ANVILOY® PRODUCTS

SHIELDING OF HIGH ENERGY X-RAYS

ANVILOY®

ABICOR® GROUP

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The shielding of high energy photonic radiation is one of the most important uses of ANVILOY® tungsten heavy alloys because of the following characteristics:

- Good mechanical properties, with a yield strength comparable to hot rolled medium carbon steel. (simpler still than nonhardened)
- Thermomechanical properties vastly superior to lead alloys.
- High attenuation of photonic radiation for a given thickness (specific attenuation)
- W-Ni-Fe offers less susceptibility to photonuclear activation than W-Ni-Cu alloys
- Low toxicity, chemical reactivity, and susceptibility to corrosion
- Easy machining – available in a wide range of sizes and shapes

These and other advantages of ANVILOY® shielding over other materials can be seen in the table below. ANVILOY® tungsten heavy alloys offer linear attenuation close to that of pure tungsten, which in turn is only slightly lower than that of depleted uranium (DU). ANVILOY® tungsten heavy alloys offer distinct advantages over both DU and Pb because they are not subject to special OSHA, EPA, NRC or other regulations governing sale, handling and/or use.

ANVILOY® tungsten heavy alloys are particularly suitable for shielding high energy photonic radiation emanating from radioisotope sources such as Co-60, from reactor operation, and from high voltage X-ray generators. Crucial for attenuation of high energy photonic radiation is the atomic number and gravimetric density. ANVILOY® tungsten heavy alloys offer many advantages over the widely used lead alloys. These include higher strength, higher thermal conductivity, better thermal stability, greatly reduced toxicity, and better shielding efficiency (up to 36% lower thickness for Co-60 radiation).

ANVILOY® tungsten heavy alloys are not appropriate for shielding alpha or other charged particle radiation, since much cheaper material solutions with lower atomic mass, such as plastics or Al alloys, are sufficient for this purpose. ANVILOY® tungsten heavy alloys should never be used for attenuation (shielding) of beta radiation. Given the high atomic number (Z) of tungsten, Bremsstrahlung would give rise to high energy X-rays, posing a greater shielding problem than the original beta radiation.

Comparison of metallic gamma shielding materials in order of attenuation efficiency

Element/ alloy	µ (cm^{-1}) for 1.25 MeV*	Z	Density (g/cm^3)	Melting Point or Solidus (C)	Thermal conductivity (W/mK)	Thermal expansion conﬃcient. (10^{-6}/K)	Ultimate Strenth (MPa)
Stainless steel (Fe-19Cr-9Ni)	0.428	mixed	~8	1400	16	17	515
Copper (Cu)	0.471	29	8.96	1083	390	17	<365
Lead (Pb)	0.667	82	11.35	328	33	29	~21
ANVILOY®	0.953-1.04	mixed	17-18.5	~1450	~70-100	~5.8-4.8	870
Tungsten (W)	1.076	74	19.3	3420	160	4.2	980
Uranium (U)	1.217	92	19.1	1132	27	19	400

*All photon attenuation values contained in this flyer were calculated with the NIST XCOM photon scattering program.

Whenever shielding is exposed to elevated temperature, e.g., decay heat from very active sources, at which lead alloys would deform or melt, tungsten heavy alloys should be used because of their high thermal conductivity and solidus temperature.

The radiation transmission (T) through a plate-shaped shield of a given material of thickness x is given by:

T=e^(-ux)

The linear attenuation coefficient µ is strongly influenced by photon energy, the Z-number, and material density of the shield. It must be noted that this simple estimate of shielding effectiveness may overestimate protection level in some cases.

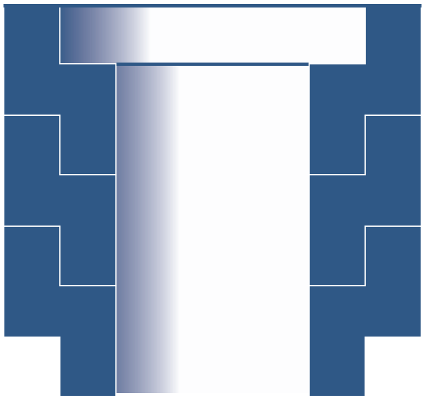
It is convenient to discuss protection level in terms of tenth value layer thickness - the thickness of shielding required to reduce the incident radiation flux by a factor of 10. By adding tenth value layer thicknesses, resultant protection level is multiplied. Accordingly, a 10000:1 attenuation would require a shielding of 4 tenth value thicknesses. The table below contains the approximate tenth-value thicknesses of various ANVILOY® tungsten heavy alloys for selected photon energies.

