NOVEL RADIATION SHIELDDING FABRIC FOR PERSONAL PROTECTION AGAINST RADIOACTIVE SOURCES

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CB 050 Vojenská chemie, toxikologie ochrana před vysoce toxickými látkami

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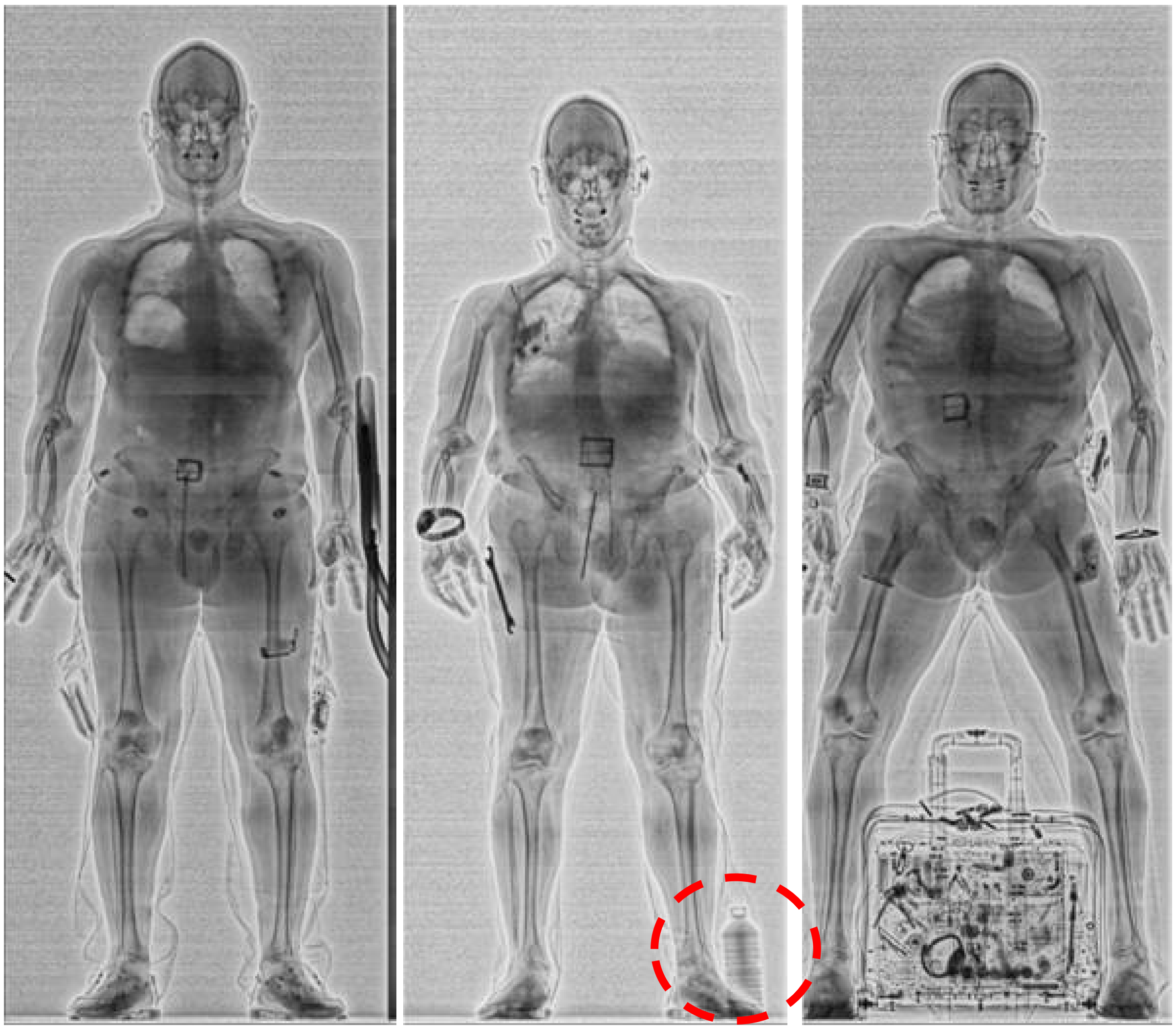
Non Destructive Imaging and Evaluation

