 17cm LOS or **8.5cm @ 60°**

SIDE Hull is 8cm steel base side hull armor on the basic T-54/55. The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional
Above trackguard = **12cm KE and ~ 25cm HEAT armor** .
Below trackguard =
8cm vs API/20-30mm APDS/APFSDS & HEAT
7.5cm vs large APDS
6.7cm large APC/HVAP

The T-55M side skirt area has a ~3cm thick metal reinforced side skirt is mounted over the side track area..The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap increases the HEAT armor by the

standoff which is ~ 9 Cone Diameters[cd] for a 3 inch warhead or 1'cd' =7cm reduction ; and up to a 5'cd' standoff for a 5 inch HEAT warhead ; this translates roughly into 7-8cm reduction in jet penetration for a 70s 2nd Generation warhead and ~19cm for 60s technology 1st gen. warhead. But the reinforced rubber sheet is likely to offer ~ 2cm HEAT plus the spaced plate effect. This rubber skirting is energetic and perforated plate so should offer 1.0 cm Ersosion and 1.3-0.7d x 1.4 [energetic] x 2 [sheathed] .
Vs 3cm API ~ 8+2.9+1cm = **11.9cm @ 0°**
Vs 25mm APDS ~ 8+2.8+1cm = **11.8cm @ 0°**
Vs 25mm APFSDS ~ 8+2.7+1cm = **11.7cm @ 0°**
HEAT ~8 + 2 + 19/7 + 1.0d **= 29/17cm @ 0° + 1.0d HEAT**

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear
½ [engine deck & tracks] **~ 2cm RHA KE & HEAT @ 90°**
¼ [top turret & front hull deck] **~ 4cm. KE & HEAT @ 90°**
1/8 th [front/sides & rear turret] ~ **30cm @ 90° KE & HEAT**
1/8 th [glacis] ~ **10cm @ 60° KE & HEAT**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE**;** while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to
front ½ = 3cm KE and 22/7cm HEAT
Rear ½ = 2cm KE and 22/7cm HEAT

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Type 59D & D1 [Approximate]

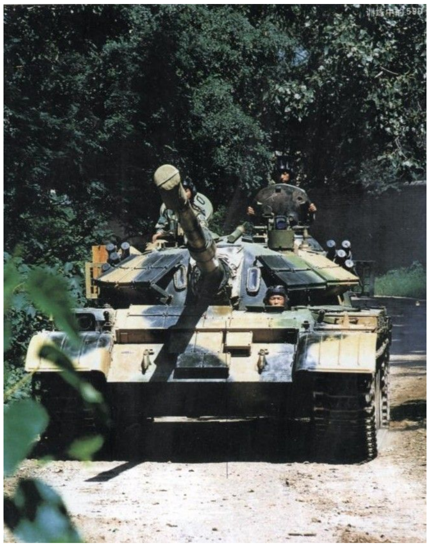
The back bone of the Chinese armies is 5000 copies of this tank that are still in existance. While there is an ongoing programe to build and field new tanks like Type 88c and Type 98, the back bone of their infantry armies is this tank. In order to give it some capability lowcost spinnoffs of the technology developed for the Type 88/98 is being back fitted to the Type 59 tank bringing it upto the Type-59D standard.
The improvements include stabilized digital FCS with Thermal sight that gives acquistion capability similar to the M-60A3 TI model matted to a improved longer 105mm gun that fires 30:1 L/d DU APFSDS rounds with penetration of atleast 600mm @ 2km range. The allround protection is boosted by grill armor around the turret and steel rubberized side hull skirts, while heavy Norinco ERA [type C?] is mounted around the front turret and hull.Chinese sources claim that the ERA boosts KE resistance by 1.8-2.6 times and the HEAT resistance by 2-3 times.Tank weight goes up by 2 tons but part of this is the change to stretched 105mm gun.The ERA arrangement looks similar to the appliqué added to the Slovenian M-55S [T-55 modified with Israeli super blazer mounted on a steel plate]..since the Israelis have given the Chinese considerable help in ammo and other areas its logical to assume this armor is from the same idea. In short the hull resistance goes from about 19cm RHAe to 49cm , suggesting a 30cm increase. The type 98 tanks get a 10cm increase from as spaced plate and 20cm from heavy ERA…so it looks like this appliqué may well be a heavy ERA mounted on steel plate?

http://www.sinodefence.com/army/tank/type59.asp

The base AFV is the original Type 59 tank that is reported [JANES]to have cast turret armor and Rolled hull armor . The plate hardness is reported [by Vasiliy Fofanov] to be *…."cast turret 270-286 HB ; rolled hull 290-300 HB and rolled top turret 330-370 HB The data is for T-54.."* . JANES reports the plate thickness to be **…..**

Glacis = 97mm @ 58° = **17cm [APC],18cm [APDS & 4cm APFSDS] & 19cm [2-3cm APFSDS & HEAT].**
Lower hull = 99mm @ 55°= **15cm [APC],16cm [APDS & 4cm APFSDS] & 17cm [2-3cm APFSDS & HEAT].**
Hull sides = 79mm …20mm around the wheels = **8cm KE & HEAT** [**13cm Ke & 38m HEAT with side skirts]**
Hull rear = 46mm @0° = **3 [APC] 4cm[API] & 5cm [HEAT]**
Hull roof = 33mm= **2-3cm KE & HEAT &** ~ **12cm KE & HEAT over glacis and front turret [1/3 top profile]**
Hull floor = 20mm= **2cm KE & 22-32cm HEAT**
[¾ front turret profile] Turret front = 203mm @ 0° x 30° ranging to 170mm @ 50°[½ with 24cm LOS thickness and ½ with 26cm LOS thickness = **22cm [APC] 23 [APDS] 24cm [APFSDS]**
Turret roof **[¼ front turret profile]** 39mm @ 79°**=R[APC &APDS] 17cm* [4cm APFSDS] 18cm [2-3cm APFSDS]& 20cm HEAT**
Turret sides = 150mm @ 0° x 30°= **15cm [APC] ; 16cm [APDS& APFSDS] & 17cm HEAT**

Turret Rear = 64mm @ 30° x 30°= **7cm KE & 7cm HEAT** [**~20- 25cm HEAT were storage boxes mounted]**



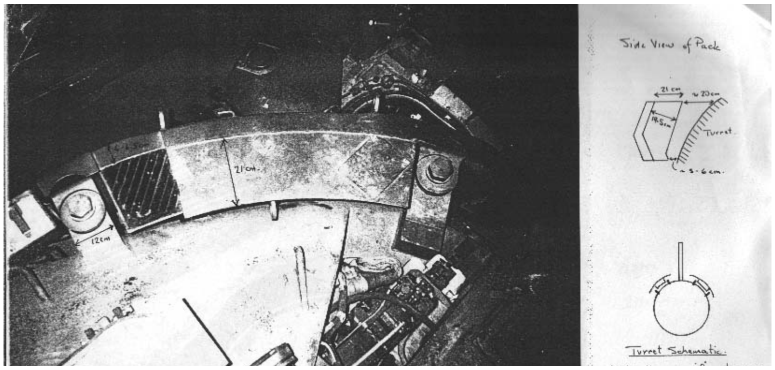
‘’’’

T- 55AM- 2[PorB] with BROW ARMOR [Approximate]

With ‘Brow armor’ added in the early 80ss after the Germans up armored the LEO-1s. . This armor was composed of thin mild steel plates suspended in rubber encased in RHA . The KE of an attacking warhead set the rubber in motion moving the plates there by eroding the penetrator. Measurements taken of this reveal the glacis thickness is 15cm with 3cm RHA casing and alternating layers with 4 x 5mm mild steel sandwiched in between 10cm rubber . The effectiveness should be [3 cm RHA x 0.88 (t/d)] + 0.96 {2cm x 0.8{mild steel] x 0.6 [t/d]} + 10cm x 0.15[rubber] = 5.1 ÷ 15 . Heavy armor packs on the **front turret** and **glacis** with **overlapping plates** extending to near the MG /Gun sight positions. The turret applique is spaced while the **glacis applique** is not.The **heavy pack** section of the turret applique ,covers about 35% of the turret profile , while the **overlapping plates** account for another 20%...leaving 45% of the turret armor exposed. The glacis packs cover ~ 55% of the **front hull** profile leaving ~ 45% of the hull armor exposed.Particularly odd is the 0.8m x 0.9m wide mantle turret area that is wide open to penetration at long range by even the most basic 105mm APDS ammo.The basics of the BDD as we know are the applique adds 2190kg to the mass of the tank and Zaloga reports that the T- 55/T- 62 goes from 200mm to 330mm KE , while the HEAT values go from 200 to 400- 450mm ....NiI Stali reports that the T- 55 turret with applique goes from 210mm to 380mm KE & 450mm , while the glacis applique goes from 200mm to 410mm KE & 380mm HEAT. My assumption is that the NiI Stali information is more accurate.

[½ front turret profile] main sloping walls is ~17cm @ 45° or ~ 25 cm LOS , 270BHN cast armor. Plus the BDD composite packs. This array was 6cm RHA + 20cm cavity with 20mm alternating rubber & 5mm thick mild steel plates @ 45°, with a 1cm thick RHA back plate.The LOS through the main heavy turret packs from the front is 33cm array wrapped in 12cm steel, for a 45cm LOS thickness . The heavy pack should add 10 & 2cm LOS RHA steel plus 4.5cm [9 x 5] mild steel & 28.5cm Rubber. The Te are 1.0/0.6 & 0.4 & 0.2 respectively, thus the erosion component should be 10 cm + 1.2cm+ 1.8cm + 5.7cm] x 1.18[confinement] = **22cm RHAe**.The T/d for the pack is 0.85/0.8/0.75/ 68 = 18.7/17.6/16.5/15cm + 1.3d/2.6d spaced plate effect or add 2.6/3.9/10.4/7cm

Vs APDS = 21.4cm + 15+7= 43.4cm LOS or **30.4cm @ 45°**
Vs sheathed/steel APFSDS = 23cm + 16.5+10.4= 49.9cm LOS or **34.9cm @ 45°**
Vs 3cm APFSDS = 23cm + 17.6+3.9=44.5cm LOS **or 31.1cm @ 45°**
Vs 2cm APFSDS = 23cm +18.7+2.6= 44.3cm LOS **or 31cm @ 45°**
Vs HEAT = 25cm +25 + 10/0= 65/50cm LOS **or 45/35cm @ 45° + 0.3d**



Georg Stark & Andrew Jaremkow

[3/10 th front turret profile] **MANTLE** is about 20cm @ 30° or 23cm LOS 270BHN cast armor. The cast reduction [0.95] and the weakened zone .Free edge effect is 0.88 [APFSDS] , while its 0.8 for APDS & APC . The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.96[120mmAPC] & 1.0 [90mm APC] 1.0 [APDS/APFSDS]
Vs 120mm AP = 16.8cm LOS or **14.5cm @ 30°**
Vs 90mm AP = 17.5cm LOS or **15.1cm @ 30°**
Vs APDS/APFSDS = 18cm LOS or **15.5cm @ 30°**
Vs HEAT = 23cm LOS or **20cm @ 45°**

[1/5 th front turret profile] **Upper front turret** = 39mm @ 79°= LOS thickness 205mm x 0.95 [cast] x T/d [0.75/0.85/0.88/0.92/0.94] =
Vs APC = 15.0cm LOS or **3.9cm @ 75°** ** **ricochet** ** [120mm APC = * ¾ ricochet *]
Vs APDS = 16.1cm LOS or **4.1cm @ 75°** ** ½ ricochet ** [L-52/L16 APDS (WHA) = * ¼ ricochet*]
Steel/Sheathed APFSDS = 17.0cm LOS or **4.4cm @ 75°** * **¼ steel APFSDS ricochet** *
2- 3cm APFSDS = 18.0cm LOS or **4.6cm @ 75°**
Vs HEAT = 20cm LOS or **5.2cm @ 75°** ** **old warheads may ricochet** **

Side turret 150mm @ x 30° = 17cm x 0.95[cast & t/d] . In addition the frontal armor packs extend part way around the front side of the turret. The area effected is only the front ¼ of the side turret. Since these are at the same angle from the side as the front the addition is the same too. The effectivenss is plus 18.7/17.6/16.5/15cm + spaced plate effect of 2.6/3.9/10.4/7cm

	¼ [Front side with Brow armor]	¾ [side with out Brow armor]
Vs APC =	15.5cm + 14 + 6 = 35cm LOS or **25 cm @ 45°**	15.5cm LOS or **13.4cm @ 30°**
Vs APDS =	16cm + 15 + 14 = 45cm LOS or **31 cm @ 45°**	16 cm LOS or **14cm @ 30°**
Vs Steel/SheathedAPFSDS =	16.3 +17.6+ 10.4 cm = 44cmLOS or **31cm @ 30°**	16.3cm LOS or **14cm @ 30°**
Vs 2cm APFSDS =	16.7cm + 18.7 + 3 = 38.cm LOS or **27cm @ 30°**	16.7cm LOS or **14cm @ 30°**
Vs HEAT =	17.3cm +25 + 10/0= 52/42m LOS **or 36/30cm @ 45° +0.3d**	17.3cm LOS or **15cm @ 30°**

Rear turret ~64mm Cast @ 30° = 74mm x 0.95 = ~ 7cm In the rear turret are mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor
Vs API/APDS = 7+0.8 = 7.8cm or **6.7cm @ 30°**
Vs HEAT 7 + 0.2 + 19/7 + 0.7d **or 23/12cm @ 30° + 0.7d**

[3/5 th Front Hull profile] Hull Glacis is 98mm @ 58° ~ 290- 300 BHN RHA = LOS plus a 15cm thick array mounted @ 60°with 3cm cover plate 12cm rubber with 5mm thin mild steel plates @ 65° suspended in the rubber .The LOS thickness figures are 6cm RHA [1.0 Te] + 20cm rubber [0.2 te] & 4cm Mild steel [0.4 Te] ...thats 11.6 x 1.18 [confinement] = 13.6cm + base armor = **33cm KE resistance** . The HEAT values should work out to 6cm + 20cm [0.3 te] + 4cm [0.8 te] + 19.5cm [base armor] x1.2[layering] = **42cm HEAT.**
Vs APC = 17cm LOS + 12.9cm = 29.9cm LOS or **15.0cm @ 60°**
Vs APDS & 4cm APFSDS = 18cm + 12.9cm = 30.9cm LOS or **15.4cm @ 60°**
Vs 2- 3cm APFSDS = 19+ 13.6cm = 32.6cm LOS or **16.3cm @ 60°**
Vs HEAT = 19.5+ 15.2cm x 1.2 = 41.6cm LOS or **20.8cm @ 60°**

[2/5 th Front Hull profile] Lower hull JANES reports 99cm @ 55° ~ 290- 300 BHN RHA = LOS thickness of 172mm , x t/d [0.88/0.92/0.94/0.96/0.98]….
Vs APC = 15cm LOS or **7.5cm @ 60°**

Vs APDS & 4cm APFSDS = 16cm LOS or **8cm @ 60°**
Vs 2-3cm APFSDS & HEAT = 17cm LOS or **8.5cm @ 60°**

SIDE Hull is 8cm steel base side hull armor on the basic T-54/55. The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional
Above trackguard = **12cm KE and ~ 25cm HEAT armor** .

Below trackguard = side skirt area has a ~3cm thick metal reinforced side skirt is mounted over the side track area..The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap increases the HEAT armor by the standoff which is ~ 9 Cone Diameters[cd] for a 3 inch warhead or 1'cd' =7cm reduction ; and up to a 5'cd' standoff for a 5 inch HEAT warhead ; this translates roughly into 7-8cm reduction in jet penetration for a 70s 2nd Generation warhead and ~19cm for 60s technology 1st gen. warhead. But the reinforced rubber sheet is likely to offer ~ 2cm HEAT plus the spaced plate effect. This rubber skirting is energetic and perforated plate so should offer 1.0 cm Ersosion and 1.3-0.7d x 1.4 [energetic] x 2 [sheathed] .
Vs 3cm API ~ 8+2.9+1cm = **11.9cm @ 0°**
Vs 25mm APDS ~ 8+2.8+1cm = **11.8cm @ 0°**
Vs 25mm APFSDS ~ 8+2.7+1cm = **11.7cm @ 0°**
HEAT ~ 8 + 2 + 19/7 + 1.0d **= 29/17cm @ 0° + 1.0d HEAT**

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear
½ [engine deck & tracks] **~ 2cm RHA KE & HEAT @ 90°**
¼ [top turret & front hull deck] **~ 4cm . KE & HEAT @ 90°**
1/8th [front/sides & rear turret] ~ **30cm @ 90° KE & HEAT**
1/8th [glacis] ~ **16cm KE & 21cm HEAT @ 60°**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff, with the improvement a 10cm plate was added to the front bottom armor. This is unknow but assumed to be more of the same Steel Rubber armor, while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~
front ¼ = 9cm KE and 24/11cm HEAT
front ¼ = 3cm KE and 22/7cm HEAT
Rear ½ = 2cm KE and 22/7cm HEAT
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T-55AMV with Kontakt ERA [Approximate]

Starting in the early 90s ,T-55AM started to appear with Kontakt 1 ERA and in the mid 90s with Kontakt 5 ERA. Th e ERA is mounted on the turret adding ~1500kg to the mass but the coverage is only ~ 60%, and should look as follows…..

[Kontakt and K-5 type]...

[¼ front turret profile] MANTLE [optical/MGPorts] is about 20cm @ 30° or 23cm LOS 270BHN cast armor. The cast reduction [0.95] and the weakened zone .Free edge effect is 0.88 [APFSDS] , while its 0.8 for APDS & APC . The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.96[120mmAPC] & 1.0 [90mm APC] 1.0 [APDS/APFSDS]

	½ Mantle	½ Mantle with Kontakt ERA
Vs APDS =	18cm LOS or **15.5cm @ 30°**	**18cm@ 30°**
Vs APFSDS =	18cm LOS or **15.5cm @ 30°**	**18cm@ 30°**
Vs HEAT =	23cm LOS or **20cm @ 30°**	**28/22cm@ 30° + 3d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits ,coverage is ¼ with Kontakt & ¾ exposed armor

[½ front turret profile] main sloping walls is ~17cm @ 45° or ~ 25 cm LOS , 270BHN cast armor. The cast reduction [0.95] and the free edge effect is 0.98 [APFSDS] , while its 0.9 for APDS. For APC its 0.95. The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.96[120mmAPC] & 1.0 [90mm APC] 1.0 [APDS/APFSDS] It should look like this. …... …..

	¼ front turret	¾ front turret with Kontakt ERA
Vs APDS =	21.4cm LOS or **15cm @ 45°**	**17cm@ 45°**
Vs APFSDS =	23cm LOS or **16.3cm @ 45°**	**18cm@ 45°**
Vs HEAT =	25cm LOS or **17.5cm @ 45°**	**27/20cm@ 45° + 4d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ½ with Kontakt & ½ exposed armor

[¼ front turret profile] **Upper front turret** = 39mm @ 79°= LOS 205mm thickness
Vs APDS **=** 16.1cm LOS or **4.1cm @ 75°** ** ½ ricochet ** [L-52/L16 APDS (WHA) = * ¼ ricochet*]
Steel/Sheathed APFSDS = 17.0cm LOS or **4.4cm @ 75°** * **¼ steel APFSDS ricochet** *
2-3cm APFSDS **=** 18.0cm LOS or **4.6cm @ 75°**
Vs HEAT = 20cm LOS or **5.2cm @ 75°** ** **old warheads may ricochet** **

Side turret 150mm @ x 30° = 17cm x 0.95[cast & t/d]

	¾ side turret	¼ frontside turret with Kontakt ERA
Vs APDS = 16.1cm LOS or	**14cm @ 30°**	**16cm@ 30°**
Vs APFSDS = 16.1cm LOS or	**14cm @ 30°**	**16cm@ 30°**
Vs HEAT = 17.3cm LOS or	**15cm @ 30 °**	**23/17cm@ 30° + 3d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is all exposed armor and no Kontakt ERA

Rear turret ~64mm Cast @ 30° = 74mm x 0.95 = ~ 7cm In the side and rear turret are sometimes mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor
Vs API/APDS = 7+0.8 =7.8cm or **6.7cm @ 30°**
Vs HEAT 7 + 0.2 + 19/7 + 0.7d **or 23/12cm @ 30° + 0.7d**

[½ Front Hull profile] Hull Glacis is 98mm @ 58° ~ 290-300 BHN RHA = LOS thickness 185mm x 1.05 [hardness] = 194mm . The T/d is of 0.88/0.92/0.94/0.96/0.98.... Kontakt adds 2cm against 2-3cm APFSDS and 3cm against sheathed APFSDS

	¼ front glacis	¾ front glacis with Kontakt ERA
Vs APDS = 18cm LOS or	**9cm @ 60°**	**10.5cm@ 60°**
Vs 4cm APFSDS = 18cm LOS or	**9cm @ 60°**	**10.5cm@ 60°**
Vs 2-3cm APFSDS = 19cm LOS or	**9.5cm @ 60°**	**10.5cm@ 60°**
Vs HEAT = 19cm LOS or	**9.5cm @ 60°**	**14/10cm@ 60° + 4d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ½ Kontakt & ½ exposed armor

[½ Front Hull profile] Lower hull JANES reports 99cm @ 55° ~ 290-300 BHN RHA = LOS thickness of 172mm , x t/d [0.88/0.92/0.94/0.96/0.98]....

	¾ lower hull	¼ lower hull with Kontakt ERA
Vs APDS = 16cm LOS or	**8cm @ 60°**	**9.5cm@ 60°**
Vs 4cm APFSDS = 16cm LOS or	**8cm @ 60°**	**9.5cm@ 60°**
Vs 2-3cm APFSDS = 17cm LOS or	**8.5cm @ 60°**	**9.5cm@ 60°**
Vs HEAT = 17cm LOS or	**8.5cm @ 60°**	**13/10cm@ 60° + 4d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is all exposed armor and no Kontakt ERA.

SIDE Hull is 8cm steel base side hull armor on the basic T-54/55. The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional Above trackguard = **12cm KE and ~ 25cm HEAT armor** plus a spaced plate. Below trackguard = side skirt area has a ~3cm thick metal reinforced side skirt is mounted over the side track area..The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap increases the HEAT armor by the standoff which is ~ 9 Cone Diameters[cd] for a 3 inch warhead or 1'cd' =7cm reduction ; and up to a 5'cd' standoff for a 5 inch HEAT warhead ; this translates roughly into 7-8cm reduction in jet penetration for a 70s 2nd Generation warhead and ~19cm for 60s technology 1st gen. warhead. But the reinforced rubber sheet is likely to offer ~ 2cm HEAT plus the spaced plate effect. This rubber skirting is energetic and perforated plate so should offer 1.0 cm Ersosion and 1.3-0.7d x 1.4 [energetic] x 2 [sheathed] .

	½ rear side hull	½ front side hull with Kontakt ERA
Vs 3cm API ~ 8+2.9+1cm =	**11.9cm @ 0°**	**13.5cm @ 0°**
Vs 25mm APDS ~ 8+2.8+1cm =	**11.8cm @ 0°**	**13.4cm @ 0°**
Vs 25mm APFSDS ~ 8+2.7+1cm =	**11.7cm @ 0°**	**13.3cm @ 0°**
HEAT ~ 8 + 2 + 19/7 + 1.0d	**= 29/17cm @ 0° + 1.0d HEAT**	**29/17cm @ 0° + 2.0d HEAT**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ¼ Kontakt & ¾ exposed armor

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear

½ [engine deck & tracks] **~ 2cm RHA KE & HEAT @ 90°**
¼ [top turret & front hull deck] **~ 4cm . KE & HEAT @ 90°**
1/8 th [front/sides & rear turret] ~ **30cm @ 90° KE & HEAT**
1/8 th [glacis] ~ **10cm @ 60° KE & HEAT**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT
===

T-55AMV with heavy Kontakt V ERA [Approximate]

Starting in the mid 90s,T-55AM started to appear with Kontakt 5 ERA. Th e ERA is mounted on the turret adding ~1500kg to the mass but the coverage is only ~ 60%, and should look as follows…..

[¼ front turret profile] MANTLE is about 20cm @ 30° or 23cm LOS 270BHN cast armor plus heavy Kontakt mounted at 60°. The cast reduction [0.95] and the weakened zone .Free edge effect is 0.88 [APFSDS] , while its 0.8 for APDS & APC . The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.96[120mmAPC] & 1.0 [90mm APC] 1.0 [APDS/APFSDS]

	½ Mantle	½ optical/MGPorts with Kontakt V ERA
Vs steel/ sheathed APFSDS = 18cm LOS or	**15.5cm @ 30°**	**36cm@ 30°**
Vs 2-3cm APFSDS = 18cm LOS or	**15.5cm @ 30°**	**31cm@ 30°**
Vs 2cm HSAPFSDS = 19cm LOS or	**9.5cm @ 60°**	**27cm@ 30°**
Vs HEAT **=** 23cm LOS or	**20cm @ 30°**	**37/30cm@ 30° + 3d**

Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 4 of above values, except "Steel/ Sheathed APFSDS", in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 2d.

[½ front turret profile] main sloping walls is ~17cm @ 45° or 12cm @ 60°, with average ~ 25 cm LOS , 270BHN cast armor. The cast reduction [0.95] and the free edge effect is 0.98 [APFSDS] , while its 0.9 for APDS. For APC its 0.95. The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.96[120mmAPC] & 1.0 [90mm APC] 1.0 [APDS/APFSDS] It should look like this.

.	¼ front turret	¾ front turret with Kontakt V ERA
Vs steel/ sheathed APFSDS 23cm LOS or	**15cm @ 45°**	**32cm@ 45°**
Vs 2-3cm APFSDS = 23cm LOS or	**16.3cm @ 45°**	**27cm@ 45°**
Vs 2cm HSAPFSDS = 19cm LOS or	**9.5cm @ 60°**	**22cm@ 45°**
Vs HEAT = 25cm LOS or	**17.5cm @ 45°**	**34/27cm@ 45° + 4d**

Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 4 of above values, except "Steel/ Sheathed APFSDS", in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 2d.

[¼ front turret profile] Upper front turret = 39mm @ 79° plus 5cm Steltexolite bolted to the roof armor. This material resists a lot like aluminum or 0.4Te KE and 0.6 Te HEAT [increased by 20% due to layering].
Vs Steel/Sheathed APFSDS = 25.0cm LOS or **6.6cm @ 75° * ¼ ricochet***
Vs 2-3cm APFSDS = 26.0cm LOS or **6.7cm @ 75°**
Vs 2cm APFSDS = 27.1cm LOS or **6.9cm @ 75°**
Vs HEAT = 38cm LOS or **9.8cm @ 75° ** old warheads may ricochet** **

Side turret 150mm cast@ x 30° = 17cm x 0.95[cast & t/d] plus K-5 ERA in the front ¼ of the side profile.

	¾ side turret	¼ frontside turret with Kontakt V ERA
Vs APDS = 16.1cm LOS or	**14cm @ 30°**	**16cm@ 30°**
Vs APFSDS = 16.1cm LOS or	**14cm @ 30°**	**16cm@ 30°**
Vs HEAT = 17.3cm LOS or	**15cm @ 30 °**	**29/23cm@ 30° + 3d**

Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 4 of above values, except "Steel/ Sheathed APFSDS", in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 2d.

Rear turret ~64mm Cast @ 30° = 74mm x 0.95 = ~ 7cm In the side and rear turret are sometimes mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor
Vs API/APDS = 7+0.8 =7.8cm or **6.7cm @ 30°**
Vs HEAT 7 + 0.2 + 19/7 + 0.7d **or 23/12cm @ 30° + 0.7d**

[½ Front Hull profile] Hull Glacis is 98mm @ 58° ~ 290-300 BHN RHA = LOS thickness 185mm x 1.05 [hardness] = 194mm . The T/d is of 0.88/0.92/0.94/0.96/0.98.... Kontakt adds 18-20cm against 2-3cm APFSDS and 23-25cm against sheathed APFSDS

	¼ front glacis	¾ front glacis with Kontakt V ERA
Vs Steel/Sheathed APFSDS = 18cm LOS or	**9cm @ 60°**	**20cm@ 60°**
Vs 2-3cm APFSDS = 19cm LOS or	**9.5cm @ 60°**	**18cm@ 60°**
Vs 2cm HSAPFSDS = 19cm LOS or	**9.5cm @ 60°**	**16cm@ 60°**
Vs HEAT = 19cm LOS or	**9.5cm @ 60°**	**18/14cm@ 60° + 4d**

Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 4 of above values, except "Steel/ Sheathed APFSDS", in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 2d.

[½ Front Hull profile] Lower hull JANES reports 99cm @ 55° ~ 290-300 BHN RHA = LOS thickness of 172mm , x t/d [0.88/0.92/0.94/0.96/0.98]...steel reinforced rubber 3cm thick sheet is suspended from the nose of the tank to act as a improvised spaced plate.

	¼ lower hull	¾ lower hull with steel/rubber sheet
Vs Steel Sheathed APFSDS = 16cm LOS or	**8cm @ 60°**	**12cm@ 60°**
Vs 2-3cm APFSDS = 17cm LOS or	**8.5cm @ 60°**	**10.5cm@ 60°**
Vs HEAT = 17cm LOS or	**8.5cm @ 60°**	**14/10cm@ 60° + 1.0d**

SIDE Hull is the basic T-55 side hull armor with the steel rubber side skirt reinforced with Hvy Kontakt 5 ERA. Below trackguard = side skirt area has a ~3cm thick metal reinforced side skirt is mounted over the side track area..The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap .The K-5 thickness looks like 3% of the array length & 14% of its height....this should make it , ~8cm thick divided into 4 sections. These look like a 2.5cm outer plate [steel?] , 1.5cm inner plate [Kontakt?] plus 2.5cm airgap and 1.5cm rear plate[Kontakt?]. The spaced plate effect is 3d /6d . That's 3.6/3.2/2.8 + 6/9cm or +18/24cm. 4/9/12/21/27cm.

	Rear ½ Side Hull	Front ½ Side Hull with K-5 ERA
Vs 3cm API	~ 8+2.9+1cm = **11.9cm @ 0°**	**26cm @ 0°**
Vs 2cm APDS /APFSDS	~ 8+2.8+1cm = **11.8cm @ 0°**	**23cm @ 0°**
Vs 2cm HS APFSDS	~ 8+2.7+1cm = **11.7cm @ 0°**	**17cm @ 0°**
HEAT ~	8 + 2 + 19/7 + 1.0d **= 29/17cm @ 0° + 1.0d HEAT**	**32/20cm @ 0° + 3.0d HEAT**

Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 2 of above values off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 2d.

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear
½ [engine deck & tracks] **~ 2cm RHA KE & HEAT @ 90°**
¼ [top turret & front hull deck] **~ 7cm . KE & 10cm HEAT @ 90°**
1/8 th [front/sides & rear turret] ~ **30cm @ 90° KE & HEAT**
1/8 th [glacis] ~ **18cm KE & 14cm+ 4d HEAT @ 60°**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT

==

T-59/69/79 with ERA [Approximate]

Norinco ERA is some times mounted on the turret adding can be either Norinco type 2 [28mm] or 3 [33mm], which should add either **10-15cm [2-4cm APFSDS] or 20-27cm [3-4cm Sheathed] & 40cm HEAT ...,** but the coverage is only ~ 60%.should look as follows....24-22-18.