Calculated Tenth Value Layer Thicknesses (in cm)

Energy (MeV)	ANVILOY® 170L	ANVILOY® 175L	ANVILOY® 180L	ANVILOY® 170F	ANVILOY® 175F	ANVILOY® 180F	ANVILOY® 185F	W ref.	Pb ref.	U ref.	ANVILOY® 180F/Lead
0.12	0.053	0.051	0.048	0.053	0.050	0.048	0.046	0.043	0.058	0.028	75%
0.14 ^{99m}Tc	0.078	0.074	0.071	0.079	0.074	0.071	0.068	0.064	0.085	0.040	80%
0.20	0.186	0.178	0.169	0.186	0.178	0.169	0.163	0.153	0.204	0.094	80%
0.36 ^{131}I	0.619	0.591	0.566	0.618	0.589	0.565	0.549	0.519	0.722	0.340	76%
0.47 ^{192}Ir	0.933	0.893	0.863	0.933	0.893	0.861	0.838	0.795	1.140	0.509	74%
0.51 from β+	1.050	1.010	0.960	1.040	0.993	0.960	0.933	0.890	1.300	0.637	72%
0.66 ^{137}Cs	1.410	1.360	1.310	1.400	1.350	1.310	1.280	1.220	1.830	1.540	70%
1.00	2.100	1.990	1.920	2.040	1.980	1.920	1.880	1.800	2.860	1.540	66%
1.25 ^{60}Co	2.420	2.350	2.280	2.410	2.340	2.280	2.220	2.140	3.460	1.910	64%
2.22 H(n,γ)	3.130	3.050	2.950	3.120	3.040	2.950	2.880	2.780	4.540	2.580	63%
6.00	3.270	3.160	3.050	3.270	3.150	3.050	2.960	2.840	4.630	2.660	64%
10.0	2.930	2.820	2.720	2.920	2.820	2.710	2.640	2.520	4.090	2.340	65%
20.0	2.390	2.280	2.200	2.380	2.280	2.200	2.140	2.020	3.270	1.880	65%

ANVILOY® tungsten heavy alloys expand very minimally with temperature increase and thus offer good dimensional stability. In shielding constructions made of several materials, the internal tungsten component expands less than a surrounding stainless steel housing over the same temperature change. Lead shields encounter risk of permanent deformation due to their greater thermal expansion. ANVILOY® tungsten heavy alloys dissipate heat 4-6 times better than austenitic stainless steel. These improved properties allow the heat from the interior to be quickly distributed over larger heat dissipation surfaces.

If large shields are required, they can be assembled from individual smaller components. In this case, offsets or "radiation joints" should always be used to prevent any straight-line leakage from occurring. Cylindrical shields could be composed of stacked rings with an axial offset (male and female stages). The offset of the radiation joints should be on the order of half the shield wall thickness.

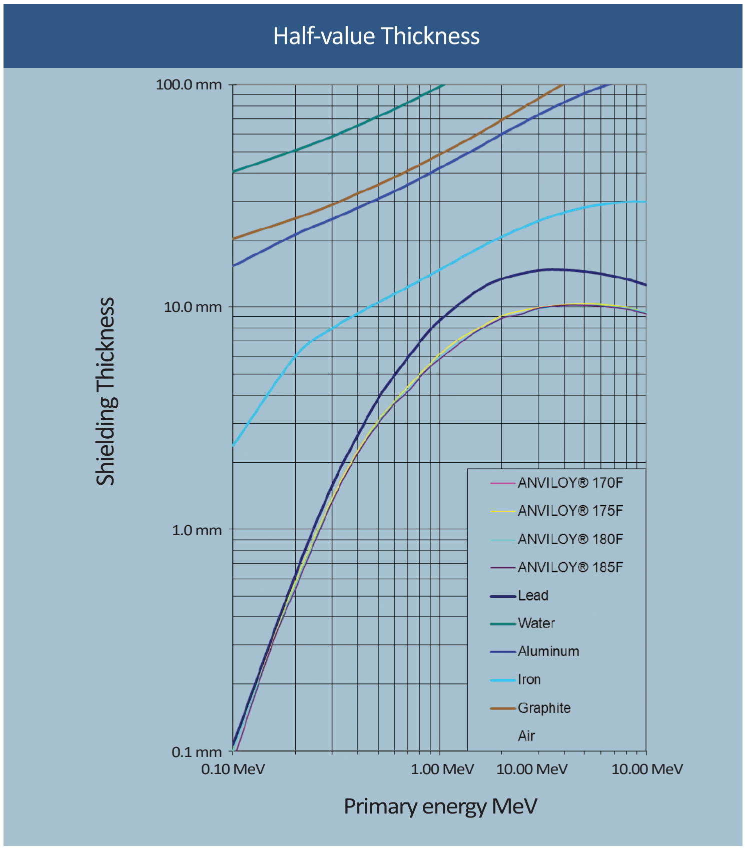


Neutron shielding is usually realized with water, hydrogen-rich polymers such as PE, or materials such as boron concrete. However, for neutron shielding, tungsten alloys alone have no significant role. Nevertheless, the high tungsten content provides better neutron absorption than many other metals (see table below). Tungsten has a neutron capture cross section more than 100 times higher than lead and almost seven times higher than pure iron. Although ANVILOY® tungsten heavy alloys have never been selected for use in a primary neutron shield because of its weight and cost, it can still play an important secondary shielding role in mixed radiation environments. A typical secondary shielding task would be the attenuation of 2.2 MeV gamma radiation from H-capture of neutrons in PE or similar H-rich primary shielding layers, in addition to an existing gamma flux.

Neutron absorption cross section of different materials

Element	Absorption cross section for Neutrons (10^{-28} m^2)
B	760
W	18
Ni	4.5
Fe	2.6
Al	0.23
Pb	0.172

The term “radiation shielding” is also used in the context of electromagnetic interference (EMI) or radio-frequency interference (RFI) shielding. However, ANVILOY® tungsten heavy alloys are unsuitable for high frequency radiation shielding due to cost, density, and low magnetic permeability.


Half-value Thickness

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