Security Scans

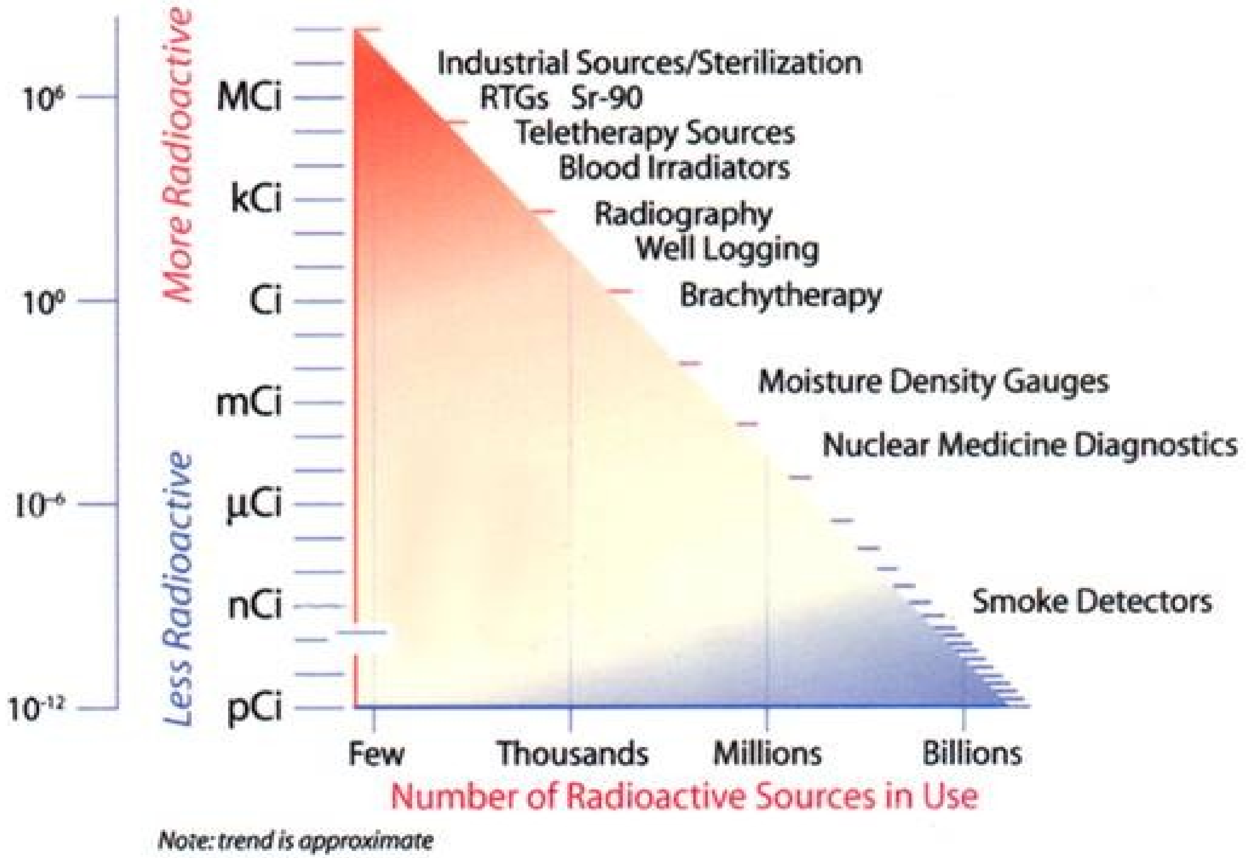


Radiation Generating Equipment

- **Healthcare**
- ***Diagnostic radiography:*** X-rays are produced only when the machine is activated. X-ray images are viewed on a film or through digital images.
- ***Diagnostic fluoroscopy***: X-ray images are viewed on a video monitor rather than on film. Fluoroscopy procedures are the largest source of occupational radiation exposure in medicine. Fluoroscopy is used to study moving structures, and to assess positioning during surgical and radiographic procedures.
- ***Radiation therapy***: Linear accelerators (powerful electron and X-ray beam machines) are used for the treatment of cancer. The energy of the X-ray radiation produced by these units is 10 to 100 times that of a diagnostic X-ray machine.
- ***Diagnostic and therapy Radionuclides:*** Tc-99m, I-131, P-32, Ir-192, Cs-137, I-125 and Y-90, are frequently used in hospitals.