	With Nor inco type B ERA	With Nor K-5 type C ERA
/ 26cm LOS cast =	 **26-28cm KE & 46 - 66cm HEAT**	24 **31-45 cm KE & 52 - 104 cm HEAT**
/ 25cm LOS cast =	 **24-26cm KE & 45 - 65 cm HEAT**	 **29-41cm KE & 46-88 cm HEAT**
[~23cm LOS cast =	 **20 cm KE & 43 - 63cm HEAT**	 **19cm KE & 23cm HEAT**
\25cm LOS cast =	 **24-26cm KE & 45 - 65 cm HEAT**	 **29-41cm KE & 46-88 cm HEAT**
\ 26cm LOS cast =	 **26-28cm KE & 46 - 66cm HEAT**	 **31-45 cm KE & 52 - 104 cm HEAT**

Type –"A" ERA Hull Glacis is = **195mm KE & HEAT** plus type "A", ERA [add **3-5cm KE & 40cm HEAT]** which would boost this to **23-24cm KE & 59cm HEAT** but the coverage is ¾ so ¼ of hits should still result in ~ 19cm KE & HEAT protection.In addition, multiple hits will reduce ERA coverage so after 15 hits it should be considered ½ Type 'A' - ½ base armor .

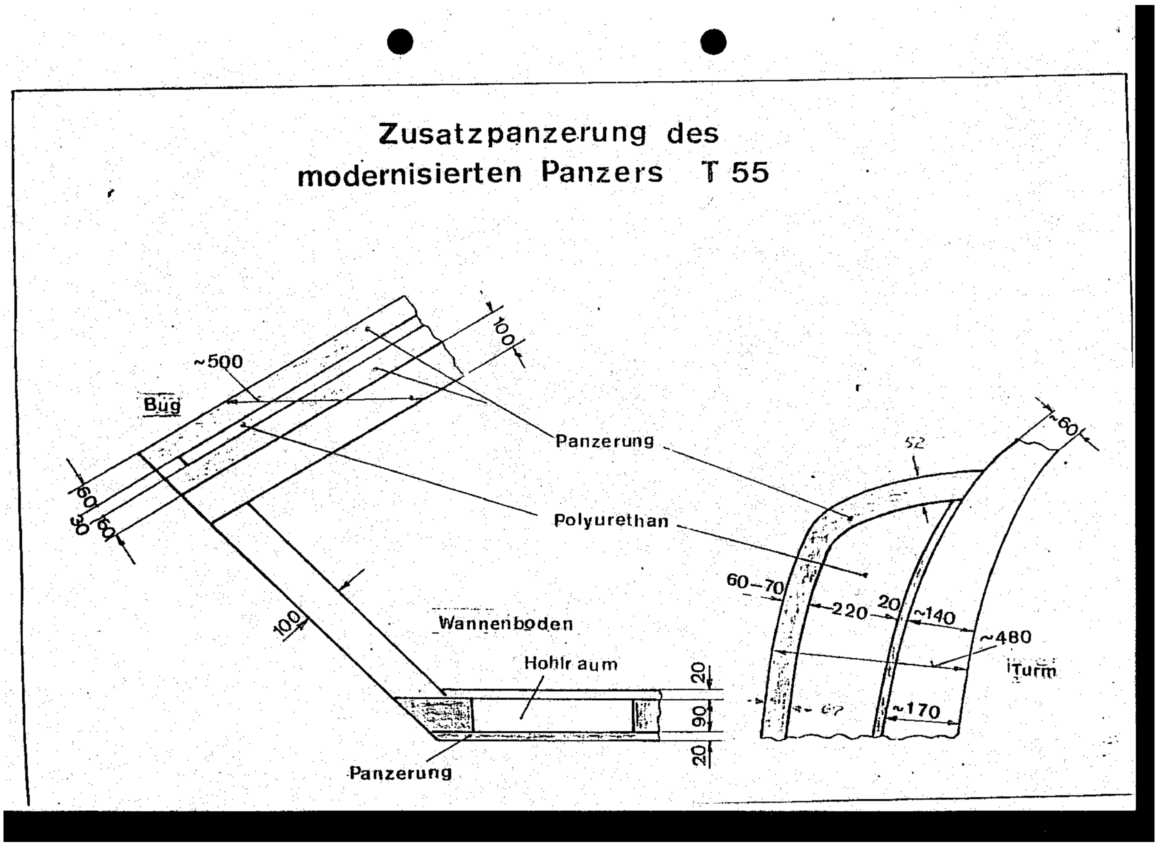
Type- "C" type ERA Hull Glacis which should add 40cm HEAT & 11cm APFSDS or [27cm Sheathed] . Like Kontakt the coverage is ~ ¾ bringing the total to **30cm APFSDS, 46cm Sheathed & ~ 60cm HEAT.** In addition, multiple hits will reduce ERA effectiveness to spaced armor so after 15 hits it should be considered reduced to **26cm APFSDS, 39cm Sheathed & ~ 40cm HEAT** .

The side hull is the same as T-59/T69/79 model with a ~3cm thick metal reinforced side skirt is mounted over the side track area. That's 8cm thick rolled steel.The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap increases the HEAT armor by the standoff which is ~ 9 Cone Diameters[cd] for a 3 inch warhead or 1'cd' =7cm reduction ; and up to a 5'cd' standoff for a 5 inch HEAT warhead ; this translates roughly into 7-8cm reduction in jet penetration for a 70s 2nd Generation warhead and ~19cm for 60s technology 1st gen. warhead. This rubber skirting is energetic but shows no evidence of 'wire mesh/perforated plate design'. Is probably really thin strands of wire in alternating layers like in tires. Its hard to gauge this but the approximate density is similar to aluminum/Fibre Glass,so this is used. FibreGlas should offer 0.4 /0.6 Te plus the spaced plate effect prorated to the effective te. So that's 0.4 x 3cm = 1.2cm + [Sqrt (1.2/3) x 1.3 d x 1.6 r x 3cm]=3.95cm + base armor 6cm .HEAT is 3cm x 0.6 x 6 + base armor [6cm] & standoff [7/18cm] = 24 /35
. In addition the front ½ of the side hull mounts Kontakt ERA and adds **16cm** as well as **~ 3-5cm KE [2cm-4cm APFSDS] .**

	Rear ½ Side Hull	Front ½ Side Hull with Kontakt ERA
That's ~ 8+5cm =	**13cm Vs 3cm API**	**15cm Vs 3cm API**
That's ~ 8+6cm =	**13cm Vs 1.5cm APDS [25mm APDS]**	**16cm Vs 1.5cm APDS [25mm APDS]**
That's ~ 8+4cm =	**11cm Vs 1cm APFSDS [25mm APFSDS]**	**13cm Vs 1cm APFSDS [25mm APFSDS]**
HEAT resistance =	**26cm Pj HEAT**	**42cm Pj HEAT**

The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional **12cm KE and ~ 25cm HEAT armor.**.

Unknow T-55 Armor upgrade [German?]



½ **Side turret** [forward] armor ~ **36cm RHAe HEAT** resistance KE resistance should be 37cm x [0.9t/d & Lc]= **33cm RHAe KE** resistance.
½ **Side turret** [Upper & rear] should be ~ **17cm RHAe HEAT & 13cm KE** resistance….adding a 5cm thick Steltexolite layer to the upper turret or adding 40cm thick Grill racks full of baggage and gear to the rear turret half , should boost this by either 21/12 or that's about **~ [upper] 28cm RHAe HEAT & 17cm KE to [grill] 31/22cm HEAT & 12cm KE**, In addition the compounded slope on the upper side turret is ~ 70° so early RPG-7 [PM-7/7M] will not fuse , while ½ of PG-7/7M hits on the grill armor should fail to due to fusing .

½ **Front turret** should be **~60cm HEAT** and **~56cm RHAe KE.**
½ **Front turret** [Upper & Mantle] should be **~20- 22cm RHAe HEAT and 17- 18cm RHAe KE.** adding a 5cm thick Steltexolite layer should boost the resistance by 1.5/3.3 to 5 /12cm ….that's about **32- 38cm RHAe HEAT & 23- 24cm KE** .

Glacis armor ; should be ~ **56cm LOS RHAe HEAT** and **~48cm KE RHAe** resistance.
Bow Armor ; should be ~ **20cm RHAe HEAT and KE** resistance. By adding a 2cm thick dozer blade , this should add 3.6/4cm [MS] + spaced plate effect of 7/0cm + 0.7d HEAT & 2.5- 3cm KE for a total of **~ 33/24cm + 0.7d RHAe HEAT & 28- 30cm RHAe KE.**

Side hull armor is most likely the basic 8cm hull plate plus 2- 3cm steel rubber skirting @ 60cm standoff. That should be [8+ 1cm+ 2- 3cm spaced plate effect] **11- 13cm KE RHAe** resistance and [8+2+20/7+ 1.5d] **30/17cm +0.9d RHAe HEAT** resistance.
Hull floor armor[forward] :should be ~ 4cm + 18cm standoff & 0.7d ~ **22cm + 0.7d RHAe HEAT** and **5cm KE RHAe** resistance.

Frontal arc resistance ; should be RPG-7[PG-7V] or 3 inch HEAT warhead and 100- 105mm APDS or any autocannon KE fire upto 60mm. **About ½ of the frontal armor** should be able to resist 1st Generation 105 APFSDS , while remaining is protected from 2nd 105mm APFSDS @ 1km range and 3rd generation 105mm APFSDS @ combat range [~ 2km range Vs 3rd gen WHA APFSDS or 3km Vs 3rd Gen DU APFSDS] . This **heavy armored ½ of the frontal** armor should also be able to resist 105mm & 120mm HEAT rounds and RPG-7L or 1st generation ATGM like TOW /HOT or AT-5/AT-8 , but not the improved versions of these warheads. **SIDE ARMOR** should resist 25- 30mm APFSDS ammo and RPG-7& 7M, while a PG-7V can be defeated @ 45- 50° side angle.

Rest as T-55 above.

"Khafji turret box actual thicknesses: tri-plate aluminum layers are 14.7mm (on the outer tri-plate) and 10.3mm on the other five layers; the rubber layers are all 4.0mm; and the steel layers are all 4.7mm; finally, the sixth or inner-most array is actually a bi-plate (two layers=aluminum and rubber only). The box itself is 6.9mm steel.

The Khafji armor turret boxes have the following dimensions: box face=405mm (top to bottom); box top=495mm (front to back); box backside=565mm (top to bottom); box underside=375mm (front to back). Each box contains six "tri-plate" arrays (with some variations) consisting of aluminum/rubber/steel layers. In some cases, the rubber layer may be the front or outer layer. Perhaps the most interesting thing about Khafji armor is it's strong similarity to the tri-plate arrays protecting the turret front of the T-72B series MBTs. "

[Jim Warford]

"Ok , if we assume 495mm thick with a series of arrays that are parrallel and 18mm + 40mm thats about > 8 layers ...what are the outer and inner steel plate thickness?

There are only 6 tri plates per box, so if we assume that each triplate is 18mm thick that would result in an airgap of 55mm between each plate at the top and 38mm at the bottom.

So they aren't quite parallel.

The armour box was about as thick as my thumb, so guesstimate about 25mm thick. This is of course then inclined back at about 45 degrees. I estimate that each plate is about 6mm thick, and the space between each array is about 30-40mm." [Dan Robertson]

HEAVY Soviet post war tanks

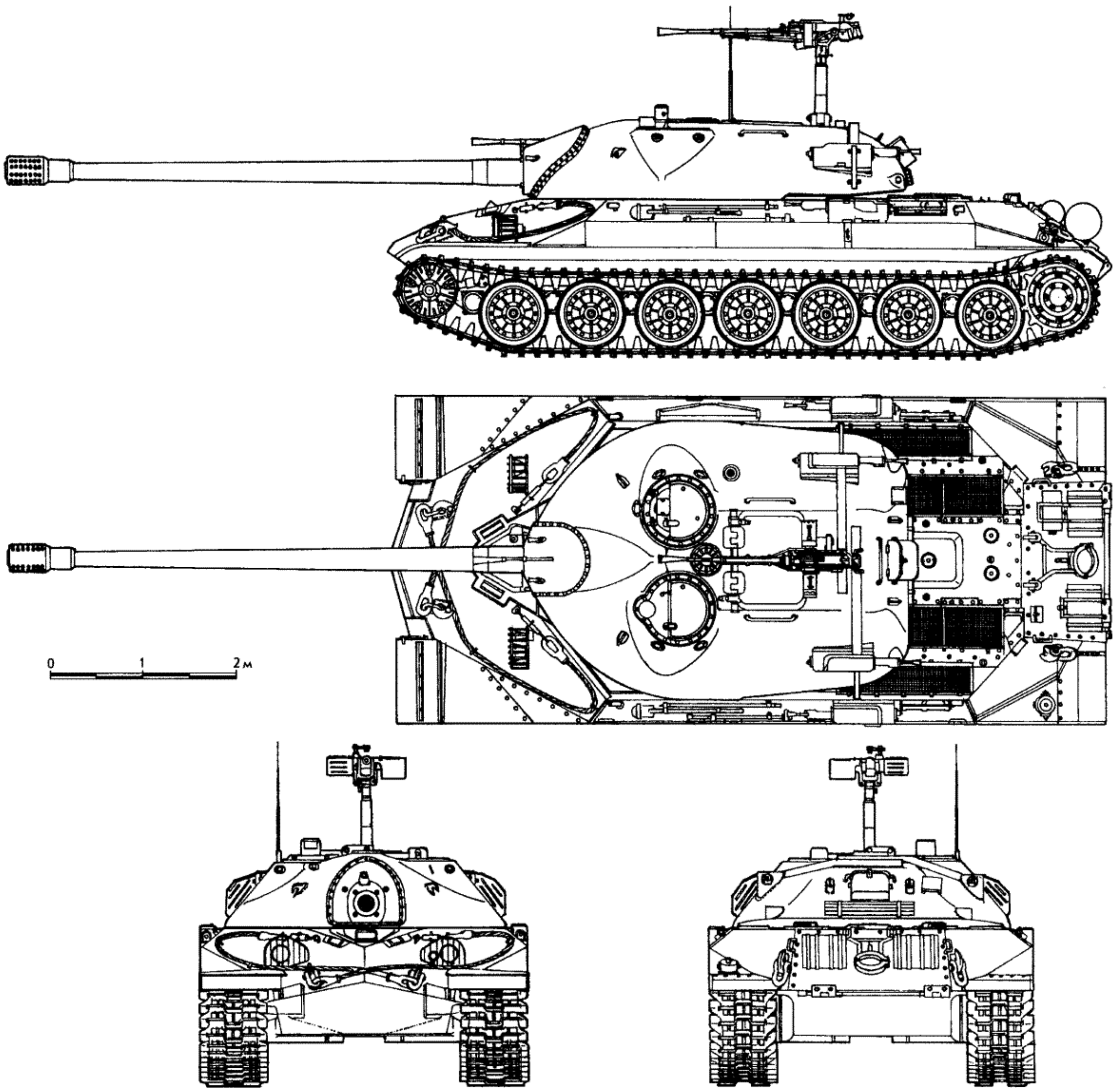
IS-7 Object 260 with S70 130mm Naval Gun. My rough translation is:

Hull
Front Max Thickness (mm)/angle (°) 210/60
Side Max Thickness (mm)/angle (°) 100 - 150/0
Rear Max Thickness (mm)/angle (°) 60 - 100/55
Bottom Max Thickness (mm) 20
Top Max Thickness (mm) 30 ?

Turret
Front Max Thickness (mm)/angle (°) 210/45
Side Max Thickness (mm)/angle (°) ~150/40
Rear Max Thickness (mm)/angle (°) ~100/15 - 65
Top Max Thickness (mm) 30 ?

1)Bronekollectsija 3/96 (Armor collection 3/96), "Sovetskije tjazelyje poslevojennyje tanki" ("Soviet Heavy Postwar Tanks") by M.B. Baryatinsky, M.W. Kolomiyets and A.N. Koshchavtsev, Moscow 1996
2)"Genij sovetskoj artillerii"("Genius of Soviet Artillery") by A.B. Shyrokorad, Moscow 2002,

ISBN 5-17-013066-X



T-10

[Karl Brandel TANK NET 07-04-2000 19:10] *" referring to "Rukovodstvo po materialnoy chasti i eksplulatatzii tankaT-10", Voenizdat Ministerstva Oborony SSSR, Moskva, 1956,declassified, which is the Soviet equivalent to the U.S. TM's, there issome additional and perhaps more accurate data on the T-10 armour thickness from Ris 33: The whole turret without weapons is weighing 6,800 Kg (page 8).*

Gun mantle*: max. 237mm LOS going down on the right side to 28mm and on the left to 47mm (both LOS).*
Turret front: *max. 315mm LOS (+ the above mentioned 28mm respectively 47mm in a very narrow area where it covers the openings for the coax and the gunners sight) going down to 220mm LOS measured 500mm on either side of the main gun axis.*
Turret rear: *max. 95mm which is about 126mm LOS.*
Turret top: *max. 40mm which is about 470mm LOS.*[50mm on the T-10M – PL]

Upper hull side: 80mm @45°.stowage boxes on each side."

JANES reports the rear hull armor 60mm
Top hull armor 25mm
Hull floor 20mm rear and 35mm front.
Zaloga reports the side hull armor at 90mm

Several Russian Books including .Steve Zalogas, report the T-10 glacis armor at 120mm @60° and the lower hull 80mm @60° with the lower side hull 50-60mm thick . Karl **Brandel** notes the turret armor is cast and ranges from 315 to 220mm -50mm thick , with the mantle area reaches 343 to 362mm LOS thickness. The compounded LOS along the main turret walls is 250mm while the upper turret is 50mm and the rear is 100mm @40°.One of the differences between T-10 and T-10M is the top turret armor goes from 40-50mm . The biggest difference between the T-10 & T-10M is the adoption of the improved M-62 122mm gun [Compared to the D-25 on the earlier version]...which boosts the MV by 200m/s.

Turret front ; ranges from 34-36cm LOS near the gun to 25cm LOS thickness at the turret corners. But The armor closest to the gun is the 'weakened zone'and offer less armor than the effective thickness suggests.The 50cm armor closest to gun is 0.6 x [lateral confinment] or 300 mm narrowing to 34-36cm x 0.75 [lateral confinement] while the main curved front walls are 0.95 x 25cm or 24cm. The HEAT armor should be the LOS thickness or 35cm along the mantle and 25cm along the main walls. The cast armor could be hard steel [> 400BHN], which should lead to increased resistance to subcaliber threats but less resistance to full caliber threats against APC ammo it should lead to 0.9 reduction , while the against APDS & APFSDS the resistance should go up 1.1 times.

KE = 24cm ..... 21cm [APC] , 26cm [APDS & APFSDS].
HEAT = 25 35cm

Side & Rear Turret . The armor is set at angles around 30-40° and the LOS thickness ranges from 19-22cm LOS thickness near front thinning to ~ 13cm LOS around back, cast reduces this further [0.95] . The effective KE around side is ~ 16cmLOS x 0.95[cast] = 0.9/0.96/0.99 while around back that's 13cm x 0.95 [cast] x 0.86/0.92/0.94 [t/d].
Front side turret = **21-18cm [KE] & 19-22cm HEAT** .
Side turret = **13 cm [APC] , 14cm [APDS] , 15cm [APFSDS] & 16cm HEAT**.
Rear Turret = **10cm [APC] 11cm [APDS/APFSDS] & 13cm HEAT** .

Hull Glacis is 120mm rolled plate @60° x 20°, the LOS thickness is 250mm, but the T/d [APC/APDS/APFSDS] is 0.9/0.96/0.99 = **21cm [APC] ,22cm [APDS] , 24cm [APFSDS]** and **25cm [HEAT]** .

Lower Front Hull is 80mm rolled plate @58° , which equals a LOS thickness of 15cm x 0.86/0.92/0.94 [t/d] = **13cm [APC] 14cm [APDS/APFSDS] & 15cm HEAT.**

Side sponsons is 80mm thick @45° which equals a LOS thickness of 113mm LOS x 0.86/0.92/0.94 [t/d] = **10cm [APC/APDS] 11cm [APFSDS & HEAT] .** .Since storage boxes are mounted along the sponson this probably raisis the HEAT value to **26cm HEAT**.

The side is 90mm thick x 0.86/0.92/0.94 [t/d] = **8cm [KE] & 9cm [HEAT] .**

The rear hull; is 60mm @30°, for a LOS thickness of 6.9cmn x 0.75/0.9/0.96 [t/d] = **5cm [APC], 6cm [APDS / APFSDS] & 7cm [HEAT] .**

Top tank armor is in three sections , the rear 1/3 [turret & engine deck] looks like just **~ 4cm RHA** , while the top turret & front hull deck seems to be **~ 5cm** thick. The front 1/3 turret and all the glacis is quite thick and may offer ~ **17cm KE & 20cm HEAT**

Bottom tank ; armor seems quite thin with plate 35-20mm thick in places. Inaddition there should be ground clearance which is standoff of 55cm leading to ~ 5-10cm Vs PJ HEAT warheads or a 15-20cm increase in NPJ HEAT.The resistance is probably **~ 4cm KE front and 2cm KE rear** , while **20-22cm HEAT** .

T-62 [Accurate]

Developed in the late 50s the T-62 was supposed to be the answer to the British Centurion and the expected M-48 with 105 , which became the M-60 tank..Its assumed the armor quality is the same as the T-55 or 270-286 BHN cast turret with 290-300 BHN rolled plate hull and the thinner sections [top turret and rear hull] utilizing the 330-370 BHN plate.JANES A&A 95/96 puts the armor thickness at .....

Glacis = 102 mm @60° = LOS thickness of 204mm **21cm KE & HEAT**
Lower hull = 102mm @54°= LOS thickness of 173mm **18cm KE & HEAT**
Hull sides = 79mm ...around the wheels 15mm + ? = **8cm KE & HEAT [13cm Ke & 38m HEAT with side skirts]**

Hull rear = 46mm @0°= **5cm KE & HEAT**
Hull roof = 31mm= **2-3cm KE & HEAT & ~ 12cm KE & HEAT over glacis and front turret[1/3 top profile]**
Hull floor = 20mm= **2cm KE & 22-32cm HEAT**
Turret front **[¾ front turret profile]** = 242mm @ 10 x 20° = LOS 265mm = **24-22cm [APFSDS & APDS] & 26cm HEAT**
Turret roof **[¼ front turret profile]** = 40mm @ 78°= LOS thickness of 192mm= **17cm KE & 19cm HEAT**
Turret sides = 153mm @ 0 x 30°= LOS thickness of 177mm = **17cm KE & 18cm HEAT**.
Turret Rear = 97mm @ 30° x 30°= LOS thickness of 125mm = **12cm KE & 13cm HEAT**.

[¼ front turret profile] MANTLE is about 24cm @ 20° or 25cm LOS 270BHN cast armor. The cast reduction [0.95] and the weakened zone .Free edge effect is 0.88 [APFSDS] , while its 0.8 for APDS & APC . The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.96[120mmAPC] & 1.0 [90mm APC] 1.0 [APDS/APFSDS]
Vs 120mm AP = **18.2cm LOS or 15.8cm @ 30°**
Vs 90mm AP = **19cm LOS or 16.5cm @ 30°**
Vs APDS/APFSDS = **19.5cm LOS or 16.9cm @ 30°**
Vs HEAT = **25cm LOS or 21.6cm @ 30°**

[½ front turret profile] main sloping walls is ~18cm @ 45° or ~ 26 cm LOS , 270BHN cast armor. The cast reduction [0.95] and the free edge effect is 0.98 [APFSDS] , while its 0.9 for APDS. For APC its 0.95. The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.96[120mmAPC] & 1.0 [90mm APC] 1.0 [APDS/APFSDS] It should look like this. …... …..
Vs 120mm AP = **22.5cm LOS or 15.7cm @ 45°**
Vs 90mm AP = **23.4cm LOS or 16.4cm @ 45°**
Vs APDS = **22.2cm LOS or 15.6cm @ 45°**
Vs APFSDS = **23.9cm LOS or 16.7cm @ 45°**
Vs HEAT = **26cm LOS or 18.2cm @ 30°**

[¼ front turret profile] Upper front turret = 40mm @ 78°= LOS thickness of 192mm cast x 0.95 [cast] x T/d [0.75/0.85/0.88/0.92/0.94] =
Vs APC = 14.0cm LOS or **3.6cm @ 75° ** ricochet ****
Vs APDS = 15cm LOS or **3.9cm @ 75° ** ¾ ricochet **** [WHA APDS= ½ ricochet @ 0-2km & ¾ ricochet @ > 2km]
Steel/Sheathed APFSDS = 15.9cm LOS or **4.1cm @ 75° * ¼ ricochet ***
2-3cm APFSDS = 16.9cm LOS or **4.4cm @ 75°**
Vs HEAT = 19cm LOS or **4.9cm @ 75° ** old warheads may ricochet ****

Side turret 150mm @ x 30° = 17cm x 0.95[cast & t/d]
Vs APC = 15.5cm LOS or **13.4cm @ 30°**
Vs APDS& APFSDS = 16.1cm LOS or **14cm @ 30°**
Vs HEAT = 17.3cm LOS or **15cm @ 30°**

Rear turret 97mm @ 30° x 30°= LOS thickness of 125mm Cast x 0.95 = 12cm KE & 13cm HEAT.
Vs API/APDS = 12 = 12 cm or **10cm @ 30°**
Vs HEAT 13 cm **or 11cm @ 30°**

[½ Front Hull profile] Hull Glacis is 102mm @ 60° ~ 290-300 BHN RHA = LOS thickness 204mm. The T/d is of 0.88/0.92/0.94/0.96/0.98….
Vs APC = 18.7cm LOS or **9.3cm @ 60°**
Vs APDS & 4cm APFSDS = 19.8cm LOS or **9.9cm @ 60°**
Vs 2-3cm APFSDS & HEAT = 20.4cm LOS or **10.2cm @ 60°**

[½ Front Hull profile] Lower hull JANES reports 102cm @ 54° ~ 290-300 BHN RHA = LOS thickness of 173mm , x t/d [0.88/0.92/0.94/0.96/0.98]….
Vs APC = 15cm LOS or **7.5cm @ 60°**
Vs APDS & 4cm APFSDS = 16cm LOS or **8cm @ 60°**
Vs 2-3cm APFSDS & HEAT = 17cm LOS or **8.5cm @ 60°**

SIDE Hull is 8cm steel base side hull armor is the same as on the basic T-54/55. The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional
Above trackguard = **12cm KE and ~ 25cm HEAT armor** .
Below trackguard =
8cm vs API/20-30mm APDS/APFSDS & HEAT
7.5cm vs large APDS
6.7cm large APC/HVAP

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear
½ [engine deck & tracks] **~ 2cm RHA KE & HEAT @ 90°**
¼ [top turret & front hull deck] **~ 4cm . KE & HEAT @ 90°**
1/8 th [front/sides & rear turret] ~ **30cm @ 90° KE & HEAT**
1/8 th [glacis] ~ **10cm @ 60° KE & HEAT**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT

All round resistance to 12.7mm API and side resistance is 20-30mm API/APDS and HEAT tipped rifle Grenades , while 25-30mm APFSDS should get ½ penetrations @ short range.The Kontakt ERA covers about 60% of the frontal arc profile. If this ERA is hit, the resistance in the frontal arc is about 23cm RHA within a ± 30° frontal arc , which should resist 40mm APFSDS. Against shaped charges that would be 23cm + 3d within a ± 30° frontal arc, that would be enough to stop SAGGERC & original versions of the Spigot ; Konkurs ; TOW & Milan ATGM plus RPG-7N/16/22 & Carl Gustav.
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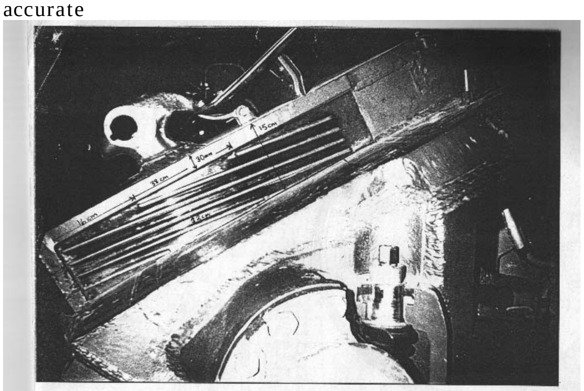
T-62M with BROW ARMOR [Approximate]

The Russians added 'Brow armor' in the early 80s after the Germans up armored their LEO-1s fleet in the mid 70s. The basics of the BDD as we know are the applique adds 2190kg to the mass of the tank and Zaloga reports that the T-62 goes from 200mm to 330mm KE , while the HEAT values go from 200 to 400-450mm ....NiI Stali company [makers of the armor] report that the T-55 turret with applique goes from 210mm to 380mm KE & 450mm , while the glacis applique goes from 200mm to 410mm KE & 380mm HEAT. My assumption is that the NiI Stali information is more accurate



Georg Stark

. This armor was composed of thin mild steel plates suspended in rubber encased in RHA . The KE of an attacking warhead set the rubber in motion moving the plates there by eroding the penetrator. Measurements taken of this reveal the turret appliqué is 21cm thick while the glacis is 15cm thick . The T-55 BDD glacis thickness is 15cm with 3cm RHA casing and alternating layers with 4 x 5mm mild steel sandwiched in between 10cm rubber .

[½ front turret profile] main sloping walls is ~ 26 cm LOS , 270BHN cast armor. Plus the BDD composite packs. This array was 6cm RHA + 20cm cavity with 20mm alternating rubber & 5mm thick mild steel plates @ 45°, with a 1cm thick RHA back plate.The LOS through the main heavy turret packs from the front is 33cm array wrapped in 12cm steel, for a 45cm LOS thickness . The heavy pack should add 10 & 2cm LOS RHA steel plus 4.5cm [9 x 5] mild steel & 28.5cm Rubber. The Te are 1.0/0.6 & 0.4 & 0.2 respectively, thus the erosion component should be 10 cm + 1.2cm+ 1.8cm + 5.7cm] x 1.18[confinement] = **22cm RHAe**.The T/d for the pack is 0.85/0.8/0.75/ 68 = 18.7/17.6/16.5/15cm + 1.3d/2.6d spaced plate effect or add 2.6/3.9/10.4/7cm

Vs APDS = 22cm + 15+7= 44.4cm LOS or **31cm @ 45°**
Vs sheathed/steel APFSDS = 24cm + 16.5+10.4= 50.9cm LOS or **35.6cm @ 45°**
Vs 3cm APFSDS = 24cm + 17.6+3.9=45.5cm LOS **or 32cm @ 45°**
Vs 2cm APFSDS = 24cm +18.7+2.6= 45cm LOS **or 31.5cm @ 45°**
Vs HEAT = 26cm +25 + 10/0= 66/51cm LOS **or 45/35cm @ 45°**

[1/5 front turret profile] Upper front turret = 40mm @ 78°= LOS thickness of 192mm cast x 0.95 [cast] x T/d [0.75/0.85/0.88/0.92/0.94] =
Vs WC APDS **=** 15cm LOS or **3.9cm @ 75°** ** ¾ **ricochet** ** [WHA APDS= ½ ricochet @ 0-2km & ¾ ricochet @ > 2km]
Steel/Sheathed APFSDS = 15.9cm LOS or **4.1cm @ 75° * ¼ ricochet** *
2-3cm APFSDS **=** 16.9cm LOS or **4.4cm @ 75°**
Vs HEAT = 19cm LOS or **4.9cm @ 75°** ** **old warheads may ricochet** **

[3/10 front turret profile] MANTLE is about 24cm @ 20° or 25cm LOS 270BHN cast armor. The cast reduction [0.95] and the weakened zone .Free edge effect is 0.88 [APFSDS] , while its 0.8 for APDS & APC. The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.96[120mmAPC] & 1.0 [90mm APC] 1.0 [APDS/APFSDS] .
Vs APDS = 20cm LOS **or 17.3cm @ 30°**
Vs APFSDS = 21cm LOS **or 18cm @ 30°**
Vs HEAT = 25cm LOS **or 22cm @ 30°**

Side Turret 150mm @ x 30° = 17cm x 0.95[cast & t/d] . In addition the frontal armor packs extend part way around the front side of the turret. The area effected is only the front ¼ of the side turret. Since these are at the same angle from the side as the front the addition is the same too. The effectivenss is plus 18.7/17.6/16.5/15cm + spaced plate effect of 2.6/3.9/10.4/7cm

	¼ [Front side with Brow armor]	¾ [side with out Brow armor]
Vs APDS =	16cm + 15 + 14 = 45cm LOS or **31 cm @ 45°**	16 cm LOS or **14cm @ 30°**
Vs Steel/SheathedAPFSDS =	16.3 +17.6+ 10.4 cm = 44cmLOS or **31cm @ 30°**	16.3cm LOS or **14cm @ 30°**
Vs 2cm APFSDS =	16.7cm + 18.7 + 3 = 38.cm LOS or **27cm @ 30°**	16.7cm LOS or **14cm @ 30°**
Vs HEAT =	17.3cm +25 + 10/0= 52/42m LOS **or 36/30cm @ 45°**	17.3cm LOS or **15cm @ 30°**

Rear Turret 97mm @ 30° x 30°= LOS thickness of 125mm Cast x 0.95 = 12cm KE & 13cm HEAT.
Vs API/APDS = 12 = 12 cm or **10cm @ 30°**
Vs HEAT 13 cm **or 11cm @ 30°**

[½ Front Hull profile] Hull Glacis is 102mm @ 60° ~ 290-300 BHN RHA = LOS plus a 15cm thick array mounted @ 60°with 3cm cover plate 12cm rubber with 5mm thin mild steel plates @ 65° suspended in the rubber .The LOS thickness figures are 6cm RHA [1.0 Te] + 20cm rubber [0.2 te] & 4cm Mild steel [0.4 Te] ...thats 11.6 x 1.18 [confinement] = 13.6cm + base armor = **35cm KE resistance** . The HEAT values should work out to 6cm + 20cm [0.3 te] + 4cm [0.8 te] + 20.4cm [base armor] x1.2[layering] = **43cm HEAT.**
Vs APC = 18.7cm LOS + 12.9cm = 31.6cm LOS or **15.8cm @ 60°**
Vs APDS & 4cm APFSDS = 19.8cm + 12.9cm = 32.7cm LOS or **16.4cm @ 60°**
Vs 2-3cm APFSDS = 20.4+ 13.6cm = 34cm LOS or **17cm @ 60°**
Vs HEAT = 20.4+ 15.2cm x 1.2 = 42.6cm LOS or **21.3cm @ 60°**

[½ Front Hull profile] Lower hull JANES reports 102cm @ 54° ~ 290-300 BHN RHA = LOS thickness of 173mm , x t/d [0.88/0.92/0.94/0.96/0.98]....
Vs APC = 15cm LOS or **7.5cm @ 60°**
Vs APDS & 4cm APFSDS = 16cm LOS or **8cm @ 60°**
Vs 2-3cm APFSDS & HEAT = 17cm LOS or **8.5cm @ 60°**

SIDE Hull is 8cm steel base side hull armor on the basic T-54/55. The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional
Above trackguard = **12cm KE and ~ 25cm HEAT armor** .

Below trackguard = side skirt area has a ~3cm thick metal reinforced side skirt is mounted over the side track area..The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap increases the HEAT armor
Vs 3cm API ~ 8+2.9+1cm = **11.9cm @ 0°**
Vs 25mm APDS ~ 8+2.8+1cm = **11.8cm @ 0°**
Vs 25mm APFSDS ~ 8+1.7+1cm = **10.7cm @ 0°**
HEAT ~ 8 + 2 + 19/7 + 1.0d **= 29/17cm @ 0° + 1.0d HEAT**

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear
½ [engine deck & tracks] **~ 2cm RHA KE & HEAT @ 90°**
¼ [top turret & front hull deck] **~ 4cm . KE & HEAT @ 90°**
1/8 th [front/sides & rear turret] ~ **30cm @ 90° KE & HEAT**
1/8 th [glacis] ~ **17cm KE & 21cm HEAT @ 60°**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff, with the improvement a 10cm plate was added to the front bottom armor. This is unknow but assumed to be more of the same Steel Rubber armor, while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~
front ¼ = 9cm KE and 24/11cm HEAT
front ¼ = 3cm KE and 22/7cm HEAT
Rear ½ = 2cm KE and 22/7cm HEAT

All round resistance to 12.7mm API and side resistance is 20-30mm API/APDS and HEAT tipped rifle Grenades , while 25-30mm APFSDS should get ½ penetrations @ short range.The Kontakt ERA covers about 60% of the frontal arc profile. If this ERA is hit, the resistance in the frontal arc is about 23cm RHA within a ± 30° frontal arc , which should resist 40mm APFSDS. Against shaped charges that would be 23cm + 3d within a ± 30° frontal arc, that would be enough to stop SAGGERC & original versions of the Spigot ; Konkurs ; TOW & Milan ATGM plus RPG-7N/16/22 & Carl Gustav.

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T-62MV [Approximate]

Appeared in the early 90s with ERA applique ["Kontakt ERA"], along with a string of improved ammo , missiles , FCS & sights to extend the lives of these tanks....These appliqués adds **3cm Ke & 3-4d reduction in HEAT** for the "**Kontakt ERA"** .

[¼ front turret profile] **MANTLE** is about 20cm @ 30° or 25cm LOS 270BHN cast armor plus heavy Kontakt mounted at 60°. The cast reduction [0.95] and the weakened zone .Free edge effect is 0.88 [APFSDS] , while its 0.8 for APDS & APC . The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.96[120mmAPC] & 1.0 [90mm APC] 1.0 [APDS/APFSDS]

	½ Mantle	½ optical/MGPorts with Kontakt ERA
Vs steel/ sheathed APFSDS = 20cm LOS or	**17.5cm @ 30°**	**20cm@ 30°**
Vs 2-2.5cm APFSDS = 21cm LOS or	**18cm @ 30°**	**20cm@ 30°**
Vs 2cm HSAPFSDS = 21cm LOS or	**18cm @ 30°**	**19cm@ 30°**
Vs HEAT = 25cm LOS or	**22cm @ 30°**	**30/25cm@ 30° + 3d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits ,coverage is ¼ with Kontakt & ¾ exposed armor

[½ front turret profile] **main sloping walls** is average ~ 26 cm LOS , 270BHN cast armor plus heavy Kontakt mounted at 60°. The cast reduction [0.95] and the free edge effect is 0.98 [APFSDS] , while its 0.9 for APDS. For APC its 0.95. The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.96[120mmAPC] & 1.0 [90mm APC] 1.0 [APDS/APFSDS] It should look like this.

.	¼ front turret	¾ front turret with Kontakt ERA
Vs steel/ sheathed APFSDS 24cm LOS or	**16cm @ 45°**	**18cm@ 45°**
Vs 2-2.5cm APFSDS = 24.5cm LOS or	**16.7cm @ 45°**	**19cm@ 45°**
Vs 2cm HSAPFSDS = 25cm LOS or	**17.5cm @ 45°**	**18cm@ 45°**
Vs HEAT = 26cm LOS or	**18cm @ 45°**	**24/21cm@ 45° + 4d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ½ with Kontakt & ½ exposed armor

[¼ front turret profile] **Upper front turret** = 40mm @ 78°= LOS thickness 205mm cast plus 5cm Steltexolite bolted to the roof armor. This material resists a lot like aluminum or 0.4Te KE and 0.6 Te HEAT [increased by 20% due to layering].
Vs WC APDS = 24.0cm LOS or **6.0cm @ 75° * ¼ ricochet** * [WHA APDS= ½ ricochet @ 0-2km & ¾ ricochet @ > 2km]
Vs Steel/Sheathed APFSDS = 25.0cm LOS or **6.6cm @ 75° * ¼ ricochet** *
Vs 2-3cm APFSDS = 26.0cm LOS or **6.7cm @ 75°**
Vs 2cm APFSDS = 27.1cm LOS or **6.9cm @ 75°**
Vs HEAT = 38cm LOS or **9.8cm @ 75°** ** **old warheads may ricochet** **

Side turret 150mm cast@ x 30° = 17cm x 0.95[cast & t/d] plus Kontakt ERA in the front ¼ of the side profile.

	¾ side turret	¼ frontside turret with Kontakt ERA
Vs APDS = 16.3cm LOS or	**14cm @ 30°**	**17cm@ 30°**
Vs APFSDS = 16.7cm LOS or	**14cm @ 30°**	**17cm@ 30°**
Vs HEAT = 17.3cm LOS or	**15cm @ 30 °**	**29/23cm@ 30° + 3d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is all exposed armor and no Kontakt ERA

Rear turret 97mm @ 30° x 30°= LOS thickness of 125mm Cast x 0.95 = 12cm KE & 13cm HEAT.
Vs API/APDS = 12 = 12 cm or **10cm @ 30°**
Vs HEAT 13 cm **or 11cm @ 30°**

[½ Front Hull profile] Hull Glacis is 102mm @ 60°~ 290-300 BHN RHA = LOS thickness 204mm. The T/d is of 0.88/0.92/0.94/0.96/0.98…. Kontakt adds 18-20cm against 2-3cm APFSDS and 23-25cm against sheathed APFSDS

	¼ front glacis	¾ front glacis with Kontakt V ERA
Vs Steel/Sheathed APFSDS = 19cm LOS or	**9.5cm @ 60°**	**11cm@ 60°**
Vs 2-3cm APFSDS = 20cm LOS or	**10cm @ 60°**	**12cm@ 60°**
Vs 2cm HSAPFSDS = 20cm LOS or	**10cm @ 60°**	**11cm@ 60°**
Vs HEAT = 20.4cm LOS or	**10.2cm @ 60°**	**17/12cm@ 60° + 4.0d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ½ Kontakt & ½ exposed armor

[½ Front Hull profile] Lower hull JANES reports 102cm @ 54° ~ 290-300 BHN RHA = LOS thickness of 173mm Plus Kontakt ERA.

	¾ lower hull	¼ lower hull with Kontakt ERA
Vs APDS = 16cm LOS or	**8cm @ 60°**	**9.5cm@ 60°**
Vs 4cm APFSDS = 16cm LOS or	**8cm @ 60°**	**9.5cm@ 60°**
Vs 2-3cm APFSDS = 17cm LOS or	**8.5cm @ 60°**	**9.5cm@ 60°**
Vs HEAT = 17cm LOS or	**8.5cm @ 60°**	**13/10cm@ 60° + 4d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is all exposed armor and no Kontakt ERA

SIDE Hull is the basic T-62 side hull armor with the steel rubber side skirt reinforced with Hvy Kontakt 5 ERA Below trackguard = side skirt area has a ~3cm thick metal reinforced side skirt is mounted over the side track area**.**The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap . Kontakt ERA is added over most of the side hull adding ~2cm KE resistance and 3d HEAT reduction.

	¼ front turret	¾ front turret with Kontakt ERA
Vs 3cm API ~ 8+2.9+1cm =	**11.9cm @ 0°**	**12cm @ 0°**
Vs 25mm APDS ~ 8+2.8+1cm =	**11.8cm @ 0°**	**12cm @ 0°**
Vs 25mm APFSDS ~ 8+1.7+1cm =	**10.7cm @ 0°**	**12cm @ 0°**
HEAT ~ 8 + 2 + 19/7 + 1.0d	**= 29/17cm @ 0° + 1.0d HEAT**	**32/20cm @ 0° + 3.0d HEAT**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ¼ Kontakt & ¾ exposed armor

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear
½ [engine deck & tracks] **~ 2cm RHA KE & HEAT @ 90°**
¼ [top turret & front hull deck] **~ 7cm . KE & 10cm HEAT @ 90°**
1/8th [front/sides & rear turret] ~ **30cm @ 90° KE & HEAT**
1/8th [glacis] ~ **18cm KE & 14cm+ 4d HEAT @ 60°**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT

All round resistance to 12.7mm API and side resistance is 20-30mm API/APDS and HEAT tipped rifle Grenades , while 25-30mm APFSDS should get ½ penetrations @ short range.The Kontakt ERA covers about 60% of the frontal arc profile. If this ERA is hit, the resistance in the frontal arc is about 23cm RHA within a ± 30° frontal

arc , which should resist 40mm APFSDS. Against shaped charges that would be 23cm + 3d within a ± 30° frontal arc, that would be enough to stop SAGGERC & original versions of the Spigot ; Konkurs ; TOW & Milan ATGM plus RPG-7N/16/22 & Carl Gustav.

T-62MV-3 [Approximate]

Appeared in the early 90s with ERA applique [“Kontakt –5” type or “Kontakt V”], along with a string of improved ammo , missiles , FCS & sights to extend the lives of these tanks….These appliqués adds **3-6cm Ke & 40cm HEAT** for the “**Kontakt ERA”** , while the more advanced **“ K-5 applique”** appeared in the mid 90s adding **14-15cm KE** to the glacis and **18-19cm** to the front turret & about **50cm HEAT** resistance.

[¼ front turret profile] MANTLE is about 20cm @ 30° or 25cm LOS 270BHN cast armor plus heavy Kontakt V mounted at 60°. The cast reduction [0.95] and the weakened zone .Free edge effect is 0.88 [APFSDS] , while its 0.8 for APDS & APC . The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.96[120mmAPC] & 1.0 [90mm APC] 1.0 [APDS/APFSDS]

	½ Mantle	½ optical/MGPorts with Kontakt V ERA
Vs steel/ sheathed APFSDS = 20cm LOS or	**17.5cm @ 30°**	**35cm@ 30°**
Vs 2-2.5cm APFSDS = 21cm LOS or	**18cm @ 30°**	**31cm@ 30°**
Vs 2cm HSAPFSDS = 21cm LOS or	**18cm @ 30°**	**28cm@ 30°**
Vs HEAT = 25cm LOS or	**22cm @ 30°**	**39/32cm@ 30° + 3d**

Effectiveness of K-5 is considered “reduced” after 16 hits [subtract 4 of above values, except “Steel/ Sheathed APFSDS”, in that case subtract 7 off the above values]. If HEAT Vs “reduce”, the K-5 covered areas reduce resistance from + 4.0d to + 1.0d

[½ front turret profile] main sloping walls is average ~ 26 cm LOS , 270BHN cast armor plus heavy Kontakt mounted at 60°. The cast reduction [0.95] and the free edge effect is 0.98 [APFSDS] , while its 0.9 for APDS. For APC its 0.95. The T/d Vs 90mm & 120mm APC rounds should decrease this armor by 0.96[120mmAPC] & 1.0 [90mm APC] 1.0 [APDS/APFSDS] It should look like this.

.	¼ front turret	¾ front turret with Kontakt V ERA
Vs steel/ sheathed APFSDS 24cm LOS or	**16cm @ 45°**	**31cm@ 45°**
Vs 2-2.5cm APFSDS = 24.5cm LOS or	**16.7cm @ 45°**	**27cm@ 45°**
Vs 2cm HSAPFSDS = 25cm LOS or	**17.5cm @ 45°**	**25cm@ 45°**
Vs HEAT = 26cm LOS or	**18cm @ 45°**	**35/28cm@ 45° + 4d**

Effectiveness of K-5 is considered “reduced” after 16 hits [subtract 4 of above values, except “Steel/ Sheathed APFSDS”, in that case subtract 7 off the above values]. If HEAT Vs “reduce”, the K-5 covered areas reduce resistance from + 4.0d to + 1.0d

[¼ front turret profile] Upper front turret = 40mm @ 78°= LOS thickness 205mm cast plus 5cm Steltexolite bolted to the roof armor. This material resists a lot like aluminum or 0.4Te KE and 0.6 Te HEAT [increased by 20% due to layering].

Vs Steel/Sheathed APFSDS = 25.0cm LOS or **6.6cm @ 75° * ¼ ricochet***
Vs 2-3cm APFSDS = 26.0cm LOS or **6.7cm @ 75°**
Vs 2cm APFSDS = 27.1cm LOS or **6.9cm @ 75°**
Vs HEAT = 38cm LOS or **9.8cm @ 75°** ** **old warheads may ricochet** **

Side turret 150mm cast@ x 30° = 17cm x 0.95[cast & t/d] plus K-5 ERA in the front ¼ of the side profile. 16-22

	¾ side turret	¼ frontside turret with Kontakt V ERA
Vs APDS = 16.3cm LOS or	**14cm @ 30°**	**31cm@ 30°**
Vs APFSDS = 16.7cm LOS or	**14cm @ 30°**	**30cm@ 30°**
Vs HEAT = 17.3cm LOS or	**15cm @ 30 °**	**29/23cm@ 30° + 3d**

Effectiveness of K-5 is considered “reduced” after 16 hits [subtract 4 of above values, except “Steel/ Sheathed APFSDS”, in that case subtract 7 off the above values]. If HEAT Vs “reduce”, the K-5 covered areas reduce resistance from + 4.0d to + 1.0d

Rear turret 97mm @ 30° x 30°= LOS thickness of 125mm Cast x 0.95 = 12cm KE & 13cm HEAT.
Vs API/APDS = 12 = 12 cm or **10cm @ 30°**
Vs HEAT 13 cm **or 11cm @ 30°**

[½ Front Hull profile] Hull Glacis is 102mm @ 60°~ 290-300 BHN RHA = LOS thickness 204mm. The T/d is of 0.88/0.92/0.94/0.96/0.98…. Kontakt adds 16-18cm against 2-3cm APFSDS and 21-25cm against sheathed APFSDS

	¼ front glacis	¾ front glacis with Kontakt V ERA
Vs Steel/Sheathed APFSDS = 19cm LOS or	**9.5cm @ 60°**	**20cm@ 60°**
Vs 2-3cm APFSDS = 20cm LOS or	**10cm @ 60°**	**18cm@ 60°**
Vs 2cm HSAPFSDS = 20cm LOS or	**10cm @ 60°**	**15cm@ 60°**
Vs HEAT = 20.4cm LOS or	**10.2cm @ 60°**	**19/15cm@ 60° + 4.0d**

Effectiveness of K-5 is considered “reduced” after 16 hits [subtract 4 of above values, except “Steel/ Sheathed APFSDS”, in that case subtract 7 off the above values]. If HEAT Vs “reduce”, the K-5 covered areas reduce resistance from + 4.0d to + 1.0d

[½ Front Hull profile] Lower hull

JANES reports 102cm @ 54° ~ 290-300 BHN RHA = LOS thickness of 173mm , x t/d [0.88/0.92/0.94/0.96/0.98]… Kontakt adds 16-18cm against 2-3cm APFSDS and 21-25cm against sheathed APFSDS.

	½ lower hull	½ lower hull with Kontakt V ERA
Vs Steel Sheathed APFSDS = 16cm LOS or	**8cm @ 60°**	**19cm@ 60°**
Vs 2-3cm APFSDS = 17cm LOS or	**8.5cm @ 60°**	**17cm@ 60°**
Vs HEAT = 17cm LOS or	**8.5cm @ 60°**	**16/12cm@ 60° + 4.0d**

SIDE Hull

is the basic T-62 side hull armor with the steel rubber side skirt reinforced with Hvy Kontakt 5 ERA Below trackguard = side skirt area has a ~3cm thick metal reinforced side skirt is mounted over the side track area**.**The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap .The K-5 thickness looks like 3% of the array length & 14% of its height….this should make it , ~8cm thick divided into 4 sections. These look like a 2.5cm outer plate [steel?] , 1.5cm inner plate [Kontakt?] plus 2.5cm airgap and 1.5cm rear plate[Kontakt?]. K-5 adds 8-11cm KE

	Rear ½ Side Hull	Front ½ Side Hull with K-5 ERA
Vs 3cm API/APDS/APFSDS	~ 8+2.9+1cm = **11.9cm @ 0°**	**19cm @ 0°**
Vs 2cm APDS /APFSDS	~ 8+2.8+1cm = **11.8cm @ 0°**	**18cm @ 0°**
Vs 2cm HS APFSDS	~ 8+2.7+1cm = **11.7cm @ 0°**	**16cm @ 0°**
Vs 25-30mm APFSDS	~ 8+1.0+1cm = **10.0cm @ 0°**	**15cm @ 0°**
HEAT	**~**8 + 2 + 19/7 + 1.0d **= 29/17cm @ 0° + 1.0d HEAT**	**32/20cm @ 0° + 3.0d HEAT**

Effectiveness of K-5 is considered “reduced” after 16 hits [subtract 2 of above values off the above values]. If HEAT Vs “reduce”, K-5 covered areas reduce resistance by 2d.

Rear hull

46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor

is in three sections , the rear
½ [engine deck & tracks] **~ 2cm RHA KE & HEAT @ 90°**
¼ [top turret & front hull deck] **~ 7cm . KE & 10cm HEAT @ 90°**
1/8th [front/sides & rear turret] ~ **30cm @ 90° KE & HEAT**
1/8th [glacis] ~ **18cm KE & 14cm+ 4d HEAT @ 60°**

Bottom tank armor

armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the ‘ground clearance’ should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT

All round resistance to 12.7mm API and side resistance is 20-30mm API/APDS and HEAT tipped rifle Grenades , while 25-30mm APFSDS should get ½ penetrations @ short range.The Kontakt-5 ERA covers about 50-60% of the frontal arc profile. If this ERA is hit, the resistance in the frontal arc is about 36cm RHA within a ± 30° frontal arc ,which should limit 1st gen 105mm APFSDS [M-111 /DM-23 /M735 & L64] to ½ penetration @ 1km and 2nd gen 105mm APFSDS [OFL-105 G1/ DM-23A1/M-744] to ½ penetrations @ 2km range. Against shaped charges that would be 23cm + 3d within a ± 30° frontal arc, that would be enough to stop SAGGERC & original versions of the Spigot ; Konkurs ; TOW & Milan ATGM plus RPG-7N/16/22 & Carl Gustav.

‘’’

OK interesting info it appears to add both armor plates and K-5 to the tank and side skirts boosting weight from 36-39.5 tons or a 3.5 ton increase…As I recall K-5 suit to T-64-90 tanks appear to add 1.5 tons and the side skirts new engine & gun should add 1.0 ton? This leaves 1 ton extra armor…which I will assume is SHS plates added to hull and cast armor added to turret.

"on the hull glacis plate and nose: armor module consisting of an armor plate and explosive reactive armor;
on the turret frontal arc: add-on armor plates and explosive reactive armor;

on the hull sides: armored skirt screens with explosive reactive armor.
Efficiency of increase of armor protection of the upgraded T-62 tank:

kinetic energy attack (APFSDS) – 1.8;
chemical energy attack (HEAT) – 2.5-3. "

This suggests **Front Hull armor** should be 20x 1.8 = **36cm KE** and 2.5-3 x 21= **52-63cm HEAT…**while **Front turret armor** should be 22-24 x 1.8**=40-43cm KE** and 26 x 2.5-3= **65-78cm HEAT.**

On T-62, I get a turret profile of 1.4m² while the hull is 2 m². Maybe this adds say 3.7cm LOS to these profiles. The lower front hull looks like the standard additions to T-64-90 upgrades IE dozer blade mount and rubberized skirting. The plates should be ~ 16mm @ 60° hard steel on the glacis and 4cm LOS cast added to the turret.

Lower hull is 17cm bring this up to 19cm ...but the spaced armor effect and rubberized skirting boost protetction to .....
2cm APFSDS = 29cm
3cm APFSDS = 31cm
3.5cm sheathed APFSDS = 41cm
The HEAT 30cm HEAT + 11+ 5 = 46cm

Glacis is 21cm LOS plus 2cm upto 22cm LOS ...add K-5 thats covering ¾ of the glacis . This ERA @ 60° looks like it adds ~ +14-15cm KE protection [2cm-4cm APFSDS] and 23-20cm [Sheathed APFSDS] +35 cm HEAT armor.
[pre]

¼ glacis profile	¾ glacis + Kontakt ERA.
2cm APFSDS = 22cm	36cm [32cm if reduced]
3cm APFSDS = 22cm	36cm [32cm if reduced]
3.5cm sheathed = 22cm	44cm [40cm if reduced]
[HEAT] = 27cm	62cm [40cm if reduced]

[/pre]
24-22cm [APFSDS & APDS] & 26cm HEAT
Upgrade boasts "kinetic energy attack (APFSDS) – 1.8 and chemical energy attack (HEAT) – 2.5-3. ", the above figures are 20cm RHAe to 36-44cm [1.8-2.2x] KE resistance and 21cm RHAe HEAT resistance to 62 [2.95 x]

18-19cm RHAe vs 2-4cm monoblock APFSDS @ 65° [@ 60°= 16-18cm]
23- 26cm RHAe vs 2-4cm sheathed APFSDS@ 65° [@ 60°= 21-25cm]

Front turret is ~ 29-31cm RHAe plus K-5 over ½ the profile. The K-5 should add ~ 16-18 cm KE protection, unless the APFSDS is sheathed in which case it adds 21-25cm. The HEAT resistance @ 60-65° is about + **45cm HEAT**

½ front turret profile is…..		½ front turret profile with Kontakt ….
2cm APFSDS = 26cm 29cm RHAe	[28cm average]	42cm 45cm RHAe [44cm average]
3cm APFSDS = 26cm 29cm RHAe	[28cm average]	43cm 46cm RHAe [45cm average]
3.5cm Sheathed = 26cm 29cm RHAe	[28cm average]	49cm 52cm RHAe [51cm average]
Vs HEAT = 28cm 30cm	[29cm average]	73cm 75cm [74cm average]

From 30° off angle treat all hits as the 'average' value.
Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 4 of above values, except 3.5cm Sheathed, in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 20cm.

Upgrade boasts "kinetic energy attack (APFSDS) – 1.8 and chemical energy attack (HEAT) – 2.5-3. ", the above figures are 24cm RHAe to 42-52cm [1.75-2.17x] KE resistance and 26cm RHAe HEAT resistance to 73-75 [2.8-2.9 x]

Side turret .Is based on T-62 with K-5 ERA. The effective KE armor ranges from **15-10 cm [2-4cm APFSDS]** near the front and around back. The HEAT armor ranges from **15 cm** near the front down to **10cm** on the side turret and **25-30cm** around back with storage boxes. The Kontakt ERA covers ¼ of the side turret profile, near the front and should add **40-50cm HEAT** & ~ **18/23cm KE [APFSDS/sheathed] .**
Thus the front Side turret should offer **…..**

¼ 35cm[APFSDS] 40cm [Sheathed] & 75cm HEAT [with K-5 ERA]
¼ 20-15cm KE & 20-15cm HEAT
½ 15-10cm KE & 30-35cm HEAT
Rear 10cm KE & 25-30cm HEAT

If more than 6 hits on the side turret then K-5 covered areas are considered "reduced" and should have the KE resistance reduced by 4cm [7cm if sheathed APFSDS], while the HEAT resistance should go down 26cm.

The side hull is the same as T-62MV model with a ~3cm thick metal reinforced side skirt is mounted over the side track area. That's 8cm thick rolled steel.The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap
plus Kontakt –5 heavy ERA covering ½ of the side hull profile .The thickness looks like 3% of the array length & 14% of its height….this should make it , ~8cm thick divided into 4 sections. The thickness looks like 3% of the array length & 14% of its height….this should make it , ~8cm thick divided into 4 sections. These look like a 2.5cm outer plate [steel?] , 1.5cm inner plate [Kontakt?] plus 2.5cm airgap and 1.5cm rear plate[Kontakt?]. The spaced plate effect is 3d /6d . That's 3.6/3.2/2.8 + 6/9cm or +18/24cm. 4/9/12/21/27cm.

	Rear ½ Side Hull	Front ½ Side Hull with K-5 ERA
That's ~ 8+5cm =	**13cm Vs 3cm API**	**24cm Vs 3cm API**
That's ~ 8+6cm =	**13cm Vs 1.5cm APDS [25mm APDS]**	**24cm Vs 1.5cm APDS [25mm APDS]**
That's ~ 8+4cm =	**11cm Vs 1cm APFSDS [25mm APFSDS]**	**24cm Vs 1cm APFSDS [25mm APFSDS]**
HEAT resistance =	**26cm Pj HEAT**	**60cm Pj HEAT**

If more than 6 hits on the side hull then K-5 covered areas are considered "reduced" and should have the KE resistance reduced by 3cm [5cm if sheathed APFSDS], while the HEAT resistance should go down 16cm
'''

From an article "Updating of T-72 armament system" by Colonel, Candidate of Technical Sciences Yuri Vasiliev:
"
The tank mounts the 2E42-2 armament stabilizer in two planes with an electro-hydraulic drive of elevation and electromechanical drive in traverse. Stabilization precision in elevation equals 0.6 mil and in traverse – 0.9 mil. The elevation speed equals to 0.05-3.5 grad/sec and that of traverse – 0.07-3 grad/sec. The slew rate is equal to 24 grad/sec. There is also an emergency turn override from the driver's seat. The first T-72 tanks were fitted with the 2E28M two-plane electro-hydraulic stabilizer superior to the former 2E42-2 stabilizer.

The 1A40-1 sight system makes also a part of the tank armament. It comprises the TPD-K1M sight-rangefinder and a built-in control adjustment sighting device. The sight-rangefinder is intended to sight the gun and co-axial machine gun (traverse sighting in automatic, semiautomatic and manual modes, elevation sighting in automatic and manual modes). It is also intended to measure distance to targets when stationary and on the move, provide lateral lead during gun firing against moving targets and sighting during firing the ZUBK14. The built-in control adjustment sighting device is intended to ensure rapid control and sight adjustment by the crew accommodated in the tank. The TPD-2-49 optical sight-rangefinders were mounted on the previous versions of T-72 tanks. They had a 1000-4000m range measuring band with a mean-square error and entering range to the sight from 3 to 5 percent of the measured range. It took 15-30 seconds to measure the range. The TPD-K1 is a laser sight with a band of measuring distance ranging from 500 to 4000m. It features a 10m error of measuring range. It takes one second to measure and enter range values at 1000m.