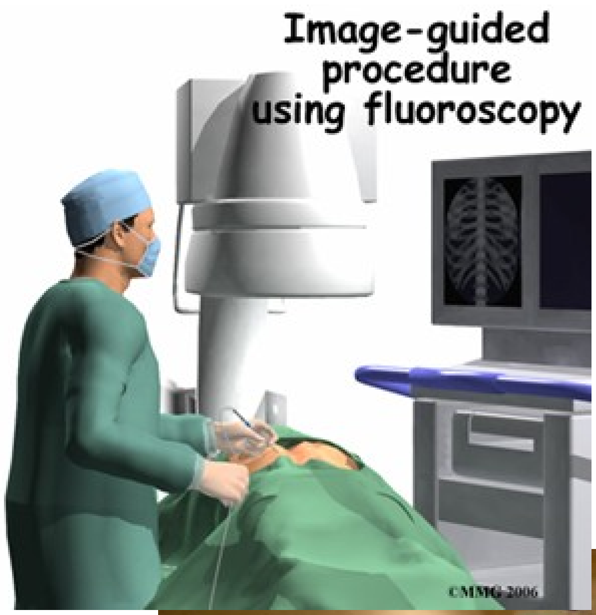
- ***Industrial and security machinery***
- ***Non-destructive*** industrial inspection machinery
- ***Gauges***
- ***Fire detectors***
- **Sterilization machines**
- ***Ion implantation machines*** used in the manufacture of electronic chips
- ***Baggage screening machines***
- ***Personnel screening machines***
- ***Research nuclear reactors***
- ***Portable nuclear power generators***
- ***Orphan sources***