T-64A and T-72

V.Chobitok's "Main battle tank T-64",
http://www.t-64.de/frame-start.htm
According to this site the original T-64 had 150mm Aluminum insert with 90mm cast steel on either side, while from T-64A on the thickness was 150mm insert with 150mm outer cast and 40mm inner cast walls.
Russian "Principle BattleTank" Book claims the T-64 armor was designed to resist all 1960s 105mm projectiles at 'beyond 800m
range'. Steve Zalogas T-72 values published from the CFE talks are "410mm KE & 500mm HEAT "for the turret and "410mm KE and 450mm HEAT" on the glacis, but Steve points out these figures are not nessearly authoritative. Russian sources put the turret armor resistance at 280mm KE and near the gun the resistance looks about 28cm [Vs APDS]. So its logical to assume the front turret resistance ranges from 28-41cm .V.Chobitok's "Main battle tank T-64", reports the T-64 turret has cast armor and aluminum

The front armor mass of the T-62 is 17-26cm steel and the weight growth between T-62 and T-64A is 36.3-37.7 tons or an 1 % increase in armor mass. The tank volume has been reduced from 12.5 m^3 in T-62 to 10.4 m^3 on T-64 or 20% increase in density, and the front armor profile of the T-62 is 4m² while T-64 is about 3.76 m² for a 6% increase in density . Thus a total potential of ~28% increase in armor mass.

T-62 Armor
Upper front turret [1/6 profile] 40mm @ 78°= LOS thickness of 192mm cast
Front turret [2/6 profile] 242mm @ 23° =263mm LOS cast
Glacis [2/6 profile] = 102mm 290-300 BHN RHA @ 60°= LOS thickness of 204mm
Lower hull [1/6 profile] = 102mm 290-300 BHN RHA @ 54°= LOS thickness of 173mm

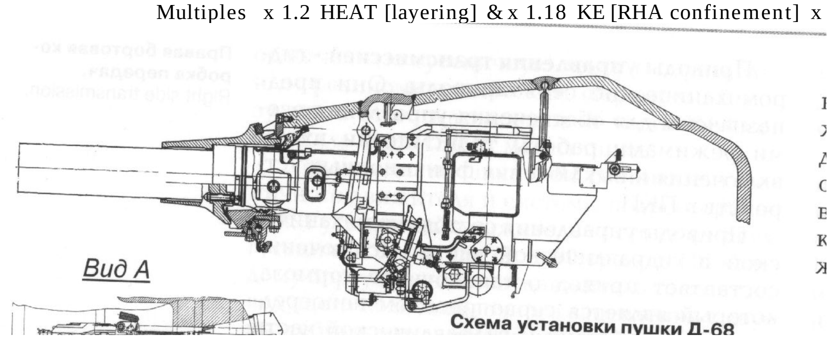
Total = average 215mm T-62 frontal armor **x 1.28= 277mm average** [x 9] 2493 – 3x 200mm 1893/6 = 316mm Steel mass on the T-64 glacis and front turret.

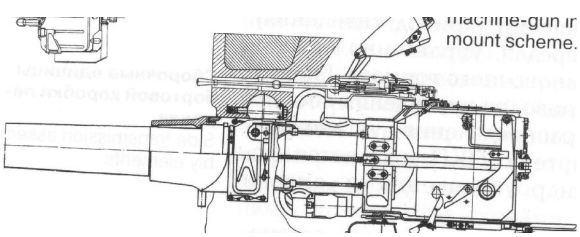
Turret front

The LOS thickness ranges from ~41 cm LOS near the gun to ~60 cm LOS thickness at the turret corners . The EARLY model was reported to feature Aluminum sandwhiched between cast steel armor with the insert thickness representing ~ 60% of the LOS thickness, 4.9 g/cc average density . Working back wards that's [31.5 x 7.83÷ 4.9]= 50cm average LOS thickness which ranges from ~60cm near the turret corners to ~41cm near the gun .

The above diagram suggest the inserts occupies over ½ front LOS thickness .

24 cm Al 5xxx [Te]= 0.35/0. 4 x 0.99/0.97/0.96/0.94/0.95 [T/d] = 8.3/8.4 /8.0/7.9/10.25 & 11cm
17 cm cast x 0.95 /1.0 [Te] x 0.94/0.92/0.9/0.88/0.95 [T/d] = 15.2/14.9/14.5/14.2/16.1cm & 17cm
Multiples x 1.2 HEAT [layering] & x 1.18 KE [RHA confinement] x [Lateral confinement]





V.Chobitok's "Main battle tank T-64"

[¼ front turret profile] **Upper front turret** = 5cm @ 76°= LOS thickness of 20cm cast x 0.95 [cast] x T/d [0.75/0.85/0.88/0.92/0.94] =

Vs APC = 14.0cm LOS or **3.8cm @ 75° ** ricochet** **
Vs APDS = 15cm LOS or **4.1cm @ 75° ** ricochet** ** [* ½ ricochet* if WHA APDS L52 or L16]
Steel/Sheathed APFSDS = 15.9cm LOS or **4.3cm @ 75° * ¼ ricochet** *
2-3cm APFSDS = 16.9cm LOS or **4.6cm @ 75°**
Vs HEAT = 19cm LOS or **4.9cm @ 75° ** old warheads may ricochet** **

[¼ front turret profile] [MG port to gunsite] Mantle		**Middle Turret [¼ front turret profile]**
2cm APFSDS =	23.5 x 1.18 x 0.9/ 0.99 = 26cm LOS or **23cm @ 30°**	33 cm LOS or **23cm @ 45°**
3cm APFSDS =	23.3 x 1.18 x0.9/ 0.97= 26cm LOS or **23cm @ 30°**	33 cm LOS or **23cm @ 45°**
4cm APFSDS =	22.6 x 1.18 x 0.9/ 0.96 = 26cm LOS or **23cm @ 30°**	32 cm LOS or **22cm @ 45°**
6-7cm APDS =	22 x 1.18 x 0.9/ 0.95 = 25.5cm LOS or **22cm @ 30°**	31 cm LOS or **22cm @ 45°**
9**0-122mm APC** =	26.36 x 1.18 x 0.8/0.98 25cm LOS or **21cm @ 30°**	35 cm LOS or **23cm @ 45°**
HEAT=	28 x 1.2 = 33cm LOS or **29cm @ 30°**	40cm LOS **or 28cm @ 45°**

[¼ front turret profile] Turret corner front		**[1/3 side Turret profile]**
2cm APFSDS =	23.5 x 1.18 x 0.9/ 0.99 = 41cm LOS or **20.5cm @ 60°**	**20cm @ 30°**
3cm APFSDS =	23.3 x 1.18 x0.9/ 0.97= 40cm LOS or **20cm @ 60°**	**20cm @ 30°**
4cm APFSDS =	22.6x 1.18 x 0.9/ 0.96 = 38cm LOS or **19cm @ 60°**	**20cm @ 30°**
6-7cm APDS =	22 x 1.18 x 0.9/ 0.95 37cm LOS or **18cm @ 60°**	**19cm @ 30°**
9**0-122mm APC** =	20 x 1.18 x 0.8/0.98 35cm LOS or **16cm @ 60°**	**16cm @ 30°**
HEAT=	28 x 1.2 = 50cm LOS or **25cm @ 60°**	**25cm @ 30°**

[2/3 side Turret profile] rear ; Ranges from 28cm thick aluminum/ cast near front , with ~ 15cm cast side armor thinning to ~ 6cm Cast around back . The half and half cast / aluminum KE armor is rougly 0.68- 0.61 while the HEAT armor is ~ 0.93 [from above] , while the cast armor is 0.95/1.0

½ side turret [Rear]

Vs APC 15.5cm LOS or **13.4cm @ 30°**
Vs APDS 16.1cm LOS or **14cm @ 30°**
Vs APFSDS 16.8cm LOS or **14.5cm @ 30**
Vs HEAT = 17.3cm LOS or **15cm @ 30°**

Rear turret 97mm @ 30° x 30°= LOS thickness of 125mm Cast x 0.95 = 12cm KE & 13cm HEAT. In the rear turret are sometimes mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor
Vs API/APDS **=** 12+ 0.8 = 12 cm or **10.6cm @ 30°**
Vs HEAT 13 cm+ 0.2 + 19/7 + 0.7d or 32/20cm LOS **or 28/17cm @ 30° +0.7d**

Glacis ; The assumed armor mass average is 316 mm on the glacis @ 67- 68°= 120mm steel mass @ angle ,of which 100mm is steel and the other 20 mm is converted into ~10.5cm thickness which suggest a density of 1.5g/cc , which is in the same region as the Steltexolite [ST- 1=1.7g/cc] . Most sources reported the glacis @ 205mm @ 67- 68° thick with layers of 80mm RHA & 105mm Steltexolite & 20mm RHA.The 20mm plate is assumed to be hardened RHA steel with a hardness around 400BHN

8cm RHA x 1.0/1.0 [Te] x 0.99/0.97/0.94 [t/d] or 0.92 [APDS t/d] = 7.9/7.8/7.5cm; 7.4cm , 7.15& 8cm [HEAT]
2x 5.25 cm ST- 1 x 0.3/ 0.38 [Te] x 0.7/0.6/0.55 [t/d] or 0.5 [T/d APDS] = 2.2/1.9/1.7; 1.57cm , 1.5& 3.93cm
2cm SHS x 1.16/1.16 [Te] x 0.88/0.7/0.6 [T/d] or 0.7 [APDS t/d] = 2.0/1.6/1.38cm/ 1.4cm / 1.35& 2.32cm [HEAT]
Modifiers x 1.24 [Thick confinement] x 0.95 [thin backing]÷ 0.38 [Cos of glacis]
Total Vs
The NiStalii Website quoted the glacis of the basic T- 72 @ resistance of 335mm Vs APFSDS and 450mm HEAT while the above prediction is 339mm Vs a 35mm wide M-735 APFSDS [less than 1% error] .This glacis is also reported to be 80mm RHA plus 2 plates of Steltexolite [105mm total] and a 20mm RHA back plate set back at 67- 68°. This glacis looks to be exact same layout as T- 64. Soviet tests of Iranian TOW missiles showed that the majority of the missiles failed to detonate on the T- 64 glacis , due to the severe angle of impact…its also interesting to note that the Milan missile is only rated as being effective at impact angles upto 65°….However Tests on the SS- 10 ATGM showed it could detonate on RHA plates @ 70°.

[2/3 Front Hull profile] Hull Glacis

2cm APFSDS = 12.1 x 1.18 ÷ 0.38 = 37.5cm LOS or **14.2cm @ 68°**
3cm APFSDS = 11.3 x 1.18 ÷ 0.38 = 35cm LOS or **13.3cm @ 68°**
4cm APFSDS& 6cm APDS = 10.58 x 1.18 ÷ 0.38 = 32.8cm LOS or **12.3cm @ 68°**
7cm APDS = 10.0 x 1.18 ÷ 0.38 = 31cm LOS or **11.8cm @ 68°**
Vs HEAT = 14.25 x 1.2 ÷ 0.38 [Cos]= 45cm LOS or **17.1cmHEAT** ** old warheads may ricochet **

[1/3 Front Hull profile] Lower hull JANES reports 100cm @ 60° ~ 290- 300 BHN RHA = LOS thickness of 173mm , x t/d [0.88/0.92/0.94/0.96/0.98]….
Vs APC = 17.5cm LOS or **8.7cm @ 60°** * ½ **ricochet** *
Vs APDS & 4cm APFSDS = 18.5cm LOS or **9.2cm @ 60°**
Vs 2- 3cm APFSDS & HEAT = 19.6cm LOS or **9.8cm @ 60°**

SIDE Hull Side armor looks like **6cm** thick , this must be an averaging of the 8cm upper sidehull of the T- 54- 62 tanks and the 2cm thick area around the wheels. The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional
Above trackguard = **12cm KE and ~ 25cm HEAT armor** .
Below trackguard =
7.5cm vs API/20- 30mm APDS/APFSDS & HEAT
6.5cm vs large APDS
5cm large APC/HVAP

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

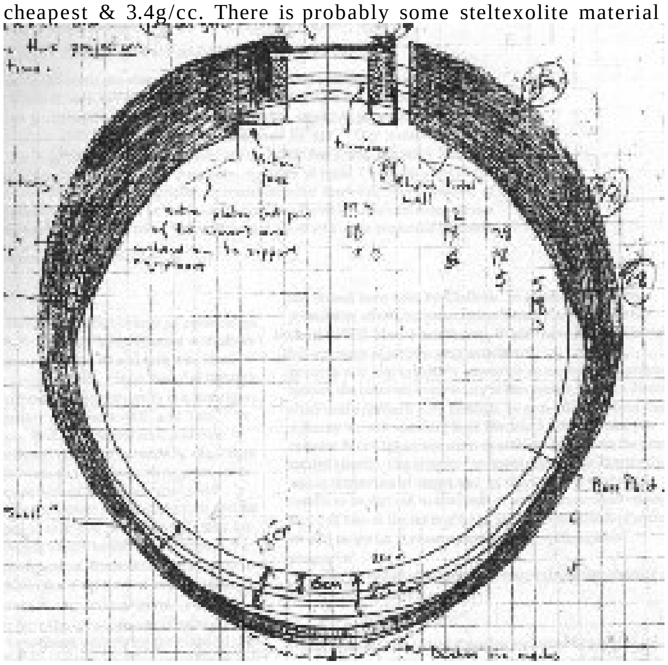
Top tank armor is in three sections , the rear
¼ [engine deck] **~ 2cm RHA KE & HEAT @ 90°**
½ [top turret & front hull deck & tracks] **~ 4cm . KE & 5cm HEAT @ 90°**
1/8 th [front/sides & rear turret] ~ **30cm @ 90° KE & HEAT**
1/8 th [glacis] ~ **14cm KE & 17cm @ 68° HEAT**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT

T-64B , T-72A & T-64R

T-64 B production started in 1979 and is similar to the T-64 in armor lay out with the following probable changes. The insert effectiveness is improved with more advanced armor materials including ceramics in the turret . Turret front ranges from 41cm LOS near the gun to 60cm LOS thickness at the turret corners and the glacis is reported to be the same as the T-64A 100mm steel and 105mm steltexolite .
http://www.t-64.de/frame-start.htm

Total weight growth between T-64A and T-64B is 38.6 tons to 40.3 tons or an 4 % increase in armor mass while the vehicle dimentions and therefor volume look the same as the T-64A, thus the adjusted armor mass should be 269mm T-64 frontal armor **x 1.04= 281mm average** frontal armor …..[x 10] 2808 –4x 200mm = 2002/6 = 33.3cm average… but the glacis is known to be ~35cm Steel mass on the T-64B , leaving ~31.7cm Steel mass front turret.
;The T-64B front turret armor mass is 31 cm steel and the LOS thickness ranges from 41cm LOS near the gun to 60cm LOS thickness at the turret corners just like T-64A. This leads to an average of ~5g/cc [32/50cm] cross sectional density and if the armor is arranged similar to T-64, thats a average insert density of ~3.0g/cc [12/30]. This insert was reported to be a black ceramic , such ceramics could be Alumina ; Alumina Nitrite or Boron Carbide , but Alumina is the cheapest & 3.4g/cc. There is probably some steltexolite material in between the ceramic tile layers ..



Andrew Jarmenkow

43cm Alumina 85/ST-1 x [Te] 0.8/0.97 x [T/d] 0.95/0.93/0.85/0.8/0.85 = 32.7/32 /29.2/27.5/29.2cm & 41.7cm
17 cm cast x 0.95 /1.0 [Te] x [T/d] 0.94/0.92/0.9/0.88/0.95 = 15.2/14.9/14.5/14.2/15.3 cm & 17 cm
Multiples x 1.2 HEAT [layering] & x 1.18 KE [RHA confinement] x 0.8/0.72/0.7/0.65/0.6 [Lc] x 0.97 [interlayers]
---to---
20cm Alumina 85/ST-1 x [Te] 0.8/0.97 x [T/d] 0.95/0.93/0.85/0.8/0.85 = 15.2/14.9 /13.6/12.8/13.6cm & 22cm
21cm cast x 0.95 /1.0 [Te] x [T/d] 0.95/0.93/0.91/0.9/0.95 = 18.9/18.5/18.2/17.9/18.9 cm & 21 cm
Multiples x 1.2 HEAT [layering] & x 1.18 KE [RHA confinement] x 0.8/0.75/0.72/0.7/0.65 [Lc] x 0.97 [interlayers]

2cm APFSDS = 34.1/47.9 x 1.18 x 0.85/0.8 x 0.97 = 33cm 45cm @ [39±6cm average]
3cm APFSDS =33.4/46.9 x 1.18 x 0.75/0.72 x 0.97 = 29cm 39cm @ [34±5cm average]
4cm APFSDS =31.8/43.7 x 1.18 x 0.72/0.7x 0.97 = 27cm 35cm @ [31±4cm average]
5-6cm APDS =30.7 /41.7x 1.18 x 0.7/0.65 x 0.97 = 25cm 31cm @ [28±3cm average]
90-122mm APC = 32.5/42.8 x 1.18 x 0.65/6 x 0.97 = 24cm 30cm @ [27±3cm average]
HEAT=[47.3+17] to [22+21]-1.2= 36cm @ the 51cm HEAT 70cm @ [57±13cm average]

[¼ front turret profile] **Upper front turret** = 5cm @ 76°= LOS thickness of 20cm cast x 0.95 [cast] x T/d [0.75/0.85/0.88/0.92/0.94] =

Vs APC = 14.0cm LOS or **3.8cm @ 75°** ** **ricochet** **
Vs APDS = 15cm LOS or **4.1cm @ 75°** ** **ricochet** ** [* ½ ricochet* if WHA APDS L52 or L16]
Steel/Sheathed APFSDS = 15.9cm LOS or **4.3cm @ 75°** * **¼ ricochet** *
2-3cm APFSDS = 16.9cm LOS or **4.6cm @ 75°**
Vs HEAT = 19cm LOS or **4.9cm @ 75°** ** **old warheads may ricochet** **

[¼ front turret profile] [MG port to gunsite] Mantle (cast) — **Middle Turret [¼ front turret profile]**

	Mantle	Middle Turret
2cm APFSDS =	33cm LOS or **29cm @ 30°**	39 cm LOS or **27cm @ 45°**
3cm APFSDS =	32cm LOS or **28cm @ 30°**	34cm LOS or **24cm @ 45°**
4cm APFSDS =	31cm LOS or **27cm @ 30°**	31 cm LOS or **22cm @ 45°**
6-7cm APDS =	28cm LOS or **24cm @ 30°**	28 cm LOS or **20cm @ 45°**
9**0-122mm APC** =	24cm LOS or **21cm @ 30°**	27 cm LOS or **19cm @ 45°**
HEAT=	36cm LOS or **31cm @ 30°**	50cm LOS **or 35cm @ 45°**

[¼ front turret profile] Turret corner front — [1/3 side Turret profile]

	Turret corner front	1/3 side Turret
2cm APFSDS	= 45cm LOS or **22.5cm @ 60°**	26cm LOS or **22.5cm @ 30°**
3cm APFSDS	= 39cm LOS or **19.5cm @ 60°**	22.5cm LOS or **19.5cm @ 30°**
4cm APFSDS	= 35cm LOS or **17.5cm @ 60°**	20cm LOS or **17.5cm @ 30°**
6-7cm APDS	= 31cm LOS or **15.5cm @ 60°**	18cm LOS or **15.5cm @ 30°**
9**0-122mm APC**	= 30cm LOS or **15cm @ 60°**	17cm LOS or **15cm @ 30°**
HEAT=	70cm LOS or **35cm @ 60°**	17cm LOS or **35cm @ 30°**

[2/3 side Turret profile] rear ;

Ranges from 28cm thick aluminum/ cast near front , with ~ 15cm cast side armor thinning to ~ 6cm Cast around back . The half and half cast / aluminum KE armor is rougly 0.68-0.61 while the HEAT armor is ~ 0.93 [from above] , while the cast armor is 0.95/1.0

2/3 side turret [Rear]
Vs APC 15.5cm LOS or **13.4cm @ 30°**
Vs APDS 16.1cm LOS or **14cm @ 30°**
Vs APFSDS 16.8cm LOS or **14.5cm @ 30**
Vs HEAT = 17.3cm LOS or **15cm @ 30°**

Rear turret

97mm @ 30° x 30°= LOS thickness of 125mm Cast x 0.95 = 12cm KE & 13cm HEAT. In the rear turret are sometimes mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor
Vs API/APDS **=** 12+ 0.8 = 12 cm or **10.6cm @ 30°**
Vs HEAT 13 cm+ 0.2 + 19/7 + 0.7d or 32/20cm LOS **or 28/17cm @ 30° +0.7d**

[2/3 Front Hull profile] Hull Glacis

The assumed armor mass average is ~35 cm on the glacis @ 67-68°= 133mm steel mass @ angle ,of which 110mm is steel and the other 33 mm is converted into ~10.5cm thickness which suggest a density of ~ 1.7g/cc , which is in the same region as the Steltexolite [STEF=1.85g/cc] . Most sources reported the glacis @ 215mm @ 67-68° thick with layers of 60mm steel plate & 105mm Steltexolite & 50mm steel back plate.

6cm RHA x 1.0/1.0 [Te] x 0.97/0.95/0.9 or 0.88 / 0.6 [t/d] = 5.8/5.7/5.4/ 5.2cm & 6cm [HEAT]
2x 5.25 cm STEF x 0.4/ 0.45 [Te] x 0.7/0.6/0.55 [t/d] or 0.5 [T/d APDS] = 2.8/2.4/2.2/2.0cm & 4.5cm
5cm RHA x 1.0/1.0 [Te] x x 0.97/0.95/0.9 or 0.88/0.6 [t/d] = 4.8/4.7/4.5/4.2 & 5cm [HEAT]
Modifiers x 1.2 [HEAT] & KE x 1.2 [RHA confinement] ÷ 0.38 [Cos of glacis]
Total Vs
2cm APFSDS = 13.4 x 1.2 ÷ 0.38 = 42cm LOS or **16cm @ 67°**
3cm APFSDS = 12.8 x 1.2 ÷ 0.38 = 40cm LOS or **15.2cm @ 67°**
4cm APFSDS = 12.1 x 1.2 ÷ 0.38 = 38.2cm LOS or **14.5cm @ 67°**
5-6cm APDS = 11.2 x 1.2 ÷ 0.38 = 35cm LOS or **13.3cm @ 67° 100-105mm**

7.2cm APDS = 10.8 x 1.2 ÷ 0.38 = 34cm LOS or **13cm @ 67° 120-122mm**
HEAT = 15.5 x 1.2 ÷ 0.38 [Cos]=49cm LOS or **18.6cm @ 67°**
Niistali reports the second model T-72 which is reported to have the same glacis arrangement to have a KE resistance of 40cm and HEAT resistance of 49cm
.http://www.niistali.ru./english/products/t72/T-72_1.htm

[1/3 Front Hull profile] Lower hull is 8cm RHA plus 2cm dozer plate @ 60° = LOS thickness of **20cm LOS** armor, x t/d [0.88/0.92/0.94/0.96/0.98]....but the spaced plate should add 1.3d to APFSDS & 2.6d to sheathed penetrators.The RHAe should work out to

2cm APFSDS = 7.8cm+ 1.4cm + 2.6cm = **21cm LOS or 10.5cm** @ 60°
3cm APFSDS = 7.7cm+ 1.4cm + 3.7cm = **22cm LOS or 11cm** @ 60°
3.5cm sheathed APFSDS = 7.6cm+ 1.3cm + 9cm = **27cm LOS or 13.5cm** @ 60°
5-6cm WC APDS = 7.3cm+ 1.3cm + 12.5cm = **30cm LOS or 14.8cm** @ 60°
6-7cm WHA APDS = 7.2cm+ 1.3cm + 6cm = **23cm LOS or 11.5cm** @ 60°
HEAT 2cm MS plate x 0.8 x 3 + 8cm RHA = **26cm LOS or 13cm** @ 60° **+ 0.7d**

SIDE Hull is 6cm Hard RHA steel base side hull armor on the basic T-64. The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional
Above trackguard = **12cm KE and ~ 25cm HEAT armor** .
Below trackguard = side skirt area has a ~3cm thick metal reinforced side skirt is mounted over the side track area..The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap increases the HEAT armor

Vs 3cm API ~ 6.6+2.9+1cm = **10.5cm @ 0°**
Vs 25mm APDS ~ 6.6+2.8+1.5cm = **11cm @ 0°**
Vs 25mm APFSDS ~ 6.6+2.7+1.5cm = **11cm @ 0°**
HEAT ~6.6 + 2 + 19/7 + 1.0d **= 27/15cm @ 0° + 1.0d HEAT**

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear
¼ [engine deck] **~ 2cm KE & 2cm HEAT @ 90°**
¼ [front hull deck & tracks] **~ 4cm. KE & 5cm HEAT @ 90°**
¼ [top turret] **~ 4cm. KE & 8cm HEAT @ 75°**
1/8th [front/sides & rear turret] ~ **30cm KE & 50cm HEAT @ 90°**
1/8th [glacis] ~ **14cm KE & 17cm @ 68° HEAT**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT
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T-64BV T-72AV & T-64RV.

Starting in 1984 the T-64BV entered service & the T-72AV in 1988, the only apparent difference is the inclusion of Kontakt ERA plus a spall liner and in mid 1980s ,plus improved APFSDS ammo[BM-26/29/32?] .Most were converted from earlier models and the
T-64RV represents rebuilds of earlier T-64 models to this level.The T-64BV is treated as the same as T-64B front turret armor with Kontakt & Liner.Close examination reveals that the ERA element is a thin steel box with two ERA plates may be as much as 4mm thick ,which at the ~ 68° angle and explode in an upward direction. These should offer ~ 0.5cm RHA + 1.5d = **+3-6cm KE protection [2cm APFSDS - 4cm sheathed]**.The HEAT resistance should be and these offer 2 x 4mm x 20 ÷ 0.38 = +**42 cm HEAT** armor. **.The Liner should add 1cm KE & 2cm HEAT on the side and front turret.**

	½ front profile		½ front profile with Kontakt		
2cm APFSDS = 33cm	45cm @ corners	[39±6cm average]	37cm	49cm @ corners	[43±6cm average]
3cm APFSDS = 29cm	39cm @ corners	[34±5cm average]	34cm	44cm @ corners	[39±5cm average]
4cm APFSDS = 27cm	35cm @ corners	[31±4cm average]	33cm	41cm @ corners	[37±4cm average
5-6cm APDS = 25cm	31cm @ corners	[28±3cm average]	32cm	38cm @ corners	[35±3cm average]
HEAT= 51cm	64cm @ corners	[57±7cm average]	95cm	108cm @ corners	[101±7cm average]

[¼ front turret profile] **Upper front turret** = 5m @ 76°= LOS thickness 205mm cast plus 5cm Steltexolite bolted to the roof armor. This material resists a lot like aluminum or 0.4Te KE and 0.6 Te HEAT [increased by 20% due to layering]. Inaddition about ½ of the upper front turret is covered in Kontakt ERA.

	½ exposed	or	½ covered in ERA
Vs Steel/Sheathed APFSDS	= 25.0cm LOS or **6.6cm @ 75°** ***¼ ricochet***		**7cm @ 75°**
Vs 2-3cm APFSDS	**=** 26.0cm LOS or **6.7cm @ 75°**		**7.6cm @ 75°**
Vs 2cm APFSDS	= 27.1cm LOS or **6.9cm @ 75°**		**7.6cm @ 75°**
Vs HEAT	= 38cm LOS or **9.8cm @ 75°** ** **old warheads may ricochet** **		**12/ 11cm@ 75° + 3d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ¼ Kontakt & ¾ exposed armor
From 30° off angle treat all hits as the 'average' value.

[¼ front turret profile] [MG port to gunsite] Mantle (cast) | **[¼ front turret profile] Middle Turret**

	¾ exposed or	[¼ with ERA]	½ exposed or	[½ with ERA]
2cm APFSDS =	33cm LOS or **29cm @ 30°**	**[32cm @ 30°]**	39 cm LOS or **27cm @ 45°**	**[30cm @ 45°]**
3cm APFSDS =	32cm LOS or **28cm @ 30°**	**[34cm @30°]**	34cm LOS or **24cm @ 45°**	**[27cm @ 45°]**
4cm APFSDS =	31cm LOS or **27cm @ 30°**	**[29cm@ 30°]**	31 cm LOS or **22cm @ 45°**	**[26cm @ 45°]**
6-7cm APDS =	28cm LOS or **24cm @ 30°**	**[28cm@30°]**	28 cm LOS or **20cm @ 45°**	**[24cm@45°]**
HEAT=	36cm LOS or **31cm @ 30°**	**[39/34cm @ 30° + 3d]**	50cm LOS **or 35cm @ 45°**	**[41/38cm @ 45°+ 4.0d]**

[¼ front turret profile] Turret corner front | [1/3 side Turret profile]

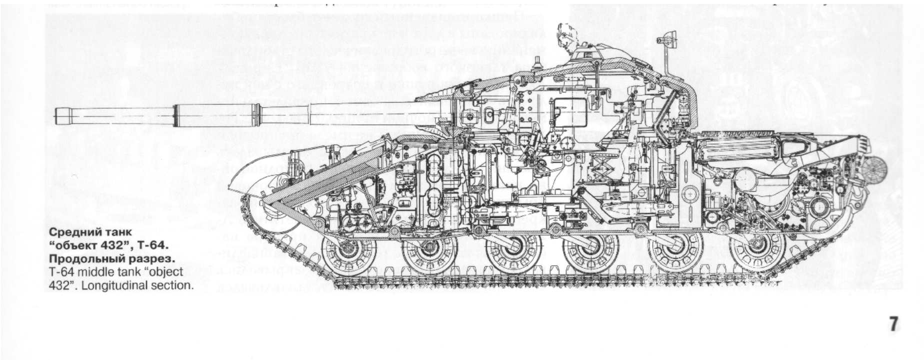
	¼ exposed or	[¾ with ERA]	¼ exposed or	[¾ with ERA]
2cm APFSDS	= 45cm LOS or **22.5cm @ 60°**	**[24cm@ 60°]**	26cm LOS or **22.5cm @ 30°**	**[24cm@ 30°]**
3cm APFSDS	= 39cm LOS or **19.5cm @ 60°**	**[22cm @ 60°]**	22.5cm LOS or **19.5cm @ 30°**	**[22cm @ 30°]**
4cm APFSDS	= 35cm LOS or **17.5cm @ 60°**	**[20cm @ 60°]**	20cm LOS or **17.5cm @ 30°**	**[20cm @ 60°]**
6-7cm APDS	= 31cm LOS or **15.5cm @ 60°**	**[19cm@ 60°]**	18cm LOS or **15.5cm @ 30°**	**[19cm@ 60°]**
HEAT=	70cm LOS or **35cm @ 60°**	**[41/37cm@ 60°+ 4d]**	17cm LOS or **35cm @ 30°**	**[41/37cm@ 60°+ 4d]**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ¼ Kontakt & ¾ exposed armor
From 30° off angle treat all hits as the 'average' value.

[2/3 side Turret profile] rear ; Ranges from 28cm thick aluminum/ cast near front , with ~ 15cm cast side armor thinning to ~ 6cm Cast around back . The half and half cast / aluminum KE armor is rougly 0.68-0.61 while the HEAT armor is ~ 0.93 [from above] , while the cast armor is 0.95/1.0

	2/3 side turret [Rear]
Vs APC	15.5cm LOS or **13.4cm @ 30°**
Vs APDS	16.1cm LOS or **14cm @ 30°**
Vs APFSDS	16.8cm LOS or **14.5cm @ 30**
Vs HEAT	= 17.3cm LOS or **15cm @ 30°**

Rear turret 97mm @ 30° x 30°= LOS thickness of 125mm Cast x 0.95 = 12cm KE & 13cm HEAT. In the rear turret are sometimes mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor
Vs API/APDS **=** 12+ 0.8 = 12 cm or **10.6cm @ 30°**
Vs HEAT 13 cm+ 0.2 + 19/7 + 0.7d or 32/20cm LOS **or 28/17cm @ 30° +0.7d**



V.Chobitok's "Main battle tank T-64"

[2/3 Front hull profile] Glacis The assumed to be T-64B plus Kontakt ERA covering ¾ of the glacis profile. These should add **+3-6cm KE protection [2cm-4cm APFSDS]** and **+42 cm HEAT** armor.

Total Vs ¼ glacis profile or ¾ glacis profile with Kontakt ERA.
2cm APFSDS = 42cm LOS = **16cm@ 67°** 45cm LOS = **17cm@ 67°**
3cm APFSDS = 40cm LOS = **15cm@ 67°** 43cm LOS = **16cm@ 67°**
4cm APFSDS = 38.2cm LOS = **14.5cm@ 67°** 40cm LOS = **15cm@ 67°**
5-6cm APDS = 36.9cm LOS = **14cm@ 67°** 39cm LOS = **15cm@ 67°**
[HEAT] = 49cm HEAT LOS = **19cm@ 67°** 58/53cm LOS = **22/20cm@ 67° + 4d**
Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ½ Kontakt & ½ exposed armor

[1/3 Front Hull profile] Lower hull is 8cm RHA plus 2cm dozer plate @ 60° = LOS thickness of **20cm LOS** armor, x t/d [0.88/0.92/0.94/0.96/0.98]....but the spaced plate should add 1.3d to APFSDS & 2.6d to sheathed penetrators.The RHAe should work out to
2cm APFSDS = 7.8cm+ 1.4cm + 2.6cm = **21cm LOS or 10.5cm** @ 60°
3cm APFSDS = 7.7cm+ 1.4cm + 3.7cm = **22cm LOS or 11cm** @ 60°
3.5cm sheathed APFSDS = 7.6cm+ 1.3cm + 9cm = **27cm LOS or 13.5cm** @ 60°
5-6cm WC APDS = 7.3cm+ 1.3cm + 12.5cm = **30cm LOS or 15cm** @ 60°
6-7cm WHA APDS = 7.2cm+ 1.3cm + 7cm = **24cm LOS or 12cm** @ 60°
HEAT 2cm MS plate x 0.8 x 3 + 8cm RHA = **26cm LOS or 13cm** @ 60

SIDE Hull is the basic side hull T-64 60mm Hard RHA armor ,with the steel rubber side skirt reinforced with Hvy Kontakt 5 ERA. Below trackguard = side skirt area has a ~3cm thick metal reinforced side skirt is mounted over the side track area..The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap . Kontakt ERA is added over most of the side hull adding ~2cm KE resistance and 3d HEAT reduction.

¼ rear side hull ¾ front side hull with Kontakt ERA
Vs 3cm API ~ 6.6+2.9+1cm = **10.5cm @ 0°** **13cm @ 0°**
Vs 25mm APDS ~ 6.6+2.8+1cm = **10.4cm @ 0°** **13cm @ 0°**
Vs 25mm APFSDS ~ 6.6+2.7+1cm = **10.3cm @ 0°** **13cm @ 0°**
HEAT ~ 6.6 + 2 + 19/7 + 1.0d **= 27/15cm @ 0° + 1.0d HEAT** **30/18cm @ 0° + 3.0d HEAT**
Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ¼ Kontakt & ¾ exposed armor

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear
¼ [engine deck] **~ 2cm KE & 2cm HEAT @ 90°**
¼ [front hull deck & tracks] **~ 4cm. KE & 5cm HEAT @ 90°**
¼ [top turret] **~ 4cm. KE & 8cm HEAT @ 75°**
1/8th [front/sides & rear turret] ~ **30cm KE & 50cm HEAT @ 90°**
1/8th [glacis] ~ **15cm KE @ 68° & 20cm HEAT @ 68° + 2d**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the ‘ground clearance’ should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**

Rear ½ = 2cm KE and 22/7cm HEAT
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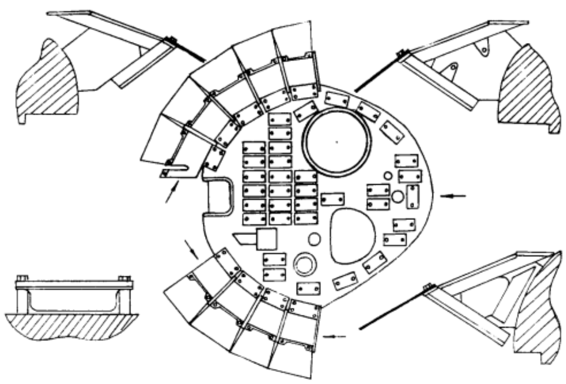
T-64U & T-72A+K-5 [T-72MP?] [Tentative]

This is a 1999s modification to the existing stocks of T-64 in Ukrainan service ,to bring them up todate with T-84D standards. This upgrade features FCS and sensor upgrades with the option to mount French 120mm and later 140mm guns plus a thermal sight. The main component of the armor up grade is "Arena" active defence system and "Kontakt 5" applique armor, but its likely the front armor inserts where also upgraded at the same time.There is clear evidence of a thick[4-5cm] liner plastered all over the interior of these turrets,this also doubles as a anti radiation sheild.The article below reports the following *"The First variant of modernization consist in installation of the built - in dynamic protection of the Ukrainian development on serial tanks T-64BV and ?-64??-1."*This reference to built in dynamic protection, strongly suggest the use of BDD type internal 'spaced plate armors ' like mounted in the T-72B & improved in the T-90 tanks.

http://armor.kiev.ua/Tanks/Modern/T64/t64u.html

V.Chobitok's "Main battle tank T-64",
http://www.t-64.de/frame-start.htm



http://armor.kiev.ua/Tanks/Modern/T64/t64u.html

Front Turret **[2/3 front turret profile]** This is assumed to be the T-64B with the insert replaced by the same type of armor applied to the T-72B tank turret., plus Kontakt 5 heavy ERA The T-64B front turret armor mass is 31 cm steel and the LOS thickness ranges from 41cm LOS near the gun to 60cm LOS thickness. This leads to an average of ~5g/cc [31/50cm] cross sectional density and average insert density of ~3.3g/cc. The T-72B/90 internal appliqué has 43cm insert appliqué with an approximate density of 3g/cc, so this is easly adaptable to the T-64U insert.

17 cm cast x 0.95 /1.0 [Te] x [T/d] 0.94/0.92/0.9/0.88/0.95 = 15.2/14.9/14.5/14.2/15.3 cm & 17cm
8cm Al type 7xxx back plate x 0.96/0.94/0.92t/d & Te 0.41/0.6 = 3.1/3.1/3cm & 4.8cm
13cm MS/rubber/MS x 0.64/0.9[te] x 0.85/0.8/0.7 [t/d] 7cm/ 6.6cm/5.8cm & 11.7cm
coverplate x 1.18 / 1.2 & Lateral confinement is 0.9-0.95 & 0.8 near the mantle.
26.5cm airgap
KE 'Spaced plate effect' = 2-4 x 6.4d/5.8d/10.8d...+ 12.8/17.4/34.5cm....
Spaced plate effect on HEAT should be only around 1.1 times the TE/LOS figure, however this is a energetic armor and in theory its spaced plate increase should be a lot more. If there was sufficient airgap this would be the case , but like KE figures the gap is insufficient.Looking at it another way, thin spaced plates offer ~ 3 times their Te/LOS effectiveness but thick plates only offer 5% to 20% improvement in their Te/LOS. When compared to energetic armors this is doubled to ~ 6 times and 10% - 40% improvement, respectively.K-5 should add 18-19cm KE resisance

	½ front turret	½ front turret with K-5 ERA
2cm APFSDS	= 24cm + 12.8= **37 49cm [Average 43 ± 10cm]**	plusERA K5 = **49 73cm [Average 61± 14cm]**
3cm APFSDS	= 23.4cm + 17.3= **31 50cm [Average 41± 10cm]**	plus ERA + K5 = **49 69cm [Average 59± 10cm]**
3.5cm sheathed	= 23cm + 34.5= **31 67cm [Average 52± 16cm]**	plus ERA + K5 = **55 91cm [Average 75±16cm]**
HEAT	11.7 + 4.8 + 17cm x 1.2= **40 49cm HEAT[Average 45± 5cm]**	plus ERA + 50cm = **45 55cm [50±5cm] + 4d**

From 30° off angle treat all hits as the 'average' value.
Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 4 of above values, except 3.5cm Sheathed, in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 26cm. If the armor is struck by tandem charges, the '+3d' is not added.

Upper front Turret **[1/3 front turret profile] See previous entry.**

Side turret .Is based on T-64BV with K-5 ERA and outer steltexolite layer [5cm thick] in addition to the inner Polyeythlin liner [PE] . **The PE Liner should add 1cm KE & 2cm HEAT, while the outer steltexolite layer should add 2cm KE & 4cm HEAT on the side turret and front turret.**The effective KE armor ranges from **25-19cm [2-4cm APFSDS]** near the front to **9-10cm KE** around back. The HEAT armor ranges from **45cm** near the front down to **30cm** on the side turret and **25-30cm** around back. The Kontakt ERA covers ¼ of the side turret profile, near the front and should add **40-50cm HEAT** & ~ **18/23cm KE [APFSDS/sheathed] .**
Thus the front Side turret should offer **.....**

¼ 40cm[APFSDS] 45cm [Sheathed] & 90cm HEAT [with K-5 ERA]
¼ 25-19cm KE & 45cm HEAT
¼ 19cm KE & 35cm HEAT
¼ 9-10cm KE & 25-30cm HEAT [also the rear turret armor]

If more than 6 hits on the side turret then K-5 covered areas are considered "reduced" and should have the KE resistance reduced by 4cm [7cm if sheathed APFSDS], while the HEAT resistance should go down 26cm

[2/3 Front hull profile] Glacis The assumed to be T-64B plus Kontakt ERA covering ¾ of the glacis profile. These should add **+3-6cm KE protection [2cm-4cm APFSDS]** and **+42 cm HEAT** armor.

Total Vs	**¼ glacis profile**	**or ¾ glacis profile with Kontakt ERA.**
2cm APFSDS =	42cm LOS = **16cm@ 67°**	45cm LOS = **17cm@ 67°**
3cm APFSDS =	40cm LOS = **15cm@ 67°**	43cm LOS = **16cm@ 67°**
4cm APFSDS =	38.2cm LOS = **14.5cm@ 67°**	40cm LOS = **15cm@ 67°**
5-6cm APDS =	36.9cm LOS = **14cm@ 67°**	39cm LOS = **15cm@ 67°**
[HEAT] =	49cm HEAT LOS = **19cm@ 67°**	58/53cm LOS = **22/20cm@ 67° +4d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ½ Kontakt & ½ exposed armor

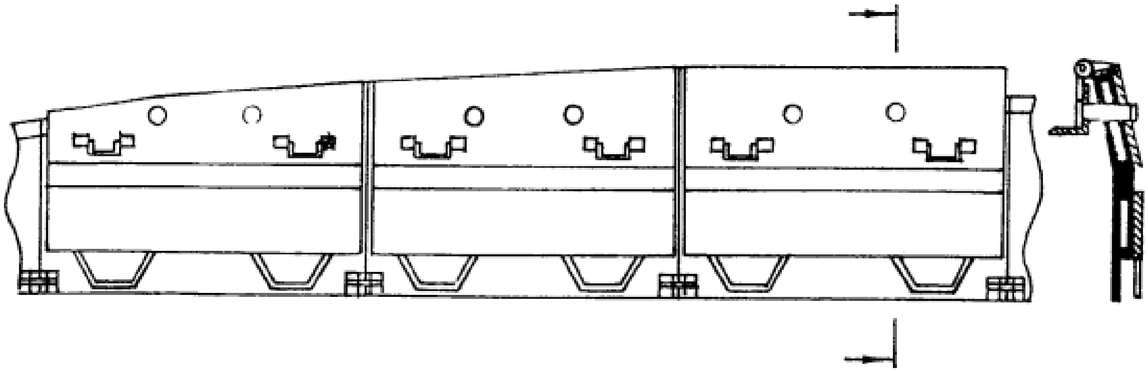
[1/3 Front Hull profile] Lower hull is 8cm RHA plus 2cm dozer plate @ 60° = LOS thickness of **20cm LOS** armor, x t/d [0.88/0.92/0.94/0.96/0.98]....but the dozer blade adds spaced plate should add 1.3d to APFSDS & 2.6d to sheathed penetrators. Steel reinforced rubber 3cm thick sheet is suspended from the nose of the tank to act as another improvised spaced plate The RHAe should work out to

	¼ lower hull plus blade	¾ lower hull plus blade with steel/rubber sheet
2cm APFSDS =	7.8cm+ 1.4cm + 2.6cm = 21cm LOS or **10.5cm @ 60°**	+2cm or **12.5cm @ 60°**
3cm APFSDS =	7.7cm+ 1.4cm + 3.7cm = 22cm LOS **or 11cm @ 60°**	+ 2cm or **13cm @ 60°**
3.5cm sheathed APFSDS =	7.6cm+ 1.3cm + 9cm = 27cm LOS or **13.5cm @ 60°**	+ 4cm or **17.5cm @ 60°**
5-6cm WC APDS =	7.3cm+ 1.3cm + 12.5cm = 30cm LOS or **14.8cm @ 60°**	**+** 5cm or **19.8cm @ 60°**
6-7cm WHA APDS =	7.2cm+1.3cm + 6cm = 23cm LOS or **11.5cm @ 60°**	+2.5cm or **13cm @ 60°**
HEAT 2cm MS plate x 0.8 x 3 + 8cm RHA	= **26cm LOS or 13cm @ 60°+ 0.7d**	47/ 30cm LOS or **23/15cm @ 60°+ 0.6d**

SIDE Hull is 6cm hard RHAsteel base side hull armor on the basic T-64B. The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional
Above trackguard = **12cm KE and ~ 25cm HEAT armor** .
Below trackguard = side skirt area has a ~3cm thick metal reinforced side skirt is mounted over the side track area..The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap increases the HEAT armor

	Rear ½ Side Hull	Front ½ Side Hull with K-5 ERA
Vs 3cm API/APDS/APFSDS	~ 6.6+2.9+1cm = **10.5cm @ 0°**	**24cm @ 0°**
Vs 2cm APDS /APFSDS	~ 6.6+2.8+1cm = **10.4cm @ 0°**	**21cm @ 0°**
Vs 2cm HS APFSDS	~ 6.6+2.7+1cm = **10.3cm @ 0°**	**15cm @ 0°**
HEAT	~8 + 2 + 19/7 + 1.0d **= 27/15cm @ 0° + 1.0d HEAT**	**33/21cm @ 0° + 2.0d HEAT**

Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 2 of above values off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 2d.



http://armor.kiev.ua/Tanks/Modern/T64/t64u.html

The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional **12cm KE and ~ 25cm HEAT armor.**.

Rear hull

46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor

is in three sections , the rear
¼ [engine deck] **~ 2cm KE & 2cm HEAT @ 90°**
¼ [front hull deck & tracks] **~ 4cm . KE & 5cm HEAT @ 90°**
¼ [top turret] **~ 4cm . KE & 8cm HEAT @ 75°**
1/8 th [front/sides & rear turret] ~ **30cm KE & 50cm HEAT @ 90°**
1/8 th [glacis] **~ 15cm KE @ 68° & 20cm HEAT @ 68° + 2d**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT

---REST as T-64BV-------------------------------------

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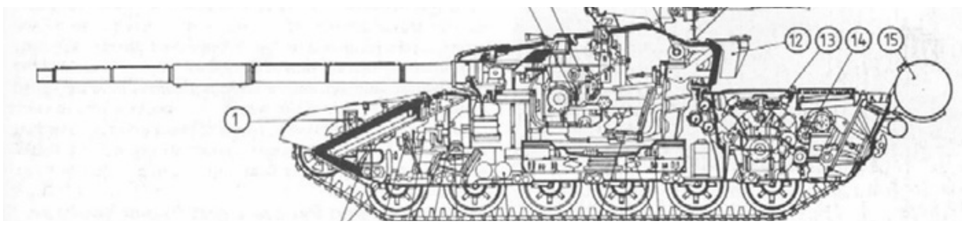
T-72 export [T-72G and T-72M]

Russian NII Stali website claims the T-72 fron turret is "cast armor 380mm KE 410mm HEAT" and the "glacis is combined with glass
reinforced plastic (GRP) 335mm KE 450mm HEAT" . Turret front ranges from 41cm LOS near the turret corners to 28cm LOS thickness at the gun embrasure , the armor is cast armored steel and should offer 0.95 of RHA . But The armor closest to the gun is the 'weakened zone'and offer less armor than the effective thickness suggests .The T-62-T-72 armor mass comparison works out to: Volume ~12.5m^3 11.0m^3 [+14%] ; Mass 36.3 38.6 tons [+6%] and Profile 4.0 m² 3.8m² [+ 5%]. For a total potential mass increase of 27% or 1.27 x 216mm = 274mm frontal steel armor mass. Since the glacis is assumed to be the same as the T-64 tank then the mass distribution looks like 274mm x 10 - 3 x 316mm Glacis –4 x 200mm upper front turret & lower hull. This leaves an average of 331mm for the front turret. This suggests the armor distribution goes from 41cm LOS near the turret corners to ~ 25cm LOS around the gun.



Vasiliy Fofanov

Front Turret 20cm cast @ 60 x 20°[~41cm LOS turret corner] 25cm cast @ ~ 30° [28cm LOSbaround MG port], depending on the projectile [t/d and lateral confinement = "Lc & T/d"] the resistance should range from….
APDS [Lc & T/d] {0.94 x 41cm to 0.82 x 28cm } x 0.95 [cast] = 21cm 37cm [average 29± 8cm]
3cm APFSDS [Lc & T/d] {0.97x 41cm to 0.9 x 28cm } x 0.95 [cast] = 24cmm 38cm [average 31± 7cm]
2cm APFSDS [Lc & T/d] {0.98x 41cm to 0.96 x 28cm } x 0.95 [cast] = 25cm 38cm [average 32 ± 6cm]
HEAT = 28- 41cm average 35± 6cm RHAe

[¼ front turret profile] Upper front turret = 5cm @ 77°= LOS thickness of 22cm cast x 0.95 [cast] x T/d [0.75/0.85/0.88/0.92/0.94] =
Vs APC = 14.0cm LOS or **4.2cm @ 75°** ** **ricochet** **
Vs APDS **=** 15cm LOS or **4.5cm @ 75°** ** **ricochet** ** [* ½ ricochet* if WHA APDS L52 or L16]
Steel/Sheathed APFSDS = 15.9cm LOS or **4.7cm @ 75°** * **¼ ricochet** *
2- 3cm APFSDS **=** 16.9cm LOS or **5cm @ 75°**
Vs HEAT = 19cm LOS or **5.6cm @ 75°** ** **old warheads may ricochet** **

[¼ front turret profile] [MG port to gunsite] Mantle		**Middle Turret [¼ front turret profile]**
2cm APFSDS =	= 26cm LOS or **25cm @ 30°**	34.5 cm LOS or **22cm @ 45°**
3cm APFSDS =	= 26cm LOS or **24cm @ 30°**	34.5cm LOS or **22cm @ 45°**
4cm APFSDS =	= 26cm LOS or **23cm @ 30°**	34.5 cm LOS or **22cm @ 45°**
6- 7cm APDS =	= 25.5cm LOS or **22cm @ 30°**	34.5 cm LOS or **22cm @ 45°**
9**0- 122mm APC**	= 25cm LOS or **21cm @ 30°**	34.5 cm LOS or **22cm @ 45°**
HEAT=	= 33cm LOS or **28cm @ 30°**	34.5cm LOS **or 24cm @ 45°**

[¼ front turret profile] Turret corner		**[1/3 side Turret profile] front**
2cm APFSDS	= 38cm LOS or **19cm @ 60°**	**19cm @ 30°**
3cm APFSDS	**=** 38cm LOS or **19cm @ 60°**	**19cm @ 30°**
4cm APFSDS	= 37cm LOS or **18.5cm @ 60°**	**18.5cm @ 30°**
6- 7cm APDS	= 37cm LOS or **18.5cm @ 60°**	**18cm @ 30°**
9**0- 122mm APC**	**=**36cmLOS or **18cm @ 60°**	**18cm @ 30°**
HEAT=	= 41cm LOS or **20cm @ 60°**	**20cm @ 30°**

[2/3 side Turret profile] rear ; Ranges from 28cm thick aluminum/ cast near front , with ~ 15cm cast side armor thinning to ~ 6cm Cast around back . The half and half cast / aluminum KE armor is rougly 0.68- 0.61 while the HEAT armor is ~ 0.93 [from above] , while the cast armor is 0.95/1.0
2/3 side turret [Rear]
Vs APC 15.5cm LOS or **13.4cm @ 30°**
Vs APDS 16.1cm LOS or **14cm @ 30°**
Vs APFSDS 16.8cm LOS or **14.5cm @ 30**
Vs HEAT = 17.3cm LOS or **15cm @ 30°**

Rear turret 97mm @ 30° x 30°= LOS thickness of 125mm Cast x 0.95 = 12cm KE & 13cm HEAT. In the rear turret are sometimes mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor
Vs API/APDS **=** 12+ 0.8 = 12 cm or **10.6cm @ 30°**
Vs HEAT 13 cm+ 0.2 + 19/7 + 0.7d or 32/20cm LOS **or 28/17cm @ 30° +0.7d**

[2/3 Front Hull profile] Hull Glacis ; The assumed armor mass average is 316 mm on the glacis @ 67- 68°= 120mm steel mass @ angle ,of which 100mm is steel and the other 20 mm is converted into ~10.5cm thickness which suggest a density of 1.5g/cc , which is in the same region as the Steltexolite [ST- 1=1.7g/cc] . Most sources reported the glacis @ 205mm @ 67- 68° thick with layers of 80mm RHA & 105mm Steltexolite & 20mm RHA.The 20mm plate is assumed to be hardened RHA steel with a hardness around 400BHN

8cm RHA x 1.0/1.0 [Te] x 0.99/0.97/0.94 [t/d] or 0.9 [APDS t/d] = 7.9/7.8/7.5cm; 7.2cm & 8cm [HEAT]
2x 5.25 cm ST- 1 x 0.3/ 0.38 [Te] x 0.7/0.6/0.55 [t/d] or 0.5 [T/d APDS] = 2.2/1.9/1.7; 1.57cm & 3.93cm
2cm SHS x 1.16/1.16 [Te] x 0.88/0.7/0.6 [T/d] or 0.5 [APDS t/d] = 2.0/1.6/1.38cm/ 1.16cm & 2.32cm [HEAT]
Modifiers x 1.24 [Thick confinement] x 0.95 [thin backing]÷ 0.38 [Cos of glacis]
Total Vs
Vs 2cm APFSDS = 12.1 x 1.18 ÷ 0.38 = 37.5cm LOS **or 14.2cm @ 68°**

Vs 3cm APFSDS = 11.3 x 1.18 ÷ 0.38 = 35cm LOS o**r 13.3cm @ 68°**
Vs 4cm APFSDS = 10.58 x 1.18 ÷ 0.38 = 32.8cm LOS **or 12.3cm @ 68°**
Vs 6-7cm APDS = 9.9 x 1.18 ÷ 0.38 = 30.7cm LOS **or 11.7cm @ 68°**
Vs HEAT = 14.25 x 1.2 ÷ 0.38 [Cos]= 45cm LOS **or 17.1cmHEAT** ** old warheads may ricochet **

The NiStalii Website quoted the glacis of the basic T-72 @ resistance of 335mm Vs APFSDS and 450mm HEAT while the above prediction is 339mm Vs a 35mm wide M-735 APFSDS [less than 1% error] .This glacis is also reported to be 80mm RHA plus 2 plates of Steltexolite [105mm total] and a 20mm RHA back plate set back at 67-68°. This glacis looks to be exact same layout as T-64. Soviet tests of Iranian TOW missiles showed that the majority of the missiles failed to detonate on the T-64 glacis , due to the severe angle of impact…its also interesting to note that the Milan missile is only rated as being effective at impact angles upto 65°….However Tests on the SS-10 ATGM showed it could detonate on RHA plates @ 70°.

[1/3 Front Hull profile] Lower hull JANES reports 100cm @ 60° ~ 290-300 BHN RHA = LOS thickness of 173mm , x t/d [0.88/0.92/0.94/0.96/0.98]….
Vs APC = 17.5cm LOS or **8.7cm @ 60°** * ½ **ricochet** *
Vs APDS & 4cm APFSDS = 18.5cm LOS or **9.2cm @ 60°**
Vs 2-3cm APFSDS & HEAT = 19.6cm LOS or **9.8cm @ 60°**

SIDE Hull Side armor looks like **6cm** thick , this must be an averaging of the 8cm upper sidehull of the T-54-62 tanks and the 2cm thick area around the wheels. The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional
Above trackguard = **12cm KE and ~ 25cm HEAT armor** .
Below trackguard =
7.5cm vs API/20-30mm APDS/APFSDS & HEAT
6.5cm vs large APDS
5cm large APC/HVAP

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d . The engine block and inner bulk head creat a 'spaced armor' cavity protecting the crew. However penetration through this engine area is likely to result in 'mobility loss'. The rear engine cavity is about 4 m^3 and the engine block is about 1 m^3 . In addition the drive train and airducts occupy a lot of this space including some fuel/oil tanks.Taking the engine block as a reference point ,the engine is 900kg &~ 1m volume ? That's a bulk density of 900kg/m^3 . This level of bulk density is similar to water or a light weight plastic and its unlikely to offer more than ~0.2 Te vs Heat and 0.1 Te vs KE threats. Given the thickness it ~ 2 meters it should offer about about 200-400mm additional protection at the cost of vehicle mobility.
. Th
1920kg/1.5m ; bulk density =1280kg/m^3 2700kg/1.64m ; bulk density =1646kg/m^3
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in severarl sections .
½ [engine deck & tracks] **~ 2cm RHA KE & HEAT @ 90°**
¼ [top turret & front hull deck] **~ 5cm . KE & HEAT @ 90°**
1/8 th [front/sides & rear turret] ~ **30cm @ 90° KE & HEAT**
1/8 th [glacis] ~ **10cm @ 60° KE & HEAT**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT

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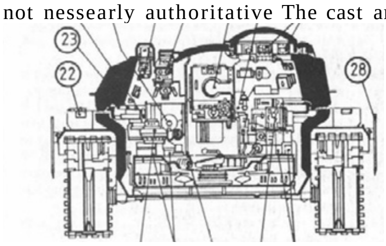
 T-72M-1 & M-84

V.Chobitok's "Main battle tank T-64",
http://www.t-64.de/frame-start.htm
Vasiliy Fofanov
http://armor.kiev.ua/fofanov/

Starting in 1979 a improved model of the export T-72 appeared with a T-64 type turret but with cheaper materials substituted. The M-84 is the Yugoslave copy of this T-72M1 tank. The Russian NII Stali website claims this T-72 M1 turret armor is *"cast steel with sandbar 380mm KE & 490 mm HEAT" and the"glacis is combined with glass reinforced plastic (GRP) 400mm KE 490 mm HEAT"* . Steve Zaloga puts the figure at 500mm KE & 560mm HEAT for the turret and 420mm KE and 490mm HEAT on the glacis, but again Zaloga points out these figures are from a CFE document and are not nessearly authoritative The cast armor of the M-84 is thought to be 270 BHN and so is the T-72 cast armor .



The front armor mass from T-72 to T-72A goes from 38.6 to 38.9 tons , when the volume and profile remains the same. So the average frontal armor mass must go from 274mm to 277mm average.The frontal glacis armor is identified as being the same as the T-64B model which is 35cm steel mass while the lower front hull is 24cm LOS and the upper front turret is 22cm LOS. This leaves an average of only 301mm front turret steel mass. Since the front turret thickness ranges from ~ 40cm near the gun to 60cm @ the turret corners, there clearly must be some low density insert used. **The reports are for "Chernosem " which is a type of 'black sand', that has been described as ' modified sand'. Sand like materials with a density of 1.8g/cc have been tested in the Int.J.Impact Engng Vol 26,pp 675-681 "High speed penetration into sand". 12:1 Steel subscale APFSDS where fired into this medium and produced a resistance of 0.18 Te, while against WHA penetrators the Te was ~ 0.12 .**The steel mass averaged over all thickness works out to an approximate cross sectional density of ~ 4.7 g/cc. If this sand is used then the approximate thickness should be roughly ½ & ½ sand /cast steel. So that should mean 20cm sand sunk into 40cm cast near the gun and at the turret corners 30cm sand is sunk into 60cm cast steel. This combination should offer a resistance of ~ 0.56 Vs steel sheathed APFSDS & 0.53 Vs WHA/DU APFSDS. The Te for sand Vs HEAT warheads should be about 0.35.

Turret front **[2/3 front turret profile]** So near the gun we have 20cm Cast [0.95/1.0] & 20cm sand [0.18 & 0.12/0.35] T/d & Lc should work out to ...
2cm APFSDS [Lc & T/d] {0.99x 60cm to 0.98 x 40cm } x 0.53 [Te] x1.2 [confinement] = **26cm 38cm [average 32± 7cm]**
3cm APFSDS [Lc & T/d] {0.99 x 60cm to 0.93 x 40cm } x 0.53 [Te] x1.2 [confinement] = **25cm 38cm [average 31± 8cm]**
4cm steel/heathed [Lc & T/d] {0.98 x 60cm to 0.9 x 40cm } x 0.56 [Te] x1.2 [confinement] = **25cm 39cm [average 32± 7cm]**
Vs HEAT [20cm x 1.0(te) + 20cm x 0.35 (te) x 1.2 (layer) = **32 49cm RHAe [average 40±8]**
The reported maximum resistance values are 38cm KE & 49cm HEAT [NiStali website]
http://www.niistali.ru./english/products/t72/T-72_1.htm **.**
From 30° off angle, treat all hits as the 'average' value.

[¼ front turret profile] [MG port to gunsite] Mantle (cast)		**Middle Turret [¼ front turret profile]**
2cm APFSDS =	33cm LOS or **29cm @ 30°**	39 cm LOS or **27cm @ 45°**
3cm APFSDS =	32cm LOS or **28cm @ 30°**	34cm LOS or **24cm @ 45°**
4cm APFSDS =	31cm LOS or **27cm @ 30°**	31 cm LOS or **22cm @ 45°**
6-7cm APDS =	28cm LOS or **24cm @ 30°**	28 cm LOS or **20cm @ 45°**
9**0-122mm APC** =	24cm LOS or **21cm @ 30°**	27 cm LOS or **19cm @ 45°**
HEAT=	36cm LOS or **31cm @ 30°**	50cm LOS **or 35cm @ 45°**

Upper front Turret **[1/3 front turret profile]** turret is 5cm @ ~ 77° = 22cm x cast [95%] or **~20 - 19/18 cm cm [2-4cm APFSDS/APDS] and 22cm HEAT.**.By the mid 80s this was greatly upgraded and changed to 5cm cast plus 5cm Steltexolite~ 76-77° or ~42-44cm LOS x 0.66cm KE & 0.85 HEAT ; thus **28 - 29cm KE and 36-37cm HEAT armor.**

Side turret LOS thickness Ranges from 28-29cm thick near front thinning to ~ 13cm around back . This is probably half and half cast / sand thus the KE armor is 0.64 while the HEAT armor is 0.82 .The effective KE armor ranges from **18cm** near the front to **8cm KE** around back. The HEAT armor ranges from **24cm** near the front down **to** **11cm** Around back. In the rear are mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor , this may amount to an additonal **~13-15cm / 5-10cm HEAT** armor. [1st /2nd Gen HEAT]

Hull Glacis The assumed armor mass average is the same as the T-64B or ~35 cm on the glacis @ 67-68°= 133mm steel mass @ angle ,of which 110mm is steel and the other 33 mm is converted into ~10.5cm thickness which suggest a density of ~ 1.7g/cc , which is in the same region as the Steltexolite [STEF=1.85g/cc] . Most sources reported the glacis @ 215mm @ 67-68° thick with layers of 60mm hard steel plate & 105mm Steltexolite & 50mm RHA back plate.