Radiation Sources

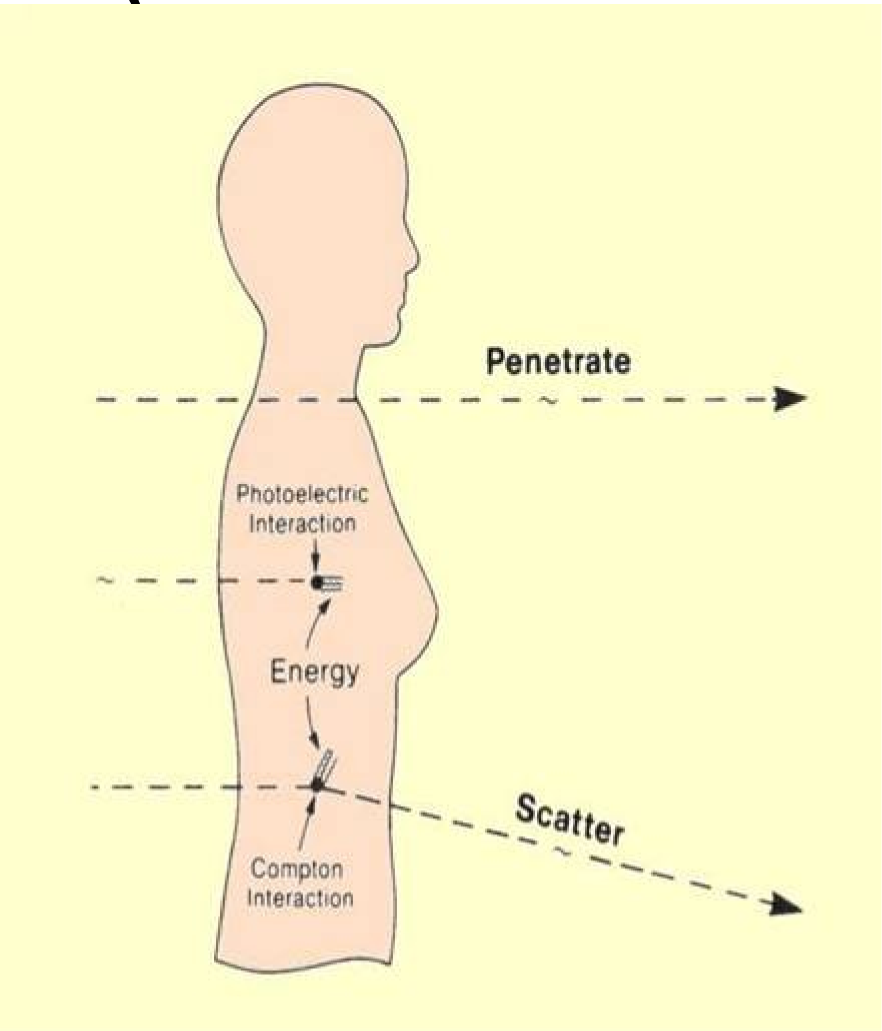


Relative number and strength of radioactive sources

Radiography Technologies



Photons Entering the Human Body (Penetration&Absorption&Scattering)