6cm RHA x 1.0/1.0 [Te] x 0.97/0.95/0.9 or 0.88 / 0.6 [t/d] = 5.8/5.7/5.4/ 5.3cm & 6cm [HEAT]
2x 5.25 cm STEF x 0.4/ 0.45 [Te] x 0.7/0.6/0.55 [t/d] or 0.5 [T/d APDS] = 2.8/2.4/2.2/2.0cm & 4.5cm
5cm RHA x 1.0/1.0 [Te] x x 0.97/0.95/0.9 or 0.88/0.6 [t/d] = 4.8/4.7/4.5/4.4 & 5cm [HEAT]
Modifiers x 1.2 [HEAT] & KE x 1.2 [RHA confinement] ÷ 0.38 [Cos of glacis]
Total Vs
2cm APFSDS = 13.4 x 1.2 ÷ 0.38 = **42cm**
3cm APFSDS = 12.8 x 1.2 ÷ 0.38 = **40cm**
4cm APFSDS = 12.1 x 1.2 ÷ 0.38 = **38.2cm**
5-6cm APDS = 11.7 x 1.2 ÷ 0.38 = **36.9cm**
[HEAT] = 15.5 x 1.2 [layering] ÷ 0.38 [Cos of glacis]=**49cm HEAT**

Niistali reports the second model T-72 which is reported to have the same glacis arrangement to have a KE resistance of 40cm and HEAT resistance of 49cm.http://www.niistali.ru./english/products/t72/T-72_1.htm

Lower hull is 8cm RHA plus 2cm dozer plate @ 65° = LOS thickness of **23.5cm LOS** armor , but the spaced plate should add 1.3d to APFSDS & 2.6d to sheathed penetrators.The RHAe should work out to …..
2cm APFSDS = 8cm+ 1.4cm @ 65° + 2.6cm = **25cm**
3cm APFSDS = 8cm+ 1.3cm @ 65° + 3.9cm = **26cm**
3.5cm sheathed APFSDS = 8cm+ 1.4cm @ 65° + 9cm = **31cm**
5-6cm WC APDS = 8cm+ 1.3cm @ 65° + 12.5cm = **34cm**
6-7cm WHA APDS = 8cm+ 1.3cm @ 65° + 6cm = **28cm**
The HEAT resistance should work out to 2cm MS plate x 0.8 x 3 + 8cm RHA @ 65° = **30cm + 0.7d HEAT**

The side hull is assumed to be the same as the T-64B side hull armor with 3cm steel reinforced rubber skirting plate mounted 60cm infront of the 6cm rolled side hull plate.
That's ~ 6+5cm = **11cm Vs 3cm API**
That's ~ 6+6cm = **11cm Vs 1.5cm APDS [25mm APDS]**
That's ~ 6+4cm = **9cm Vs 1cm APFSDS [25mm APFSDS]**
HEAT resistance = 24cm Npj & 35m Pj HEAT
The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional **12cm KE and ~ 25cm HEAT armor.**

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear
1/3 [engine deck] **~ 2cm RHA KE & HEAT @ 90°**
1/3 [top turret & front hull deck] **~ 4cm . KE & HEAT @ 90°**
1/3 [The front turret and glacis] ~ **26cm KE 32/20 HEAT @ 30°**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT

 M-84A & upgraded T-72A

Some time in the mid to late 1980s the T-72A were upgraded to a better level of protection , employing steltexolite coverings on the outer turret weakened side and rear areas and a spall liner inside the turret as well as 16mm hard steel added to the glacis. It appears the tank weight went up 500kg in the process and with the addition of any Kontakt type ERA it would up again by 1.5 tons. In addition to the Kontakt ERA ,the sand bar in the turret was removed and heavily modified .Report from a worker in VTI (Military-technical institute) in Serbia about armor layout on M-84A. "*As he remembered armour is: *turret front is 270BHN cast armour. *Instead of sandbars inserts are: -SiC encased in 2-3mm of Al followed by 10mm of hard rubber, followed by Al-Mg? legure honeycomb filled with quartz sand. He also said that sand is not "free" but mixed with epoxy".[*BOJAN] . If we assume normal tile of ceramic is 2-3cm thick then we get 13cm insert of 2.5-3.5 cm SiC encased in aluminum then 1cm rubber than 9cm Sandbar/Epoxy in a aluminum honeycomb. The mixing of sand and epoxy should reduce the mass to ~ 1.4g/cc and the inclusion of Aluminum honeycomb should only add ~50kg/m^2 ….thus this combination brings the mass back up to 1.65g/cc.The glacis is reported to have 16mm steel added @ 67° which should add ~460kg .So the aluminum encased ceramic tile is likely to only be ~ 6cm thick plus 1cm Rubber .Its likely that the sand impregnated epoxy suspended in an aluminum honey comb , will behave at least as well as a glass reinforced fibre or a TE of 0.33 Vs KE & 0.5 HEAT.

Kontakt ERA :Late model T-72 & M-84s had Kontatk ERA covering roughly ½ of the front tank profile & ¼ of the side tank profile .Close examination reveals that the ERA element is a thin steel box with two ERA plates may be as much as 4mm thick ,which at the ~ 68° angle and explode in an upward direction. These should offer ~ 0.5cm RHA + 1.5d = **+3-6cm KE protection [2cm-4cm APFSDS]**..The HEAT resistance should be and these offer 2 x 4mm x 20 ÷ 0.38 = **+42 cm HEAT** armor

Turret front **[2/3 front turret profile]** ranges from 40cm near the gun to 60cm LOS thickness at the turret corners and the materials should offer the following resistance relative to RHA.
6cm SiC x 1.1/1.4 [Te] x T/d & Lc = [0.67 0.44] = 0.75 0.5/1.4 x 6cm= **4.5cm /3.8cm/3cm& 8.4cm**
19cm epoxy/Sand/Honeycomb x 0.33/0.5 [Te] x 0.98 0.9= **6.15/5.9/5.6cm & 9.5cm**
25cm Cast x 0.95/1.0 x 0.98 0.9 = **23.3/22.3/21.4cm & 25cm**
Confinement should boost this by 1.18 x Ke & x 1.2 for HEAT

	½ front turret profile is…..	½ front turret profile with Kontakt ….
2cm APFSDS =	**32cm 48cm RHAe [40cm ± 8cm average]**	**35cm 51cm RHAe [43cm ± 8cm average]**
3cm APFSDS =	**30cm 46cm RHAe [38cm ± 8cm average]**	**34cm 50cm RHAe [42cm ± 8cm average]**
4cm APFSDS =	**28cm 42cm RHAe [35cm ± 7cm average]**	**33cm 47cm RHAe [40cm ± 7cm average]**
Vs HEAT =	**41cm 61cm [51cm ±10cm average]**	**82cm 103cm [92cm ±10cm average]**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ¼ Kontakt & ¾ exposed armor
From 30° off angle, treat all hits as the 'average' value.

Upper front turret **[1/3 front turret profile]** is 5cm cast plus 5cm Steltexolite~ 76-77° or ~42-44cm LOS x 0.66cm KE & 1.02 HEAT ; thus ¼ of the profile is **28-29cm KE and 43-45 cm HEAT armor.** ¾ profile includes Kontakt ERA thus **31-35cm KE and 85-87 cm HEAT armor. Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ½ Kontakt & ½ exposed armor.**

Side & Rear turret LOS thickness Ranges from 30cm thick near front thinning ~ 20cm on the sides and down to ~ 13cm around back . This is probably the same as the front turret armor and thus the KE armor is 0.8 while the HEAT armor is 1.02 .The effective KE armor ranges from **24cm** near the front side turret to **16cm** on the side turret and **10cm KE** around back. The HEAT armor ranges from **31 cm** near the front side down to **20cm** on the side and **13 cm** around back. In the rear are mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor , this may amount to an additonal **5-10cm HEAT** armor. Along the side turret , **Kontakt ERA** adds **27cm HEAT** over ¼ of the side turret profile.In addition it should boost KE values by **~ 3-5cm KE [2cm-4cm APFSDS] , this boosts the protection to 26-28cm KE & 58cm HEAT [Pj] in the front half of the side turret.**

Glacis: Key modification here was the 16mm SHS plate [~ 430 BHN?] added to the front glacis.In addition ¾ of the glacis is covered in Kontakt ERA adding ~ **+3-6cm KE protection [2cm-4cm APFSDS]**.and **+42 cm HEAT** armor**.**

1.6cm SHS x 1.2/1.2 [Te] x 0.85/0.8/0.75/ 0.7 [t/d] = 1.6/1.5/1.44 / 1.3cm & 1.9cm [HEAT]
6cm RHA x 1.0/1.0 [Te] x 0.97/0.95/0.9 or 0.88 / 0.6 [t/d] = 5.8/5.7/5.4/ 5.3cm & 6cm [HEAT]
2x 5.25 cm STEF x 0.4/ 0.45 [Te] x 0.7/0.6/0.55 [t/d] or 0.5 [T/d APDS] = 2.8/2.4/2.2/2.0cm & 4.5cm
5cm RHA x 1.0/1.0 [Te] x x 0.97/0.95/0.9 / 0.88 [t/d] = 4.8/4.7/4.5/4.4 & 5cm [HEAT]
Modifiers x 1.2 [HEAT] & KE x 1.22 [SHS/RHA confinement] ÷ 0.38 [Cos of glacis]
Total Vs
2cm APFSDS = 15 x 1.22 ÷ 0.38 = **48cm [¾ of the profile has Kontakt with 51cm KE resistance]**
3cm APFSDS = 14.3 x 1.22 ÷ 0.38 = **46cm [¾ of the profile has Kontakt with 49cm KE resistance]**
3.5cm sheathed = 13.5 x 1.22 ÷ 0.38 = **43.5cm [¾ of the profile has Kontakt with 49cm KE resistance]**
5-6cm APDS = 13 x 1.22 ÷ 0.38 = **41.7cm [¾ of the profile has Kontakt with 48cm KE resistance]**
[HEAT] = 17.4 x 1.2 [layering] ÷ 0.38 [Cos of glacis]=**55cm HEAT [¾ of the profile has Kontakt with 97cm HEAT resistance]**
Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ½ Kontakt & ½ exposed armor.

The side hull Is assumed to be the same as the T-72A plus ERA. Along the front ½ of the side hull , Kontakt ERA is mounted that adds **16cm HEAT [Pj]** & as well as **~ 3-5cm KE [2cm-4cm APFSDS] .**

	Rear ½ Side Hull	Front ½ Side Hull with Kontakt ERA
That's ~ 6+5cm =	**11cm Vs 3cm API**	**13cm Vs 3cm API**
That's ~ 6+6cm =	**11cm Vs 1.5cm APDS [25mm APDS]**	**14cm Vs 1.5cm APDS [25mm APDS]**
That's ~ 6+4cm =	**9cm Vs 1cm APFSDS [25mm APFSDS]**	**11cm Vs 1cm APFSDS [25mm APFSDS]**

HEAT resistance = 24cm Pj HEAT 40cm Pj HEAT
Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ¼ Kontakt & ¾ exposed armor.

The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional **12cm KE and ~ 25cm HEAT armor.**

------------------------------REST AS T-72A/M-84--

With KONTAKT-5 type ERA

This reperesents a 1990s modification of these tanks that should include improved ammo [APFSDS] and FCS improvements.The essential armor improvement is the addition of K-5 over the front turret and glacis. Kontakt 5 differes from Kontakt, in that the ERA elements are mounted inside a armored box with a thickness of ~ 25mm. Combined this should offer ~ 18-19 cm KE protection, unless the APFSDS is sheathed in which case it adds 23-28cm.
The HEAT resistance @ 60-65° is about + **54cm HEAT**
[2/3 front turret profile]

½ front turret profile is…..			**½ front turret profile with Kontakt ….**		
2cm APFSDS = 32cm	**48cm RHAe**	**[40cm ± 8cm average]**	**50cm**	**66cm RHAe**	**[58cm ± 8cm average]**
3cm APFSDS = 30cm	**46cm RHAe**	**[38cm ± 8cm average]**	**48cm**	**64cm RHAe**	**[56cm ± 8cm average]**
4cm APFSDS = 28cm	**42cm RHAe**	**[35cm ± 7cm average]**	**47cm**	**61cm RHAe**	**[54cm ± 7cm average]**
3.5cm Sheathed = 29cm	**44cm RHAe**	**[37cm ± 7cm average]**	**56cm**	**71cm RHAe**	**[64cm ± 7cm average]**
Vs HEAT = 41cm	**61cm**	**[51cm ±10cm average]**	**95cm**	**115cm**	**[105cm ±10cm average]**

From 30° off angle treat all hits as the 'average' value.
Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 4 of above values, except 3.5cm Sheathed, in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 26cm.

[1/3 front turret profile] upper front turret see previous entry.

Glacis; This is treated as the M-84A with Kontakt –5 heavy ERA covering ¾ of the glacis . This ERA looks like it adds ~ **+14-15cm KE protection [2cm-4cm APFSDS]** and **24-23cm [Sheathed APFSDS]** + **50 cm HEAT** armor.

Total Vs	**¼ glacis profile**	**¾ glacis profile with Kontakt ERA.**
2cm APFSDS =	15 x 1.22 ÷ 0.38 = **48cm**	**62cm [58cm if reduced]**
3cm APFSDS =	14.3 x 1.22 ÷ 0.38 = **46cm**	**60cm [55cm if reduced]**
3.5cm sheathed =	13.5 x 1.22 ÷ 0.38 = **43.5cm**	**66cm [59cm if reduced]**
[HEAT] =	17.4 x 1.2 [layering] ÷ 0.38= **55cm**	**105cm [79cm if reduced]**

Effectiveness of K-5 is considered "reduced" after 12 hits [subtract 4 off the above values, except 3.5cm Sheathed, in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 26cm.

Lower hull is the M-84A plus a steel reinforced rubber skirting hinged on the front hull nose. This rubber skirting is energetic plate but shows no evidence of 'wire mesh/perforated plate design'. Is probably really thin strands of wire in alternating layers like in tires. Its hard to gauge this but the approximate density is similar to aluminum/Fibre Glass,so this is used. FibreGlas should offer 0.4 /0.6 Te plus the energetic spaced plate effect. So that's 0.4 x 3cm = 1.2cm + [Sqrt (1.2/3) x 1.3 d x 1.6 r x 3cm]=3.95cm + base armor .HEAT is 3cm x 0.6 x 6 + base armor & standoff [5/12cm]. In addition to the T-64B with dozer blade this should add 2cm x 0.2 & 1cm x 0.6 plus the spaced plate effect .
The RHAe should work out to …..
2cm APFSDS = 25cm + 1.2cm + 3.2cm = **29cm**
3cm APFSDS = 26cm + 1.2cm + 3.95cm = **31cm**
3.5cm sheathed APFSDS = 31cm+ 1.1cm + 8.5cm = **41cm**
The HEAT 30cm HEAT + 11+ 5 = **46cm**

The side hull is the same as T-64B model plus Kontakt –5 heavy ERA covering ½ of the side hull profile .The thickness looks like 3% of the array length & 14% of its height….this should make it , ~8cm thick divided into 4 sections. These look like a 2.5cm outer plate [steel?] , 1.5cm inner plate [Kontakt?] plus 2.5cm airgap and 1.5cm rear plate[Kontakt?].?]. Should add **35cm HEAT resistance** as well as **11-12cm RHAe vs 2-4cm monoblock APFSDS & 18-19cm RHAe vs 2-4cm sheathed APFSDS**

	Rear ½ Side Hull	Front ½ Side Hull with K-5 ERA
That's ~ 6+5cm =	**11cm Vs 3cm API**	**22cm Vs 3cm API**
That's ~ 6+6cm =	**11cm Vs 1.5cm APDS [25mm APDS]**	**22cm Vs 1.5cm APDS [25mm APDS]**
That's ~ 6+4cm =	**9cm Vs 1cm APFSDS [25mm APFSDS]**	**22cm Vs 1cm APFSDS [25mm APFSDS]**

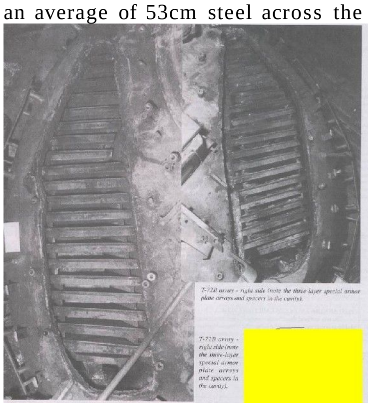
HEAT resistance = 24cm Pj HEAT 60cm Pj HEAT
If more than 6 hits on the side hull then K-5 covered areas are considered "reduced" and should have the KE resistance reduced by 3cm [5cm if sheathed APFSDS], while the HEAT resistance should go down 16cm
‘’’

T-72B & S

JANES reports the T-72B entered service in the mid 1980s with Kontakt ERA and Steve Zalogas [Soviet /Russian Arty & Armor Design Practice…] indicates the T-72B turret has BDD type armor in the turret utilizing Aluminum instead of mild steel.The
array has 380mm cast steel and 435mm insert with the Aluminum/rubber combination.The stated resistance of the turret- is 530mm
KE armor and 520mm HEAT protection..

The T-72B turret is reported to have 815mm armor thickness in the middle of the turret . Around the mantle the thickness is about 60cm cast , while the LOS thickness near the 'corner of the turret' is around 0.9 meter LOS thickness.Jim Warfords JoMO article [may 2002,pp4-7] shows an insert cavity with 21 multi layered packs, each with 21mm Aluminum & 6mm rubber + 3mm plate[MS ?] , followed by a 22mm airgap…then the next array. The rear wall is lined with a 45 mm thick plate and both inserts are reported to weight a total of 1,723lbs [783kg] ? The front turret profile is ~ 1.4m² and the inserts cavities occupy roughly 2/3 of this so the insert is similar to 783kg/7850kg ÷ 0.98 [1.4 x 0.7] = 10.2cm LOS steel mass. The rear plate [45mm] looks like @ 45° , from the front leading to a LOS thickness of 6.5cm. Jim Warford reports these plates amount to 381lbs total or 173kg mass …which in turn leads to ~ 22mm steel mass. So clearly this rear plate is not steel. Given the LOS thickness of ~ 6.5cm that leads to an assumed material density of ~ 2.6-2.7g/cc. This strongly suggests the rear plate is Aluminum [density 2.66-2.8g/cc] .

The air gap occupies about 42% of the LOS thickness leaving about 20cm solid [4 plates 5cm LOS] and the remaining steel mass of 7.9cm/21.5cm thickness leads to ~ 2.9/cc array density. If we assume a 21mm aluminum + 6mm rubber + 3mm Mild Steel sandwich, this should also be ~ 2.9g/cc . Theres hardly any rubber and the gap between plates is too narrow to benefit from any synergistic effect of multiple plates. So each 'spaced plate effect' should be diameter/gap-0.5 or + 1/2.7/3.8cm per airgap. A LOS thickness through the front suggests any projectile will have to penetrate ~ 4-5 layers to traverse the insert cavity.. roughly 50cm steel mass and 42cm in the middle & 60cm around the mantle for an average of 53cm steel across the front turret.[2.66-2.16m x 0.58m = 1.4m²].



Armor Magazine – Jim Warford

T-72BV is supposed to come with Kontakt ERA in the late 80s, unlike previous ERA kits these arrays are mounted flush to the turret wall and only will offer ~ 200mm additional HEAT protection [8 x 20 ÷ 0.866÷ 0.9]. The KE resistance should be similar to other Kontakt models offering 0.5cm + 1.1d-0.9d-1.6d = + 2cm-3cm-6cm.

Through the 815mm section thats roughly
10cm cover cast plate & 28cm cast Te 0.95 x 0.92/0.91/0.9 & 1.0 t/d = 8.7/8.6/8.5cm+26.6cm
6.5cm Aluminum back plate x 0.94/0.93/0.92t/d & Te 0.35 = 2.8/2.6/2.6cm & 3.2
21.5cm Aluminum/rubber/MS x 0.338/0.43[te] x 0.88/0.85/0.7 [t/d] 5.9cm/ 5.7cm/4.7cm & 8.6
Lateral confinement is 0.9 & 0.8 near the mantle.
KE 'Spaced plate effect' = 4 x 1/2.7/3.8cm …+ 4cm/ 10.8cm /15.2cm

2cm high strength APFSDS = 39.7cm + 2.8cm= 42 - 42 - 46cm [Average 43± 3cm] plusERA = 44 - 46 - 51cm [Average 47 ± 4cm]
2cm APFSDS = 39.7cm + 4= 43-44-49cm [Average 45± 4cm] plusERA = 46cm = 45-49-53cm [Average 49± 4cm]
3cm APFSDS= 39.3cm + 10.8= 46-50-55cm [Average 50± 5cm] plus ERA =49cm = 48-51-56cm [Average 52± 4cm]
3.5cm sheathed = 37.5cm +30.4= 46-69-76cm [Average 63± 13cm] plus ERA = 57 = 48-71-78cm [Average 56±6cm]

HEAT 8.6 + 3.2+ 38cm = 50-50-55cm + 0.2d HEAT[Average 58± 4cm] plus ERA = 55cm + 27-30cm =80-82-93cm [85±6cm]
Upper front turret = 5m @ 76°= LOS thickness 205mm cast plus 5cm Steltexolite bolted to the roof armor. This material resists a lot like aluminum or 0.4Te KE and 0.6 Te HEAT [increased by 20% due to layering]. Inaddition about ½ of the upper front turret is covered in Kontakt ERA.

[¼ front turret profile] Upper front turret

	½ exposed	or	½ covered in ERA
Vs Steel/Sheathed APFSDS	= 25.0cm LOS or **6.6cm @ 75°**		**7cm @ 75° * ¼ ricochet***
Vs 2-3cm APFSDS	= 26.0cm LOS or **6.7cm @ 75°**		**7.6cm @ 75°**
Vs 2cm APFSDS	= 27.1cm LOS or **6.9cm @ 75°**		**7.6cm @ 75°**
Vs HEAT	= 38cm LOS or **9.8cm @ 75°**		**12/ 11cm@ 75° + 3d** ** old warheads may ricochet **

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ¼ Kontakt & ¾ exposed armor
From 30° off angle treat all hits as the 'average' value.

[¼ front turret profile] Mantle Area [½ front turret profile] sloping wall

	¾ exposed	or [¼ with ERA]	¼ exposed	or [¾ with ERA]
2cm HS APFSDS	= 42cm LOS or **42cm @ 0°**	**[44cm@ 0°]**	46cm LOS or **32cm @ 45°**	**[34cm@ 45°]**
2cm APFSDS =	43cm LOS or **43cm @ 0°**	**[45cm @ 0°]**	49 cm LOS or **34cm @ 45°**	**[36cm @ 45°]**
3cm APFSDS =	46cm LOS or **46cm @ 0°**	**[47cm @0°]**	55cm LOS or **38cm @ 45°**	**[40cm @ 45°]**
3.5cm APFSDS =	46cm LOS or **46cm @ 0°**	**[47cm@ 0°]**	76cm LOS or **53cm @ 45°**	**[55cm @ 45°]**
HEAT=	50cm LOS or **50cm @ 0°**	**[57/52cm @ 0° + 2d]**	56cm LOS or **43/39cm @ 45°**	**[46/43cm @ 45°+ 3.0d]**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is reduced to ½ Kontakt & ½ exposed armor.

[½ side Turret profile] front side average 60-80cm LOS 0.6/0.7= Te & .68 +ERA

	¼ exposed	or [¾ with ERA]
2cm HSAPFSDS	= 40cm LOS or **28cm @ 45°**	**[29cm@ 45°]**
2cm APFSDS	= 42cm LOS or **29cm @ 45°**	**[30cm@ 45°]**
3cm APFSDS	= 44cm LOS or **31cm @ 45°**	**[32cm @ 45°]**
3.5cm APFSDS	= 49cm LOS or **34cm @ 45°**	**[35cm @ 45°]**
HEAT=	54/47cm LOS or **38/33cm @ 45°**	**[40/34cm @ 60°+ 3d]**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is reduced to ½ Kontakt & ½ exposed armor.

[½ side Turret profile] rear ;

The thickness is 30-40cm around back, this is probably half and half Cast / STEF, thus the KE armor is 0.66 while the HEAT armor is 0.85. Storage boxes 40cm thick are mounted around the side turret covering about ½ the profile , that should increase the shaped charge resistance somewhat.

	¼ side turret [Rear]	¾ side turret with storage boxes
Vs APDS	**=** 26cm LOS or **23cm @ 30°**	26cm + 2.7cm LOS or **29cm @ 30°**
Vs Sheathed	**=** 25cm LOS or **22cm @ 30°**	25cm + 1.8cm LOS or **27cm @ 30°**
Vs APFSDS	= 24cm LOS or **21cm @ 30°**	24cm + 0.9cm LOS or **25cm @ 30°**
Vs HEAT	= 35cm LOS or **29cm @ 30°**	35cm + 15/1cm + LOS or **44/30cm @ 30° + 0.7d**

Rear turret

The thickness is ~ 15-20cm around back, this is probably half and half Cast / STEF, thus the KE armor is 0.66 while the HEAT armor is 0.85. In the rear turret are sometimes mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor
Vs API/APDS 20 x 0.66 **=** 12.2 + 0.8 = 13 cm or **11cm @ 30°**
Vs HEAT 20 x 0.85 = 17cm LOS + 0.2 + 19/7 = 36 /24 **or 31/21cm @ 30° +0.7d**

Glacis is reported to be 235mm @ 67-68° thick with probably 60mm RHA outer plate + 2 x 52.5mm Steltexolite [STEF?] plates and then a 50mm RHA back plate and a 20mm hard

steel[~ 430 BHN?] cover plate was added to the front glacis.In addition ¾ of the glacis is covered in Kontakt ERA
2cm SHS x 1.2/1.2 [Te] x 0.88/0.85/0.8 [t/d] = 2.1/2.0/1.9cm & 3.6cm [HEAT]
6cm RHA x 1.0/1.0 [Te] x 0.97/0.95/0.9 [t/d] = 5.8/5.7/5.4cm & 6cm [HEAT]
2x 5.25 cm STEF x 0.4/ 0.45 [Te] x 0.7/0.6/0.5 [t/d] = 2.8/2.4/2.2cm & 4.5cm
5cm RHA x 1.0/1.0 [Te] x 0.97/0.95/0.9 [t/d] = 4.8/4.7/4.5cm & 5cm [HEAT]
Modifiers x 1.2 [HEAT] & KE x 1.26 [SHS/Thick confinement] ÷ 0.38 [Cos of glacis]
Vs 2cm APFSDS = 15.5 x 1.26 ÷ 0.38 = 51cm [¾ of the profile has Kontakt with 54cm KE resistance]
Vs 3cm APFSDS = 14.8 x 1.26 ÷ 0.38 = 49cm [¾ of the profile has Kontakt with 52cm KE resistance]
Vs 3.5cm Sheathed = 14 x 1.26 ÷ 0.38 = 46cm [¾ of the profile has Kontakt with 52cm KE resistance]
[HEAT] = 19.1 x 1.2 [layering] ÷ 0.38 [Cos of glacis]=60cm HEAT [¾ of the profile has Kontakt

[2/3 Front hull profile] Glacis

The assumed to be T-72 plus Kontakt ERA covering ¾ of the glacis profile..

Total Vs	**¼ glacis profile**	**or**	**¾ glacis profile with Kontakt ERA.**
2cm APFSDS =	51cm LOS = **19cm@ 68°**		54cm LOS = **20cm@ 68°**
3cm APFSDS =	49cm LOS = **19cm@ 68°**		52cm LOS = **20cm@ 68°**
4cm APFSDS =	46cm LOS= **17.5cm@ 68°**		52cm LOS = **20cm@ 68°**
[HEAT] =	60cm HEAT LOS = **23cm@ 68°**		65/60cm LOS = **25/23cm@ 68° +3.0d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ½ Kontakt & ½ exposed armor

[1/3 Front Hull profile] Lower hull

is 8cm RHA plus 2cm dozer plate @ 65° = LOS thickness of 23.5cm LOS, x t/d [0.88/0.92/0.94/0.96/0.98]....but the spaced plate should add 1.3d to APFSDS & 2.6d to sheathed penetrators.The RHAe should work out to
2cm APFSDS = 7.8cm+ 1.4cm + 2.6cm = 24cm LOS or **12cm @ 60°**
3cm APFSDS = 7.7cm+ 1.4cm + 3.7cm = 26cm LOS or **13cm @ 60°**
3.5cm sheathed APFSDS = 7.6cm+ 1.3cm + 9cm = 30cm LOS or **15cm @ 60°**
6-7cm WHA APDS = 7.2cm+ 1.3cm + 6cm = 26cm LOS or **13cm @ 60°**
HEAT 2cm MS plate x 0.8 x 3 + 8cm RHA = 23cm LOS or **12cm @ 60° + 0.7d**

SIDE Hull

is the basic side hull T-72/64 60mm Hard RHA armor with the steel rubber side skirt reinforced with Kontakt ERA. The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap . Kontakt ERA is added over most of the side hull adding ~2cm KE resistance and 2d HEAT reduction.

	¼ front turret	¾ front turret with Kontakt ERA
Vs 3cm API ~	6.6+2.9+1.1cm = **10.5cm @ 0°**	**13cm @ 0°**
Vs 25mm APDS/ APFSDS	6.6+2.8+1.4cm = **11cm @ 0°**	**13cm @ 0°**
Vs 10mm APFSDS	~ 6.6+1.9+1.5cm = **10cm @ 0°**	**12cm @ 0°**
HEAT ~	6.6 + 2 + 19/7 + 1.0d **= 27/15cm @ 0° + 1.0d HEAT**	**30/18cm @ 0° + 2.0d HEAT**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ¼ Kontakt & ¾ exposed armor

Rear hull

46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor

is in three sections , the rear
¼ [engine deck] **~ 2cm KE & 2cm HEAT @ 90°**
¼ [front hull deck & tracks] **~ 4cm . KE & 5cm HEAT @ 90°**
¼ [top turret] **~ 7cm . KE & 11cm HEAT @ 75° + 2d**
1/8th [front/sides & rear turret] ~ **30cm KE & 50cm HEAT @ 90°**
1/8th [glacis] **~ 15cm KE @ 68° & 20cm HEAT @ 68° + 2d**

Bottom tank armor

armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT

‘,,,’

T-72BM

The T-72BM appears to have entered service in the late 1980s and is assumed to be the T-72B with more effective K-5 ERA plus other improvements in protection , like reinforced skirting on the front lower hull and reinforced upper front turret armor [roof]

HEAT 8.6 + 3.2+ 38cm = 50-50-55cm + 0.2d HEAT[Average 58± 4cm] plus ERA = 55cm + 27-30cm =80-82-93cm [85±6cm] .Through the 815mm section thats roughly 10cm cover cast plate & 28cm cast back plate [Te] 0.95 x 0.92/0.91/0.9 & 1.0 [t/d] = 8.7/8.6/8.5cm+26.6cm
8cm Aluminum back plate x 0.94/0.93/0.92t/d & Te 0.35 = 2.8/2.6/2.6cm & 3.2
20cm Aluminum/rubber/MS x 0.338/0.43[te] x 0.88/0.85/0.7 [t/d] 5.9cm/ 5.7cm/4.7cm & 8.6
Lateral confinement is 0.9-0.95 & 0.8 near the mantle.
KE 'Spaced plate effect' = 4 x 1/2.7/3.8cm …+ 4cm/ 10.8cm /15.2cm
K-5 should add 18-19cm KE resisance Vs monoblock penetrators and 23-24cm Vs sheathed penetrators.

½ front turret ½ front turret with K-5 ERA
2cm HSAPFSDS = 39.7cm + 2.8cm= 42 -42 -46cm [Average 43± 3cm] = +K-5+ 13 = 56-56-61cm [Average 57± 4cm]
2cm APFSDS = 39.7cm + 4cm **=** 43-44-49cm [Average 45± 4cm] = + K-5+18 = 61-62-67cm [Average 63± 4cm]
3cm APFSDS = 39.3cm + 10.8= 46-50-55cm [Average 50± 5cm] + K-5+19 = 65-69-74cm [Average 69± 4cm]
3.5cm sheathed = 37.5cm +30.4= 46-69-76cm [Average 63± 13cm] + K-5+ 23 = 69-92-99cm [Average 86±6cm]
HEAT 8.6 + 3.2+ 38cm x 1.1=60-55-60cm HEAT[Average 58± 4cm] plus ERA = 58cm + K-5 =

[¼ front turret profile] Upper front turret

	½ exposed	or ½ covered in ERA
Vs Steel/Sheathed APFSDS	= 25.0cm LOS or **6.6cm @ 75°**	**7cm @ 75° * ¼ ricochet***
Vs 2-3cm APFSDS	= 26.0cm LOS or **6.7cm @ 75°**	**7.6cm @ 75°**
Vs 2cm APFSDS	= 27.1cm LOS or **6.9cm @ 75°**	**7.6cm @ 75°**
Vs HEAT	= 38cm LOS or **9.8cm @ 75°**	**12/ 11cm@ 75° + 3d** ** old warheads may ricochet **

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ¼ Kontakt & ¾ exposed armor

[¼ front turret profile] Mantle Area(cast) [½ front turret profile] sloping wall

	¾ exposed	or [¼ with K-5 ERA]	¼ exposed	or [¾ with ERA]
2cm HS APFSDS =	42cm LOS or **42cm @ 0°**	**[56cm@ 0°]**	44cm LOS or **31cm @ 45°**	**[41cm@ 45°]**
2cm APFSDS =	43cm LOS or **43cm @ 0°**	**[61cm @ 0°]**	46 cm LOS or **32cm @ 45°**	**[45cm @ 45°]**
3cm APFSDS =	46cm LOS or **46cm @ 0°**	**[65cm @ 0°]**	52cm LOS or **37cm @ 45°**	**[50cm @ 45°]**
3.5cm APFSDS =	46cm LOS or **46cm @ 0°**	**[69cm@ 0°]**	71cm LOS or **50cm @ 45°**	**[67cm @ 45°]**
HEAT=	50cm LOS or **54/50cm @ 0°**	**[65/60cm @ 0° + 3d]**	56cm LOS or **43/39cm @ 45°**	**[53/49cm @ 45°+ 4.0d]**

If more than 6 hits on the side turret then 'K-5 covered areas' are considered "reduced" and should have the KE resistance reduced by 4cm [7cm if sheathed APFSDS], while the HEAT resistance should go down + 1.5d

[front ½ side Turret profile] side average 60-80cm LOS 0.6/0.7= Te & .68 +ERA K-5 should add 18-19cm KE resisance Vs monoblock penetrators and 23-24cm Vs sheathed penetrators.

	½ exposed or		[½ with K-5 ERA]
2cm HSAPFSDS	= 40cm LOS or **28cm @ 45°**	53cm los	**[37cm@ 45°]**
2cm APFSDS	= 42cm LOS or **29cm @ 45°**	60cm LOS	**[42cm@ 45°]**
3cm APFSDS	= 44cm LOS or **31cm @ 45°**	63cm LOS	**[44cm @ 45°]**
3.5cm APFSDS	= 49cm LOS or **34cm @ 45°**	72cm LOS	**[50cm @ 45°]**
HEAT=	54/ 47cm LOS or **38/ 33cm @ 45°**	57/48cm LOS	**[48/43cm @ 60°+ 4d]**

If more than 6 hits on the side turret then 'K-5 covered areas' are considered "reduced" and should have the KE resistance reduced by 4cm [7cm if sheathed APFSDS], while the HEAT resistance should go down + 1.5d

[rear ½ side Turret profile] ; The thickness is 30- 40cm around back, this is probably half and half Cast / STEF, thus the KE armor is 0.66 while the HEAT armor is 0.85. Storage boxes 40cm thick are mounted around the side turret covering about ½ the profile , that should increase the shaped charge resistance somewhat.

	¼ side turret [Rear]	¾ side turret with storage boxes
Vs APDS	**=** 26cm LOS or **23cm @ 30°**	26cm + 2.7cm LOS or **29cm @ 30°**
Vs Sheathed	**=** 25cm LOS or **22cm @ 30°**	25cm + 1.8cm LOS or **27cm @ 30°**
Vs APFSDS	= 24cm LOS or **21cm @ 30°**	24cm + 0.9cm LOS or **25cm @ 30°**
Vs HEAT	= 35cm LOS or **29cm @ 30°**	35cm + 15/1cm + LOS or **44/30cm @ 30° + 0.7d**

Rear turret The thickness is ~ 20cm around back, this is probably half and half Cast / STEF, thus the KE armor is 0.66 while the HEAT armor is 0.85. In the rear turret are sometimes mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor

Vs API/APDS 20 x 0.66 **=** 12.2 + 0.8 = 13 cm or **11cm @ 30°**

Vs HEAT 20 x 0.85 = 17cm LOS + 0.2 + 19/7 = 36 /24 **or 31/21cm @ 30° +0.7d**

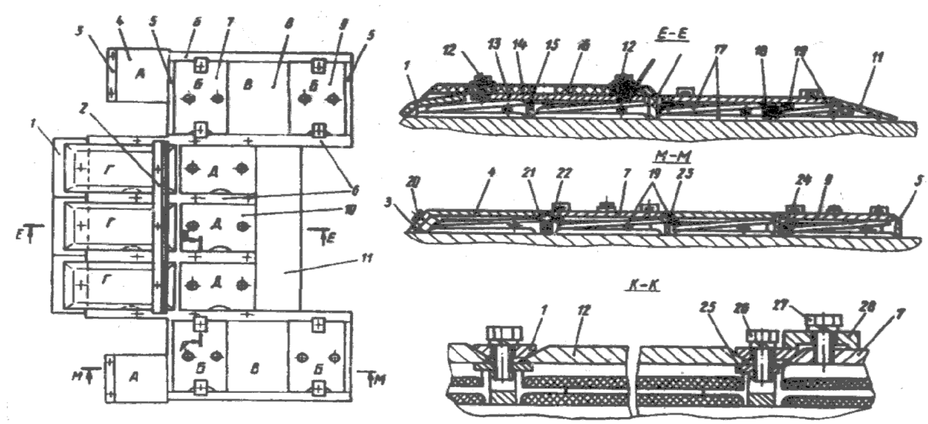
Hull Glacis is reported to be 235mm @ 67-68° thick with probably 60mm RHA outer plate + 2 x 52.5mm Steltexolite [STEF?] plates and then a 50mm RHA back plate and a 20mm hard steel[~ 430 BHN?] cover plate was added to the front glacis.In addition ¾ of the glacis is covered in K-5 ERA that adds ~ **+14- 15cm KE protection [2cm-4cm APFSDS]** and **23-24cm [Sheathed APFSDS] +50 cm HEAT** armor .

2cm SHS x 1.2/1.2 [Te] x 0.88/0.85/0.8 [t/d] = 2.1/2.0/1.9cm & 3.6cm [HEAT]
6cm RHA x 1.0/1.0 [Te] x 0.97/0.95/0.9 [t/d] = 5.8/5.7/5.4cm & 6cm [HEAT]
2x 5.25 cm STEF x 0.4/ 0.45 [Te] x 0.7/0.6/0.5 [t/d] = 2.8/2.4/2.2cm & 4.5cm
5cm RHA x 1.0/1.0 [Te] x 0.97/0.95/0.9 [t/d] = 4.8/4.7/4.5cm & 5cm [HEAT]
Modifiers x 1.2 [HEAT] & KE x 1.26 [SHS/Thick confinement] ÷ 0.38 [Cos of glacis]

[2/3 Front hull profile] Glacis The assumed to be T-72 plus Kontakt ERA covering ¾ of the glacis profile, which adds 17cm & 23-24cm ..

Total Vs	**¼ glacis profile**	**or**	**¾ glacis profile with Kontakt ERA.**
2cm HS APFSDS =	51cm LOS = **19cm@ 68°**		64cm LOS = **24cm@ 68°**
2cm APFSDS =	51cm LOS = **19cm@ 68°**		68cm LOS = **26cm@ 68°**
3cm APFSDS =	49cm LOS = **19cm@ 68°**		66cm LOS = **25cm@ 68°**
Sheathed APFSDS =	46cm LOS= **17.5cm@ 68°**		70cm LOS = **27cm@ 68°**
[HEAT] =	60cm HEAT LOS = **23cm@ 68°**		65/60cm LOS = **30/28cm@ 68° +3.0d**

Effectiveness of K-5 is considered "reduced" after 12 hits [subtract 4 off the above values, except 3.5cm Sheathed, in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 26cm.



http://armor.kiev.ua/Tanks/Modern/T64/t64u.html

[1/3 Front Hull profile] Lower hull is 8cm RHA plus 2cm dozer plate @ 65° = LOS thickness of 23.5cm LOS, x t/d [0.88/0.92/0.94/0.96/0.98]....but the spaced plate should add 1.3d to APFSDS & 2.6d to sheathed penetrators.A 3cm thick steel reinforced rubber sheet , is suspended from the nose of the front hull . Inaddition to the spaced plate effect this should offering 1.5cm KE and 2cm HEAT .The RHAe should work out to

2cm APFSDS = 9.2cm + 1.4cm + 5.2cm = 30cm LOS or **15cm @ 60°**
3cm APFSDS = 9.1cm + 1.4cm + 7.4cm = 32cm LOS or **16cm @ 60°**
3.5cm sheathed APFSDS = 8.9cm + 1.3cm + 18cm = 42cm LOS or **21cm @ 60°**
HEAT 2cm MS plate x 0.8 + 8cm RHA + 2cm = 39/25cm LOS or **20/13cm @ 60° + 0.6d**

SIDE Hull is the basic side hull T-72/64 60mm Hard RHA armor with the steel rubber side skirt reinforced with heavy Kontakt 5 ERA. The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap . These look like a 2.5cm outer plate [steel?] , 1.5cm inner plate [Kontakt?] plus 2.5cm airgap and 1.5cm rear plate [Kontakt?]

	Rear ½ Side Hull	Front ½ Side Hull with K-5 ERA
Vs 3cm API ~	6.6+2.9+1.1cm = **10.5cm @ 0°**	**21cm @ 0°**
Vs 25mm APDS/ APFSDS	6.6+2.8+1.4cm = **11cm @ 0°**	**22cm @ 0°**
Vs 10mm APFSDS	~ 6.6+1.9+1.5cm = **10cm @ 0°**	**21cm @ 0°**
HEAT ~	6.6 + 2 + 19/7 + 1.0d **= 27/15cm @ 0° + 1.0d HEAT**	**30/18cm @ 0° + 2.0d HEAT**

Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 2 of above values off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 2d.

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°

Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear

¼ [engine deck] **~ 2cm KE & 2cm HEAT @ 90°**
¼ [front hull deck & tracks] **~ 4cm . KE & 5cm HEAT @ 90°**
¼ [top turret] **~ 7cm . KE & 11cm HEAT @ 75° + 2d**
1/8 th [front/sides & rear turret] ~ **30cm KE & 50cm HEAT @ 90°**
1/8 th [glacis] ~ **25cm KE @ 68° & 28cm HEAT @ 68° + 2d**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE ; while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ front ½ = 3cm KE and 22/7cm HEAT

Rear ½ = 2cm KE and 22/7cm HEAT
',,'

T-80

The T-80 armor was reported to be based on the T-64 design so the armor this is whats used as the model .The LOS thickness ranges from ~41cm LOS near the gun to ~60cm LOS thickness at the turret corners .

Front Turret
24 cm Al 5xxx [Te]= 0.35/0. 4 x 0.99/0.97/0.96/0.94/0.95 [T/d] = 8.3/8.4 /8.0/7.9/10.25 & 11cm
17 cm cast x 0.95 /1.0 [Te] x 0.94/0.92/0.9/0.88/0.95 [T/d] = 15.2/14.9/14.5/14.2/16.1cm & 17cm
Multiples x 1.2 HEAT [layering] & x 1.18 KE [RHA confinement] x [Lateral confinement]
2cm APFSDS = 23.5 x 1.18 x 0.9/ 0.99 = 25cm near gun 41cm @ corners [32±10cm average]
3cm APFSDS = 23.3 x 1.18 x0.9/ 0.97= 25cm near gun 40cm @ corners [31±9cm average]
4cm APFSDS = 22.6x 1.18 x 0.9/ 0.96 = 24cm near gun 38cm @ corners [30±9cm average]
5-6cm APDS = 22 x 1.18 x 0.9/ 0.95 24cm near gun 37cm @ corners [29±8cm average]
90-122mm APC = 26.36 x 1.18 x 0.8/0.98 25cm near gun 45cm @ corners[35±10cm average]
HEAT= 28 x 1.2 = 33cm near gun 50cm @ corners [40±8cm average]

[¼ front turret profile] Upper front turret = 5cm @ 76°= LOS thickness of 20cm cast x 0.95 [cast] x T/d [0.75/0.85/0.88/0.92/0.94] =

Vs APC = 14.0cm LOS or **3.8cm @ 75°** ** **ricochet** **
Vs APDS = 15cm LOS or **4.1cm @ 75°** ** **ricochet** ** [* ½ ricochet* if WHA APDS L52 or L16]
Steel/Sheathed APFSDS = 15.9cm LOS or **4.3cm @ 75°** * **¼ ricochet** *
2-3cm APFSDS = 16.9cm LOS or **4.6cm @ 75°**
Vs HEAT = 19cm LOS or **4.9cm @ 75°** ** **old warheads may ricochet** **

[¼ front turret profile] [MG port to gunsite]	**Mantle**	**Middle Turret [¼ front turret profile]**
2cm APFSDS =	23.5 x 1.18 x 0.9/ 0.99 = 26cm LOS or **23cm @ 30°**	33 cm LOS or **23cm @ 45°**
3cm APFSDS =	23.3 x 1.18 x0.9/ 0.97= 26cm LOS or **23cm @ 30°**	33 cm LOS or **23cm @ 45°**
4cm APFSDS =	22.6 x 1.18 x 0.9/ 0.96 = 26cm LOS or **23cm @ 30°**	32 cm LOS or **22cm @ 45°**
6-7cm APDS =	22 x 1.18 x 0.9/ 0.95 = 25.5cm LOS or **22cm @ 30°**	31 cm LOS or **22cm @ 45°**
9**0-122mm APC** =	26.36 x 1.18 x 0.8/0.98 25cm LOS or **21cm @ 30°**	35 cm LOS or **23cm @ 45°**
HEAT=	28 x 1.2 = 33cm LOS or **29cm @ 30°**	40cm LOS **or 28cm @ 45°**

[¼ front turret profile] Turret corner front		**[1/3 side Turret profile]**
2cm APFSDS	= 23.5 x 1.18 x 0.9/ 0.99 = 41cm LOS or **20.5cm @ 60°**	**20cm @ 30°**
3cm APFSDS	= 23.3 x 1.18 x0.9/ 0.97= 40cm LOS or **20cm @ 60°**	**20cm @ 30°**
4cm APFSDS	= 22.6x 1.18 x 0.9/ 0.96 = 38cm LOS or **19cm @ 60°**	**20cm @ 30°**
6-7cm APDS	= 22 x 1.18 x 0.9/ 0.95 37cm LOS or **19cm @ 60°**	**19cm @ 30°**
9**0-122mm APC**	= 20 x 1.18 x 0.8/0.98 35cm LOS or **16cm @ 60°**	**16cm @ 30°**
HEAT=	28 x 1.2 = 50cm LOS or **25cm @ 60°**	**25cm @ 30°**

[2/3 side Turret profile] rear ;Ranges from 28cm thick aluminum/ cast near front , with ~ 15cm cast side armor thinning to ~ 6cm Cast around back . The half and half cast / aluminum KE armor is rougly 0.68-0.61 while the HEAT armor is ~ 0.93 [from above] , while the cast armor is 0.95/1.0

½ side turret [Rear]
Vs APC 15.5cm LOS or **13.4cm @ 30°**
Vs APDS 16.1cm LOS or **14cm @ 30°**
Vs APFSDS 16.8cm LOS or **14.5cm @ 30**
Vs HEAT = 17.3cm LOS or **15cm @ 30°**

Rear turret 97mm @ 30° x 30°= LOS thickness of 125mm Cast x 0.95 = 12cm KE & 13cm HEAT. In the rear turret are sometimes mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor
Vs API/APDS **=** 12+ 0.8 = 12 cm or **10.6cm @ 30°**
Vs HEAT 13 cm+ 0.2 + 19/7 + 0.7d or 32/20cm LOS **or 28/17cm @ 30° +0.7d**

[2/3 Front Hull profile] Glacis is reported to be 205mm thick and is assumed to be similar to the T-64 glacis, but an IDR 1986 article suggested the actual arrangement was in 4 plates with two outer steel plates followed by a fibre glass layer and then a thin back plate.Further the prototype T-80A glacis has been reported as the basis for the T-80U glacis , this features a ~ 6cm thick steel cover plate with ~ 10cm composite [Fibre glass] mid section and 4.5cm steel rear plate . This is close to the improvement over the T-64 glacis and is used for this model .

6cm RHA x 1.0/1.0 [Te] x 0.97/0.95/0.9/0.87 [t/d] = 5.8/5.7/5.4/5.2cm & 6cm [HEAT]
2x 5.25 cm ST-1 x 0.3/ 0.38 [Te] x 0.7/0.6/0.55 [t/d] or 0.5 [T/d APDS] = 2.2/1.9/1.7; 1.57cm & 3.93cm
4cm RHA x 1.0/1.0 [Te] x 0.95/0.9/0.88 / 0.85 [t/d] = 3.8/3.6/3.5cm/ 3.4cm & 4cm [HEAT]
Modifiers x 1.2 [confinement & layering] ÷ 0.38 [Cos of glacis]
2cm APFSDS = 11.8 x 1.2 ÷ 0.38 = **37.3cm** LOS or **14.2cm @ 68°**
3cm APFSDS = 11.2 x 1.2 ÷ 0.38 = **35.3cm** LOS or **13.3cm @ 68°**
4cm APFSDS = 10.6 x 1.2 ÷ 0.38 = **33.5cm** LOS or **12.3cm @ 68°**
5-6cm APDS = 10.2 x 1.2 ÷ 0.38 = **32.2cm** LOS or **11.7cm @ 68°**
Vs HEAT 13.9 x 1.2 ÷ 0.38 [Cos]=**44cm** LOS or **17.1cmHEAT**

[1/3 Front Hull profile] Lower hull looks like 9cm @ 65° = LOS thickness ÷ 0.426 or **21cm LOS** armor. X t/d [0.88/0.92/0.94/0.96/0.98]....
Vs APC = 18.3cm LOS or **9.2cm @ 60°**
Vs APDS & 4cm APFSDS = 19.4cm LOS or **9.7cm @ 60°**
Vs 2-3cm APFSDS & HEAT = 21cm LOS or **10.5cm @ 60°**

SIDE Hull Side armor looks like **6cm** thick , this must be an averaging of the 8cm upper sidehull of the T-54-62 tanks and the 2cm thick area around the wheels. The fuel tanks along the sponsons should add 65cm x 0.1 KE and 0.3 HEAT or an additional
Above trackguard = **12cm KE and ~ 25cm HEAT armor** .
Below trackguard =
7.5cm vs API/20-30mm APDS/APFSDS & HEAT
6.5cm vs large APDS
5cm large APC/HVAP

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear
½ [engine deck & tracks] **~ 2cm RHA KE & HEAT @ 90°**
¼ [top turret & front hull deck] **~ 5cm . KE & HEAT @ 90°**
1/8th [front/sides & rear turret] ~ **30cm @ 90° KE & HEAT**
1/8th [glacis] ~ **10cm @ 60° KE & HEAT**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT

T-80 B

This tank was reported to enter service in the late 70s as the main battle tank for the Red army in Europe replacing the various marks of the T-64 through out the 1980s, but production was slow as only ~4000 were produced in 7 years. The maximum armor level of the T-80B is reported tobe 500mm KE armor and the front turret thickness isreported to be about 440mm with an 130mm insert @ ~ 30°x 30° angle for a LOS thickness of ~ 76cm LOS , but its clear this thinness reaches ~ 50 cm near the gun in the "weakened zone". The turret armor is reported to feature **Corrundum** [alumina]which is usually a grinding material that is maunfactured cheaply in 'pelete' form, similar to "Chernosem"[Sand] . Russian test on various KEP Vs sand show that the longer the penetrator the more damage it suffers as it penetrates sand at higher and higher velocity. There is a melt temp that effects steel penetrators more than Tungsten but also suggests that HEAT warheads should suffer more.Resistance looks as follows

12:1 L/d Steel penetrator 8% of RHAe @ 1.3km/s ; 11% of RHAe @ 1.6km/s and 13% of RHAe @ 1.8km/s
7.5:1 L/d WHA penetrator 8% of RHAe @ 1.3km/s ; 10% of RHAe @ 1.6km/s and 12% of RHAe @ 1.8km/s
[Int.J.Impact Engng. Vol26, pp675- 681].... So to a first approximation Te of sand looks like ~ 0.12. Since alumina offers about ½ more resistance than glass , I will assume the alumina ceramic peletes perform ½ better than sand...or 0.18

Mantle area= 40cm Cast or 35cm Cast [0.95] + 15cm sand [0.18] = 36 cm x 1.2 x 0.8/0.9
Middle turret area = 65cm cast/sand [0.57] = 37 cm x 1.2 x 0.85 - 0.95
Corner turret area = 75cm cast/sand [0.57] = 43 cm x 1.2 cm x 0.92- 0.97
From ± 30° off angle that's roughly ~ 60- 65cm average LOS

[¼ front turret profile] Upper front turret

Vs Steel/Sheathed APFSDS = 25.0cm LOS or **6.6cm @ 75°** ***¼ ricochet***
Vs 2- 3cm APFSDS **=** 26.0cm LOS or **6.7cm @ 75°**
Vs 2cm APFSDS = 27.1cm LOS or **6.9cm @ 75°**
Vs HEAT = 38cm LOS or **9.8cm @ 75°** ** **old warheads may ricochet** **

[¼ front turret profile] Mantle Area / [¼ front turret profile] middle turret

	Mantle Area	middle turret
2cm HS APFSDS	= 35cm LOS or **35cm @ 0°**	40cm LOS or **35cm @ 30°**
2cm APFSDS	= 36cm LOS or **36cm @ 0°**	40 cm LOS or **35cm @ 30°**
3cm APFSDS	= 37cm LOS or **37cm @ 0°**	41cm LOS or **36cm @ 30°**
3.5cm APFSDS	= 39cm LOS or **39cm @ 0°**	42cm LOS or **36cm @ 30°**
HEAT=	47cm LOS or **47cm @ 0°**	56cm LOS or **49cm @ 30°**

[¼ front turret profile] corner turret average / [½ side Turret profile] front side

	corner turret average	front side
2cm HS APFSDS	= 47cm LOS or **33cm @ 45°**	41cm LOS or **29cm @ 45°**
2cm APFSDS	= 48cm LOS or **33cm @ 45°**	41cm LOS or **29cm @ 45°**
3cm APFSDS	= 49cm LOS or **34cm @ 45°**	41cm LOS or **29cm @ 45°**
3.5cm APFSDS	= 50cm LOS or **43cm @ 45°**	42cm LOS or **29cm @ 45°**
HEAT=	65cm LOS or **50cm @ 45°**	52cm LOS or **36cm @ 45°**

[½ side Turret profile] rear ; The thickness is 30- 40cm around back, this is probably half and half Cast / STEF, thus the KE armor is 0.66 while the HEAT armor is 0.85. Storage boxes 40cm thick are mounted around the side turret covering about ½ the profile , that should increase the shaped charge resistance somewhat.

	¼ side turret [Rear]	¾ side turret with storage boxes
Vs APDS	= 26cm LOS or **23cm @ 30°**	26cm + 2.7cm LOS or **29cm @ 30°**
Vs Sheathed	**=** 25cm LOS or **22cm @ 30°**	25cm + 1.8cm LOS or **27cm @ 30°**
Vs APFSDS	= 24cm LOS or **21cm @ 30°**	24cm + 0.9cm LOS or **25cm @ 30°**
Vs HEAT	= 35cm LOS or **29cm @ 30°**	35cm + 15/1cm + LOS or **44/30cm @ 30° + 0.7d**

Rear turret The thickness is ~ 20cm around back, this is probably half and half Cast / STEF, thus the KE armor is 0.66 while the HEAT armor is 0.85. In the rear turret are sometimes mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor
Vs API/APDS 20 x 0.66 **=** 12.2 + 0.8 = 13 cm or **11cm @ 30°**
Vs HEAT 20 x 0.85 = 17cm LOS + 0.2 + 19/7 = 36 /24 **or 31/21cm @ 30° +0.7d**

Hull Glacis for the T- 80B glacis is assumed to be based on the T- 80 glacis and the T- 80A prototype configuration with improved plates

6cm RHA x 1.0/1.0 [Te] x 0.97/0.95/0.9/0.87 [t/d] = 5.8/5.7/5.4/5.2cm & 6cm [HEAT]
2x 5.25 cm STEF x 0.4/ 0.45 [Te] x 0.7/0.6/0.55 [t/d] or 0.5 [T/d APDS] = 2.8/2.4/2.2/2.0cm & 4.5cm
4cm RHA x 1.0/1.0 [Te] x 0.95/0.9/0.88 / 0.85 [t/d] = 3.8/3.6/3.5cm/ 3.4cm & 4cm [HEAT]
Modifiers x 1.2 [confinement & layering] ÷ 0.38 [Cos of glacis]

[2/3 Front hull profile] Glacis

2cm APFSDS = 12.4 x 1.2 ÷ 0.38 = 39cm LOS or **15cm @ 68°**
3cm APFSDS = 11.7 x 1.2 ÷ 0.38 = 37cm LOS or **14cm @ 68°**
4cm APFSDS = 11.1 x 1.2 ÷ 0.38 = 35cm LOS or **13cm @ 68°**
5- 6cm APDS = 10.6 x 1.2 ÷ 0.38 = 33.5cm LOS or **12.7cm @ 68°**
[HEAT] = 14.5 x 1.2 ÷ 0.38 [Cos] = 46cm LOS or **18cm@ 68°**

[1/3 Front Hull profile] Lower hull is 8cm RHA plus 2cm dozer plate @ 65° = LOS thickness of 23.5cm LOS, x t/d [0.88/0.92/0.94/0.96/0.98]....but the spaced plate should add 1.3d to APFSDS & 2.6d to sheathed penetrators.The RHAe should work out to
2cm APFSDS = 7.8cm+ 1.4cm + 2.6cm = 24cm LOS or **12cm @ 60°**
3cm APFSDS = 7.7cm+ 1.4cm + 3.7cm = 26cm LOS or **13cm @ 60°**

3.5cm sheathed APFSDS = 7.6cm+ 1.3cm + 9cm = 30cm LOS or **15cm @ 60°**
6-7cm WHA APDS = 7.2cm+ 1.3cm + 6cm = 26cm LOS or **13cm @ 60°**
HEAT 2cm MS plate x 0.8 x 3 + 8cm RHA = 23cm LOS or **12cm @ 60° + 0.7d**

SIDE Hull is the basic side hull T-72/64 60mm Hard RHA armor. The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap
Vs 3cm API ~ 6.6+2.9+1.1cm = **10.5cm @ 0°**
Vs 25mm APDS/ APFSDS 6.6+2.8+1.4cm = **11cm @ 0°**
Vs 10mm APFSDS ~ 6.6+1.9+1.5cm = **10cm @ 0°**
HEAT ~ 6.6 + 2 + 19/7 + 1.0d **= 27/15cm @ 0° + 1.0d HEAT**

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear
¼ [engine deck] **~ 2cm KE & 2cm HEAT @ 90°**
¼ [front hull deck & tracks] **~ 4cm. KE & 5cm HEAT @ 90°**
¼ [top turret] **~ 7cm. KE & 11cm HEAT @ 75° + 2d**
1/8th [front/sides & rear turret] ~ **30cm KE & 50cm HEAT @ 90°**
1/8th [glacis] ~ **15cm KE @ 68° & 20cm HEAT @ 68° + 2d**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE; while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT

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T-80 BV [Approximate]

This improved version of the T-80 tank was reported to enter service in the mid 80s as the main battle tank for the Red army in Europe replacing the various marks of the T-64 through out the late 1980s. The armor is the same as the T-80B plus the following improvements. A 3cm thick Semi Hard steel plate was added to the glacis followed by Kontakt ERA, added to the front turret & glacis.
T-80B was modified to BV standard with Kontakt ERA starting in 1983.Close examination reveals that the plates are much thicker than the ~ 3mm that has been reported on the Blazer reactive armor. They may be as much as 6-7mm ,which at the 65-70° angle should cover ¾ of the front turret profile.
Mantle area= 40cm Cast or 35cm Cast [0.95] + 15cm sand [0.18] = 36 cm x 1.2 x 0.8/0.9 = **35-39cm [APDS - APFSDS] 47cm HEAT**
Middle turret area = 65cm cast/sand **[0.57] =** 37 cm x 1.2 x 0.85 - 0.95 = **38-42cm [APDS - APFSDS] & 56cm HEAT**
Corner turret area = 75cm cast/sand **[0.57] =** 43 cm x 1.2 cm x 0.92-0.97 = **47-50cm [APDS - APFSDS] & 65cm HEAT**
From ± 30° off angle that's roughly ~ 60-65cm average LOS with a resistance of ~ **37-40cm [APDS - APFSDS] & 56cm HEAT**

[¼ front turret profile] Upper front turret

	½ exposed or	½ covered in ERA
Vs Steel/Sheathed APFSDS	= 25.0cm LOS or **6.6cm @ 75°**	**7cm @ 75° * ¼ ricochet***
Vs 2-3cm APFSDS	**=** 26.0cm LOS or **6.7cm @ 75°**	**7.6cm @ 75°**
Vs 2cm APFSDS	= 27.1cm LOS or **6.9cm @ 75°**	**7.6cm @ 75°**
Vs HEAT	= 38cm LOS or **9.8cm @ 75°**	**12/ 11cm@ 75° + 3d** old warheads may ricochet** **

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ¼ Kontakt & ¾ exposed armor

[¼ front turret profile] Mantle Area [¼ front turret profile] middle turret

	¾ exposed or [¼ with ERA]	¼ exposed or [¾ with ERA]
2cm HS APFSDS	= 35cm LOS or **35cm @ 0° [37cm@ 0°]**	40cm LOS or **35cm @ 30° [36cm@ 30°]**

2cm APFSDS = 36cm LOS or **36cm @ 0°** **[38cm @ 0°]** 40 cm LOS or **35cm @ 30°** **[37cm @ 30°]**
3cm APFSDS = 37cm LOS or **37cm @ 0°** **[38cm @0°]** 41cm LOS or **36cm @ 30°** **[38cm @ 30°]**
3.5cm APFSDS = 39cm LOS or **39cm @ 0°** **[40cm@ 0°]** 42cm LOS or **36cm @ 30°** **[38cm @ 30°]**
HEAT= 47cm LOS or **47cm @ 0°** **[51/47cm @ 0° + 2.0d]** 56cm LOS or **49cm @ 30°** **[53/49cm @ 30°+ 2.0d]**
Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is reduced to ½ Kontakt & ½ exposed armor.