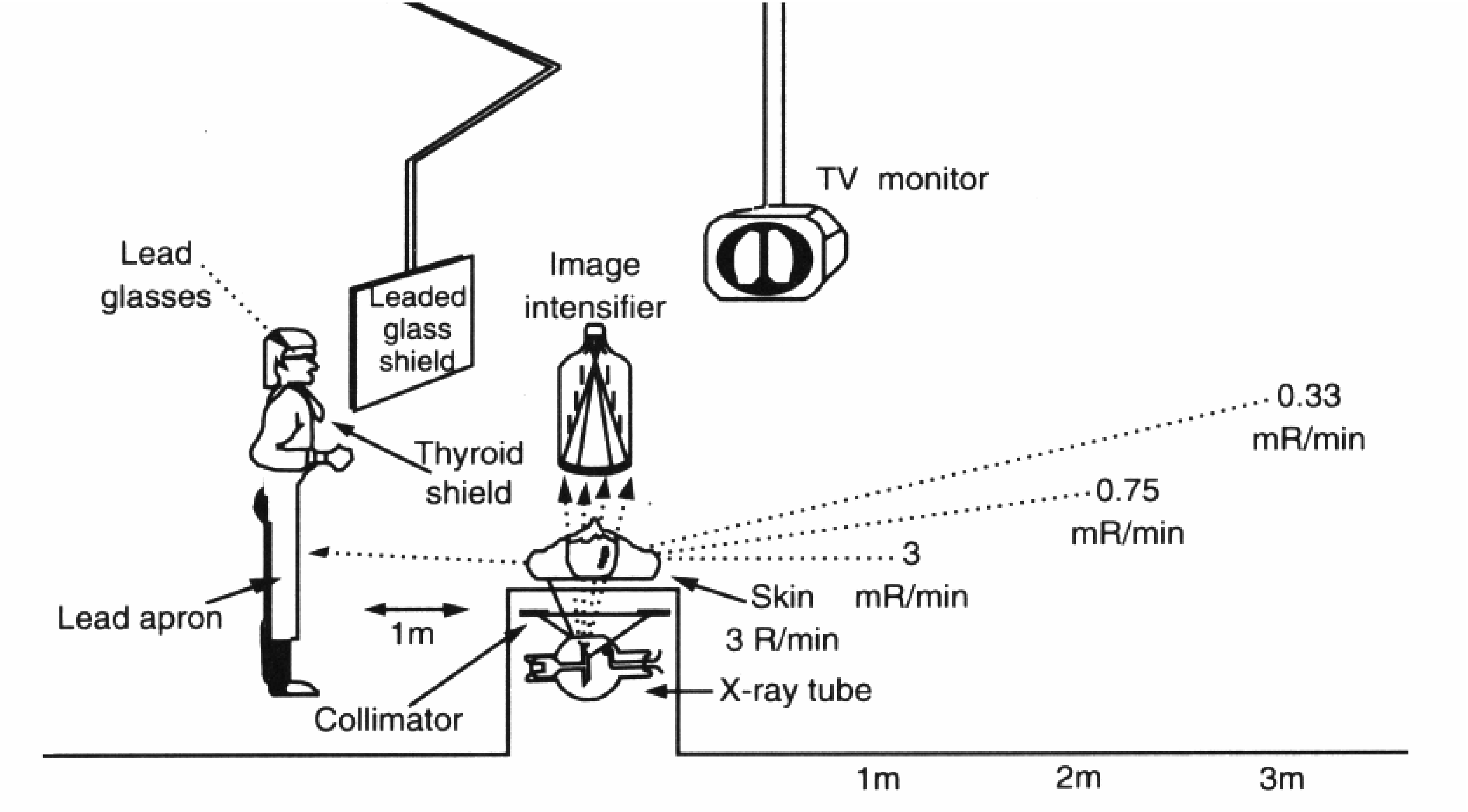


- There are two kinds of interactions through which photons deposit their energy due to interactions with electrons:
- Penetration
- Through photoelectric interaction the photon loses all its energy
- Through Compton interaction photon loses a portion of its energy, and the remaining energy is scattered.