[¼ front turret profile] sloping wall [½ side Turret profile] front side average

<u>¼ exposed or [¾ with ERA]</u> <u>¼ exposed or [¾ with ERA]</u>

2cm HS APFSDS = 47cm LOS or **33cm @ 45°** **[34cm@ 45°]** 41cm LOS or **29cm @ 45°** **[31cm@ 45°]**
2cm APFSDS = 48cm LOS or **33cm @ 45°** **[35cm @ 45°]** 41cm LOS or **29cm @ 45°** **[31cm@ 45°]**
3cm APFSDS = 49cm LOS or **34cm @ 45°** **[35cm @45°]** 41cm LOS or **29cm @ 45°** **[31cm @ 45°]**
3.5cm APFSDS = 50cm LOS or **43cm @ 45°** **[44cm@ 45°]** 42cm LOS or **29cm @ 45°** **[31cm @ 45°]**
HEAT= 65cm LOS or **50cm @ 45°** **[57/52cm @ 45° + 2d]** 52cm LOS or **36 cm @ 45°** **[42/38cm @ 45°+ 3d]**
Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is reduced to ½ Kontakt & ½ exposed armor.

[½ side Turret profile] rear ; The thickness is 30- 40cm around back, this is probably half and half Cast / STEF, thus the KE armor is 0.66 while the HEAT armor is 0.85. Storage boxes 40cm thick are mounted around the side turret covering about ½ the profile , that should increase the shaped charge resistance somewhat.

	¼ side turret [Rear]	¾ side turret with storage boxes
Vs APDS	= 26cm LOS or **23cm @ 30°**	26cm + 2.7cm LOS or **29cm @ 30°**
Vs Sheathed	= 25cm LOS or **22cm @ 30°**	25cm + 1.8cm LOS or **27cm @ 30°**
Vs APFSDS	= 24cm LOS or **21cm @ 30°**	24cm + 0.9cm LOS or **25cm @ 30°**
Vs HEAT	= 35cm LOS or **29cm @ 30°**	35cm + 15/1cm + LOS or **44/30cm @ 30° + 0.7d**

Rear turret The thickness is ~ 20cm around back, this is probably half and half Cast / STEF, thus the KE armor is 0.66 while the HEAT armor is 0.85. In the rear turret are sometimes mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor
Vs API/APDS 20 x 0.66 = 12.2 + 0.8 = 13 cm or **11cm @ 30°**
Vs HEAT 20 x 0.85 = 17cm LOS + 0.2 + 19/7 = 36 /24 **or 31/21cm @ 30° +0.7d**

Hull Glacis Most sources reported the T-80BV glacis received a 30mm thick hard steel plate and Kontakt ERA in the mid 80s , other wize its treated as the same as T-80B.The Kontakt ERA covers ¾ of the glacis and adds ~ **+3- 6cm KE protection [2cm- 4cm APFSDS]**.and **+42 cm HEAT** armor.

3cm SHS x 1.2/1.2 [Te] x 0.92/0.88/0.85 or 0.8 / 0.6 [t/d] = 3.3/3.2/3.0 cm& 3.6cm [HEAT]
6cm RHA x 1.0/1.0 [Te] x 0.97/0.95/0.9 or 0.88 / 0.6 [t/d] = 5.8/5.7/5.4cm & 6cm [HEAT]
2x 5.25 cm STEF x 0.4/ 0.45 [Te] x 0.7/0.6/0.55 [t/d] or 0.5 [T/d APDS] = 2.8/2.4/2.2 cm & 4.5cm
4cm RHA x 1.0/1.0 [Te] x 0.95/0.9/0.88 / 0.85 [t/d] = 3.8/3.6/3.5cm & 4cm [HEAT]
Modifiers x 1.2 [HEAT] & KE x 1.27 [thick SHS/RHA confinement] ÷ 0.38 [Cos of glacis]
2cm APFSDS = 15.7 x 1.27 ÷ 0.38 = 52.5cm [¾ of the profile has Kontakt ERA with 56cm KE resistance]
3cm APFSDS = 14.9 x 1.27 ÷ 0.38 = 50cm [¾ of the profile has Kontakt ERA with 54cm KE resistance]
3.5cm Sheathed = 14.1 x 1.27 ÷ 0.38 = 47cm [¾ of the profile has Kontakt ERA with 53cm KE resistance]
[HEAT] = 19.1 x 1.2 [layering] ÷ 0.38 [Cos of glacis]= 60cm HEAT [¾ of the profile has Kontakt ERA

[2/3 Front hull profile] Glacis The assumed to be T-72 plus Kontakt ERA covering ¾ of the glacis profile..

Total Vs	**¼ glacis profile**	**or**	**¾ glacis profile with Kontakt ERA.**
2cm HSAPFSDS =	52cm LOS = **20cm@ 68°**		53cm LOS = **20cm@ 68°**
2cm APFSDS =	52cm LOS = **20cm@ 68°**		56cm LOS = **21cm@ 68°**
3cm APFSDS =	50cm LOS = **19cm@ 68°**		54cm LOS = **21cm@ 68°**
4cm APFSDS =	47cm LOS = **18cm@ 68°**		53cm LOS = **20cm@ 68°**
[HEAT] =	60cm HEAT LOS = **23cm@ 68°**		65/60cm LOS = **25/23cm@ 68° +4.0d**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ½ Kontakt & ½ exposed armor

[1/3 Front Hull profile] Lower hull is 8cm RHA plus 2cm dozer plate @ 65° = LOS thickness of 23.5cm LOS, x t/d [0.88/0.92/0.94/0.96/0.98]....but the spaced plate should add 1.3d to APFSDS & 2.6d to sheathed penetrators.A 3cm thick steel reinforced rubber sheet , is suspended from the nose of the front hull . Inaddition to the spaced plate effect this should offering 1.5cm KE and 2cm HEAT .The RHAe should work out to
2cm APFSDS = 9.2cm + 1.4cm + 5.2cm = 30cm LOS or **15cm @ 60°**
3cm APFSDS = 9.1cm + 1.4cm + 7.4cm = 32cm LOS or **16cm @ 60°**
3.5cm sheathed APFSDS = 8.9cm + 1.3cm + 18cm = 42cm LOS or **21cm @ 60°**
HEAT 2cm MS plate x 0.8 + 8cm RHA + 2cm = 39/25cm LOS or **20/13cm @ 60° + 0.6d**

SIDE Hull is the basic side hull T-72/64 60mm Hard RHA armor with the steel rubber side skirt reinforced with Kontakt ERA. The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap . Kontakt ERA is added over most of the side hull adding ~2cm KE resistance and 2d HEAT reduction.

	¼ front turret	¾ front turret with Kontakt ERA
Vs 3cm API ~	6.6+2.9+1.1cm = **10.5cm @ 0°**	**13cm @ 0°**
Vs 25mm APDS/ APFSDS	6.6+2.8+1.4cm = **11cm @ 0°**	**13cm @ 0°**
Vs 10mm APFSDS	~ 6.6+1.9+1.5cm = **10cm @ 0°**	**12cm @ 0°**
HEAT ~	6.6 + 2 + 19/7 + 1.0d **= 27/15cm @ 0° + 1.0d HEAT**	**30/18cm @ 0° + 2.0d HEAT**

Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ¼ Kontakt & ¾ exposed armor

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =
Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear
¼ [engine deck] **~ 2cm KE & 2cm HEAT @ 90°**
¼ [front hull deck & tracks] **~ 4cm . KE & 5cm HEAT @ 90°**
¼ [top turret] **~ 7cm . KE & 11cm HEAT @ 75° + 2d**
1/8th [front/sides & rear turret] ~ **30cm KE & 50cm HEAT @ 90°**
1/8th [glacis] **~ 15cm KE @ 68° & 20cm HEAT @ 68° + 2d**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE **;** while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT

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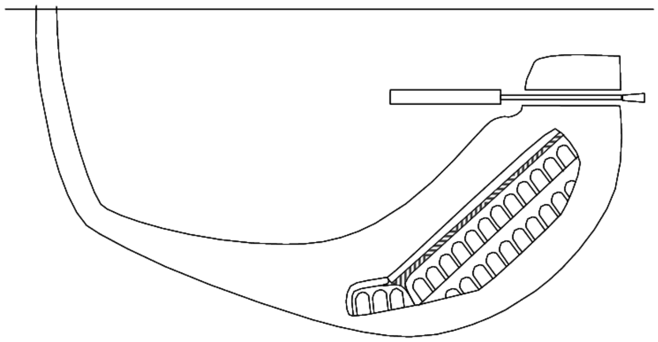
T-80 U/UM-1 [Approximate]

The T-80 turret volume is 1.9m^3 and a profile of 1.1 m² leading to an average armor density of 4.6 tons per m^3 . The T-72B has 6.1 tons and 1.85 m^3 volume and a profile of 1.1 m² ,so the T-80U has about 4.6 /3.3 = 1.39 times as much turret armor mass as T-72B. for a total of 45.2cm x 1.39 = T-80U front turret armor mass of 63 cm steel mass . Mius the known solid thickness of 50cm leaves insert with 13cm steel mass /40-60cm cavity or 2.88 g/cc cross sectional density.The cavity, as shown in the T-80U manuel , features two rows of ceramic [Alumina?] cylinders about12x 6cm ,with a plate in the middle [Aluminum?] and surrounded by some material [probably a Steltexolite?] .If we assume Cast/STEF/ AD85/AD85/STEF/Al-5xxx/Cast , that's + 11.2+ 81.6 ÷ 7.85 = 15cm steel mass against 14.7cm estimated , pretty close.



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Note: one of the armor differences between T-80B and T-80UM is that the upper turret represents ~ 1/ 3 of the profile of the T-80B turret, but only ¼ the profile of the T-80UM turret.

Front Turret [¾ front turret profile]

T-80A turret looks like 0.5 meter around the gun , thicknening from 0.85m to 1.1m thick [LOS] armor as you move past the MG port towards the turret corners. This has 1/2 cast armor and 1/2 insert of which ~ 31cm is ceramic [AD-85?]... while the rest is polyurthen with a thin metal plate in rear[Aluminum?].

Cast is about 0.95 [Te] x 50-55cm thickness and t/d is 0.99/0.99 [2cm/3cm APFSDS]= **47-52cm 50-55**
Ceramic[AD-85]is ~ 0.82[Te] x 15-31cm thickness and t/d is 0.91/0.81= **11.2- 23.1& 10-20.6cm. 6.5-13.5**
Polyurthene is about 0.2[Te] x 18-20cm and t/d is 0.91/0.81= **3.3-3.6cm & 2.9-3.2cm. 2.3-2.4**
Inner plate is ~ 4cm aluminum with 0.4 [Te] and a 0.94/0.9t/d= **1.5/1.44 cm. 1.44**
50- 60-72cm steel armor mass? Me = 0.95- 1.1 –1.17 x 0.95-0.9 [2-4cm t/d] x 0.6-0.57 [2-4cm w/d] x 1.25 [coverplate]

The lateral confinement [W/d] of 3:1 vs 20mm diameter APFSDS and 2:1 for 30mm diameter APFSDS , with thick confinement. That translates into a value of about 0.63 @ 2cm & 0.6 @ 3cm. With ceramic models that feature ceramic mounted on thick soft material [Fibrglas or Poly] the resistance has been shown to be 95% of what the Te figures suggest, while such thick outer plates will not offer much advantage.The total works out to about **38cm** around the gun mantle and ….
2cm APFSDS = 47-52cm + 11.2- 23.1+ 3.3-3.6cm + 1.5cm x 1.25 [confinement] x 0.6 [Lc above] = **47cm esistance near the MG port to 60cm @ the turret corners. Average 51±12cm**
4cm APFSDS 47-52cm + 10-20.6cm + 2.9-3.2cm + 1.45cm x 1.25 [confinement] x 0.57 [Lc above] = **43cm resistance near the MG port to 54cm near the turret corners. Average 47±9cm**
50-55cm thickness x Cast x 0.95 [Te] = 45-50cm
15-31cm x Ceramic[AD-85]x 1.0[Te] = 15-31cm
18-20cm Polyurthene x 0.25[Te] x = 4.5-5cm
4cm thick Aluminum plate 0.6[Te] = 2.4cm
From straight on **65cm near gun 90cm at the corners;** [**Average 74±15cm]** and from 30° off angle **71cm ± 3cm**

Kontakt ERA covers ~ ½ of the front turret profile over the thickest most sections leading to a boost in resistance of +18-19cm [2-4cm APFSDS] or +23-26cm [2-4cm sheathed APFSDS]
½ front turret ½ front turret with K-5 ERA
2cm HS APFSDS = 39.7cm + 9.3= **38-47-60cm [Average 51± 4cm]** plusERA = + K-5 = **49-58-71cm [Average 69± 10cm]**
2cm APFSDS = 39.7cm + 9.3= **38-47-60cm [Average 51± 4cm]** plusERA = + K-5 = **56-65-78cm [Average 69± 10cm]**
3cm APFSDS= 39.3cm + 9.7= **38-45-57cm [Average 49± 4cm]** plus ERA = + k-5= **57-64-76cm [Average 68± 11cm]**
3.5cm sheathed = 37.5cm + 19.5= **38-43-54cm [Average 47± 8cm]** plus ERA = + K-5 = **62-67-78cm [Average 71±9cm]**
HEAT 8.6 + 3.2+ 38cm x 1.1= **60-65-90cm HEAT[Average 74± 4cm]** plus ERA = + K-5 = **110-115-140cm** [**126±16cm]**

[¼ front turret profile] Upper front turret

	½ exposed	or	½ covered in ERA
Vs Steel/Sheathed APFSDS	= 25.0cm LOS or **6.6cm @ 75°**		**7cm @ 75° *¼ ricochet***
Vs 2-3cm APFSDS	= 26.0cm LOS or **6.7cm @ 75°**		**7.6cm @ 75°**
Vs 2cm APFSDS	= 27.1cm LOS or **6.9cm @ 75°**		**7.6cm @ 75°**

Vs HEAT = 38cm LOS or **9.8cm @ 75°** **12/ 11cm@ 75° + 3d** old warheads may ricochet ****
Percentage of coverage is reduced by 2% with each hit so after 15 hits coverage is ¼ Kontakt & ¾ exposed armor

[¼ front turret profile] Mantle Area(cast) [½ front turret profile] sloping wall

	¾ exposed or [¼ with K-5 ERA]		¼ exposed or [¾ with ERA]	
2cm HS APFSDS	= 45cm LOS or **39cm @ 30°**	**[51cm@ 0°]**	60cm LOS or **42cm @ 45°**	**[54cm@ 45°]**
2cm APFSDS	= 45cm LOS or **39cm @ 30°**	**[55cm @ 0°]**	60 cm LOS or **42cm @ 45°**	**[58cm @ 45°]**
3cm APFSDS	= 46cm LOS or **39cm @ 30°**	**[57cm @ 0°]**	57cm LOS or **40cm @ 45°**	**[58cm @ 45°]**
3.5cm APFSDS	= 46cm LOS or **40cm @ 30°**	**[63cm@ 0°]**	54cm LOS or **38cm @ 45°**	**[61cm @ 45°]**
HEAT=	60cm LOS or **52cm @ 30°**	**[68/62cm @ 0° + 3d]**	90cm LOS or **63cm @ 45°**	**[80/73cm @ 45°+ 4.0d]**

If more than 6 hits on the side turret then 'K-5 covered areas' are considered "reduced" and should have the KE resistance reduced by 4cm [7cm if sheathed APFSDS], while the HEAT resistance should go down + 1.0d

[front ½ side Turret profile] side average 60-80cm LOS 0.6/0.7= Te & .68 +ERA K-5 should add 18-19cm KE resisance Vs monoblock penetrators and 23-24cm Vs sheathed penetrators.

	½ exposed or	[½ with K-5 ERA]
2cm HSAPFSDS	= 40cm LOS or **28cm @ 45°**	53cm los **[37cm@ 45°]**
2cm APFSDS	= 42cm LOS or **29cm @ 45°**	60cm LOS **[42cm@ 45°]**
3cm APFSDS	= 44cm LOS or **31cm @ 45°**	63cm LOS **[44cm @ 45°]**
3.5cm APFSDS	= 49cm LOS or **34cm @ 45°**	72cm LOS **[50cm @ 45°]**
HEAT=	54/47cm LOS or **38/ 33cm @ 45°**	57/48cm LOS **[40/34cm @ 45°+ 4d]**

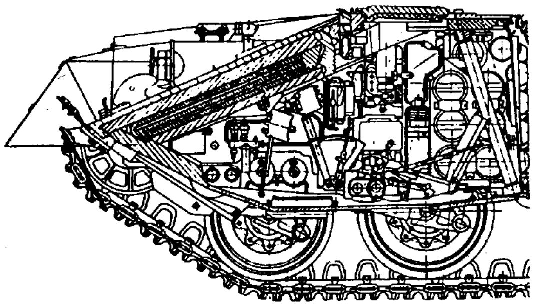
If more than 6 hits on the side turret then 'K-5 covered areas' are considered "reduced" and should have the KE resistance reduced by 4cm [7cm if sheathed APFSDS], while the HEAT resistance should go down + 1.5d

[rear ½ side Turret profile] ;The thickness is 30- 40cm around back, this is probably half and half Cast / STEF, thus the KE armor is 0.66 while the HEAT armor is 0.85. Storage boxes 40cm thick are mounted around the side turret covering about ½ the profile , that should increase the shaped charge resistance somewhat.

	¼ side turret [Rear]	¾ side turret with storage boxes
Vs APDS	**=** 26cm LOS or **23cm @ 30°**	26cm + 2.7cm LOS or **29cm @ 30°**
Vs Sheathed	**=** 25cm LOS or **22cm @ 30°**	25cm + 1.8cm LOS or **27cm @ 30°**
Vs APFSDS	= 24cm LOS or **21cm @ 30°**	24cm + 0.9cm LOS or **25cm @ 30°**
Vs HEAT	= 35cm LOS or **29cm @ 30°**	35cm + 15/1cm + LOS or **44/30cm @ 30° + 0.7d**

Rear turret The thickness is ~ 20cm around back, this is probably half and half Cast / STEF, thus the KE armor is 0.66 while the HEAT armor is 0.85. In the rear turret are sometimes mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor
Vs API/APDS 20 x 0.66 = 12.2 + 0.8 = 13 cm or **11cm @ 30°**
Vs HEAT 20 x 0.85 = 17cm LOS + 0.2 + 19/7 = 36 /24 **or 31/21cm @ 30° +0.7d**

Glacis is reported to be based on the T-80B glacis or about 235mm thick with a 30mm hard steel[~ 430 BHN?] outer plate , followed by a ~ 60mm thick hard steel plate. Going on the above diagrame ,the rear plate looks like ~45mm which would leave the inserts @ 100mm made up of 5 layers with two layers about 1cm thick each sandwiched between a 2cm inner layer encased in two outer layers about 3cm thick. The 1cm inner layers are the same material while the rest are the other materials. .The mass increase from T62 to T-80B [36.3 tons 42.5 tons] is about 17% increase, while the volume change from T-62 to T-80B is 13% increase in density [12.5m^3 11.1m^3]. The front hull profile on T-80B is 1.93m², while the T-62A is 2.16m² [2.16/1.93] , again leading to a 12% higher armor mass for the same weight or 48% mass total increase over the T-62 glacis & hull [377mm x 1.48 = 558mm]. The T-80B lower hull is 90mm @ 64°= 205mm, so that leaves the glacis with 353mm or 134mm steel @ 67°. The insert look like two different materials and 134mm minus the known steel mass of 105mm that leaves 29.2 mm steel over 100mm insert or 2.92g/cc. This could suggest that the armor to be Steel rubber/STEF or a "BDD type arrangement", similar to the upgraded armor for the glacis of the T-62 & T-55 tanks . Thus the thick layers are rubber and the thin plates are metal , in this case it could be 2 x 1cm MS [7.8/cc] plus 8cm of Rubber [1.44g/cc] = 2.72g/cc or 8cm STEF [1.85g/cc] & 2cm MS = 3.0g/cc. .In addition ¾ of the glacis is covered in K-5 ERA that adds ~ **+17cm KE protection [2cm- 4cm APFSDS]** and **23-24cm [Sheathed APFSDS]** + **50 cm HEAT** armor .



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3cm SHS x 1.2/1.2 [Te] x 0.9/0.88/0.85/ 0.8 [t/d] = 3.2/3.1/3.0/ 2.9cm & 3.6cm [HEAT]
6cm SHS x 1.2/1.2 [Te] x 0.97/0.95/0.9 / 0.88 [t/d] = 7/6.8/6.5/ 6.3cm & 7.2cm [HEAT]
10 cm Rubber/MS/Rubber x 0.3/ 0.31 [Te] x 0.7/0.6/0.55/ 0.5 [T/d] = 2.2/1.9/1.7; 1.57cm & 3.26cm
5cm RHA x 1.0/1.0 [Te] x x 0.97/0.95/0.9 / 0.88 [t/d] = 4.8/4.7/4.5/4.4 & 5cm [HEAT]
Modifiers x 1.2 [HEAT] & KE x 1.18 [RHA confinement] ÷ 0.38 [Cos of glacis]
Total Vs

[2/3 Front hull profile] **Glacis** The assumed to be T-72 plus Kontakt ERA covering ¾ of the glacis profile.

Total Vs	**¼ glacis profile**	**or**	**¾ glacis profile with Kontakt ERA.**
2cm HS APFSDS =	53cm LOS = **20cm@ 68°**		66cm LOS = **25cm@ 68°**
2cm APFSDS =	53cm LOS = **20cm@ 68°**		70cm LOS = **27cm@ 68°**
3cm APFSDS =	51cm LOS = **19cm@ 68°**		68cm LOS = **26cm@ 68°**
Sheathed APFSDS =	49cm LOS= **18.5cm@ 68°**		72cm LOS = **27cm@ 68°**
[HEAT] =	60cm HEAT LOS = **23cm@ 68°**		65/60cm LOS = **30/28cm@ 68° +3.0d**

Effectiveness of K-5 is considered "reduced" after 12 hits [subtract 4 off the above values, except 3.5cm Sheathed, in that case subtract 7 off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance to + 1.0d.

[1/3 Front Hull profile] Lower hull is 8cm RHA plus 2cm dozer plate @ 65° = LOS thickness of 23.5cm LOS, x t/d [0.88/0.92/0.94/0.96/0.98]....but the spaced plate should add 1.3d to APFSDS & 2.6d to sheathed penetrators.A 3cm thick steel reinforced rubber sheet , is suspended from the nose of the front hull . Inaddition to the spaced plate effect this should offering 1.5cm KE and 2cm HEAT .The RHAe should work out to

2cm APFSDS	= 9.2cm + 1.4cm + 5.2cm = 30cm LOS or **15cm @ 60°**
3cm APFSDS	= 9.1cm + 1.4cm + 7.4cm = 32cm LOS or **16cm @ 60°**
3.5cm sheathed APFSDS	= 8.9cm + 1.3cm + 18cm = 42cm LOS or **21cm @ 60°**
HEAT	2cm MS plate x 0.8 + 8cm RHA + 2cm = 39/25cm LOS or **20/13cm @ 60° + 0.6d**

SIDE Hull is the basic side hull T-72/64 60mm Hard RHA armor with the steel rubber side skirt reinforced with heavy Kontakt 5 ERA. The side skirts added the ~ 3cm thick reinforced rubber [with steel?] plate plus 60cm airgap . These look like a 2.5cm outer plate [steel?] , 1.5cm inner plate [Kontakt?] plus 2.5cm airgap and 1.5cm rear plate [Kontakt?]

	Rear ½ Side Hull	Front ½ Side Hull with K-5 ERA
Vs 3cm API ~	6.6+2.9+1.1cm = **10.5cm @ 0°**	**21cm @ 0°**
Vs 25mm APDS/ APFSDS	6.6+2.8+1.4cm = **11cm @ 0°**	**22cm @ 0°**
Vs 10mm APFSDS	~ 6.6+1.9+1.5cm = **10cm @ 0°**	**21cm @ 0°**
HEAT ~	6.6 + 2 + 19/7 + 1.0d **= 27/15cm @ 0° + 1.0d HEAT**	**30/18cm @ 0° + 2.0d HEAT**

Effectiveness of K-5 is considered "reduced" after 16 hits [subtract 2 of above values off the above values]. If HEAT Vs "reduce", K-5 covered areas reduce resistance by 2d.

Rear hull 46mm plate probably 350 BHN leading to a 1.1 x t/d =

Vs APC = 3cm @ 0°
Vs API = 4cm @ 0°
Vs HMG/ HEAT = 5cm @ 0°

Top tank armor is in three sections , the rear
¼ [engine deck] **~ 2cm KE & 2cm HEAT @ 90°**
¼ [front hull deck & tracks] **~ 4cm . KE & 5cm HEAT @ 90°**
¼ [top turret] **~ 7cm . KE & 11cm HEAT @ 75° + 2d**
1/8 th [front/sides & rear turret] ~ **30cm KE & 50cm HEAT @ 90°**
1/8 th [glacis] ~ **25cm KE @ 68° & 26cm HEAT @ 68° + 2d**

Bottom tank armor armor seems quite thin with plate 25-16mm thick in places. Inaddition there should be ground clearance standoff. The resistance is probably ~ 2-3cm KE ; while the standoff in the 'ground clearance' should offer a standoff of 55cm leading to ~ **front ½ = 3cm KE and 22/7cm HEAT**
Rear ½ = 2cm KE and 22/7cm HEAT

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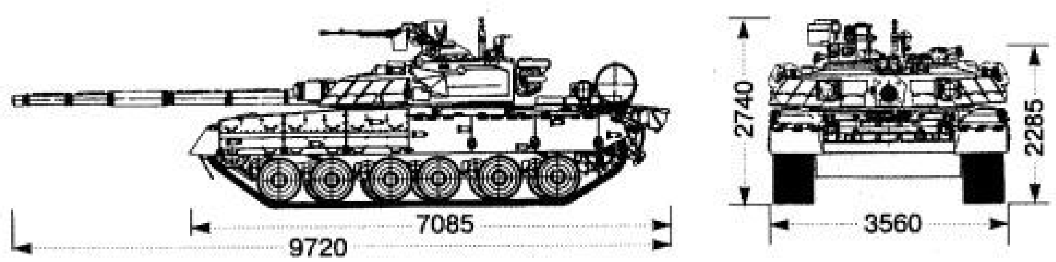
T-84 [Tentative]

The T-84 uses the same hull as the T-80U but uses a new welded turret.The maximum armor thickness of this turret is probably similar to the T-80U front turret armor ,which is reported tobe 815mm thick and the insert is probably similar to the T-90 with ~ 380mm LOS insert thickness suggested ....



The turret is welded with almost half insert which is probably AD-90 mounted on STEF .The KE value of this combo is probably 0.9+ 0.41/2 =0.66 and HEAT value of 0.55+ 1.5/2=1.025 .Thus the effectiveness is 1.66/2 = 0.83 KE and 1.02 HEAT around the front turret and 0.7 KE and 0.775 HEAT around the rest of the turret. Thus the 815mm front turret LOS thickness translates into 0.83 x 815 or 67cm KE resistance while the mantle reaches ~ 83cm and the sloping walls reach 60cmKE resistance . However the 'free edge effect' should reduce the KE values below these figures, the area near the gun would go down to 0.6 mantle to 50cm KE while the 815mm section should be ~**0.9 x 67cm or 61cm** while the main walls would be ~ 0.95 times **60cm or 57cm** . SO the weakened area is around **50-51cm** while the main walls are **61-57cm KE** . The HEAT values should be 720-815 x 1.02 or ~ **73-83cm** along the main walls .

Looking closely at the angles on the T-84 seems close to theT-80 fit and therefore 60° x 35-45° [or 2.11 - 2.24 times] thus thats 15-17cm KE armor . Maybe the effect of scatter ,mentioned above, is part of the answer .If we take the 700mm figure to equal 77-78° slope of the upper turret thats ~15cm at normal impact,and if we read 400mm equal to front turret slope of K-5 on thats ~17cm normal impact.Based on that the figures are 15-17cm HEAT compared to 7.1-7.5cm KE or or 2.1-2.26 x the KE values....

T-84 est Turret Armor
/70-72cm LOS x 0.83 [Weld/ STEF/AD-90]= 60 x 0.95=57[free edge effect] plus K-5 ~**76±2cm KE and 118±4cm HEAT**
| 81.5cm LOS x 0.83 [Weld/ STEF/AD-90]= 67cm x ~ 0.85=57cm [free edge effect] plus K-5 = **76±2cm KE & ~128±4cm HEAT**
[~90-80cm [mantle + airgap] ~70-60 cm LOS x[free edge effect]= 0.6-0.75 = **42-45 cm KE /68-78cm HEAT**
|81.5cm LOS x 0.83 [Weld/ STEF/AD-90]= 67cm x ~ 0.85=57cm [free edge effect] plus K-5 = **76±2cm KE & ~128±4cm HEAT**.

\70- 72cm LOS x 0.83 [Weld/ STEF/AD- 90]= 60 x 0.95=57[free edge effect] plus K-5 ~**76±2cm KE and 118±4cm HEAT**
K-5 turret coverage seems to be about 60%.

Upper front turret is 5cm cast plus 5cm Steltexolite @~ 82- 83 ° or 72- 82cm LOS x 0.7 = **50- 57 KE** and x 0.77 for **55- 63cm HEAT** armor.Where ERA covers this the armor its plus **7- 8cm KE and 36± 17cm HEAT.**

Side turret Is likely to be 40cm thick and ~ 15- 20cm around back . This is probably half and half Rolled plate / STEF thus the KE armor is 0.7 while the HEAT armor is 0.77 .The effective KE armor is ~ **28cm** and **10- 14cm** around back. The HEAT armor **31cm** on the side to **15- 12cm** around back. In the side and rear turret are mounted external storage boxes ~50cm thick that will offer a modicum of spaced armor , this may amount to an additonal **~13- 15cm** HEAT armor..Additionally K-5 is mounted around the front side of the turret.

REST AS T- 80UM