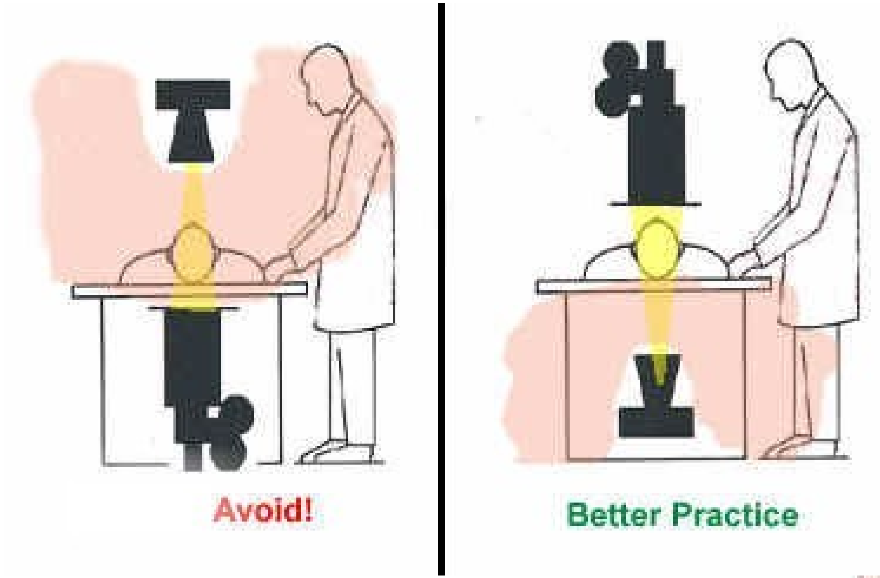
Primary radiation

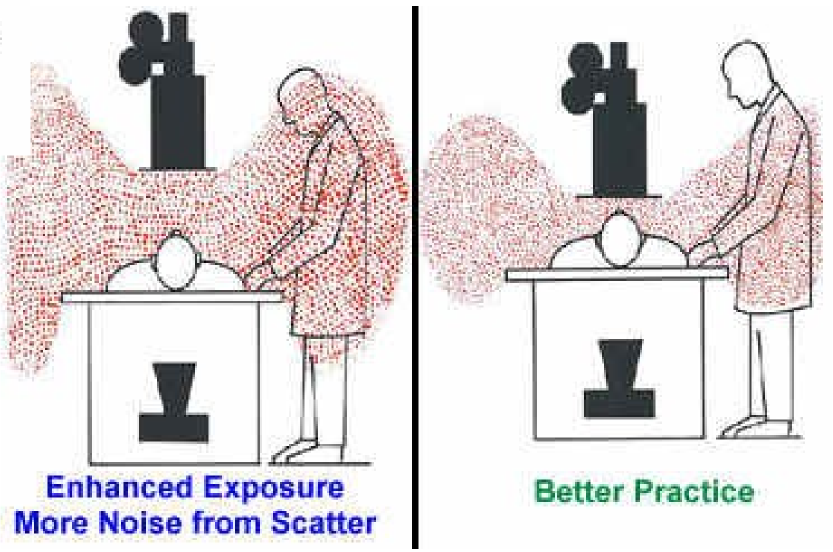
Scattered radiation

Leakage radiation

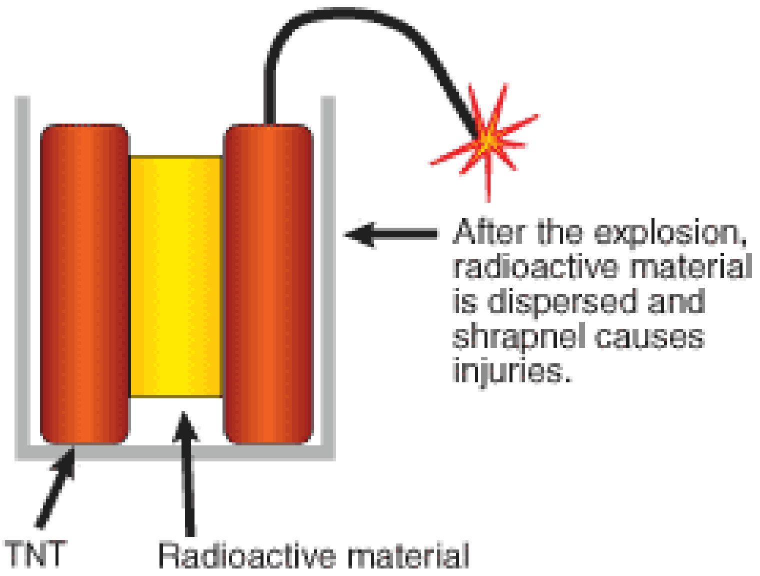


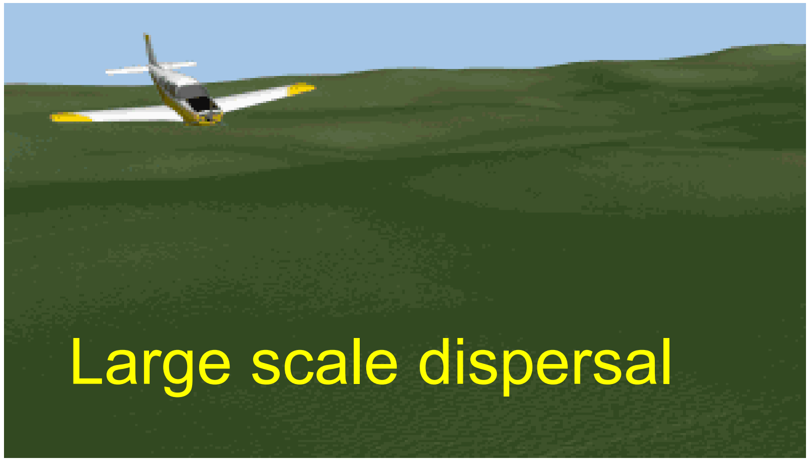
Scattered Radiation Exposure

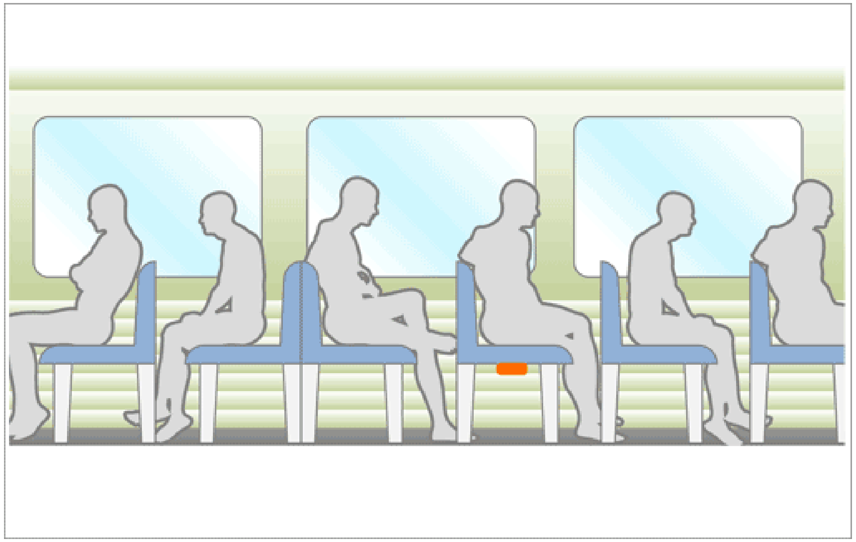




RDDs and REDs





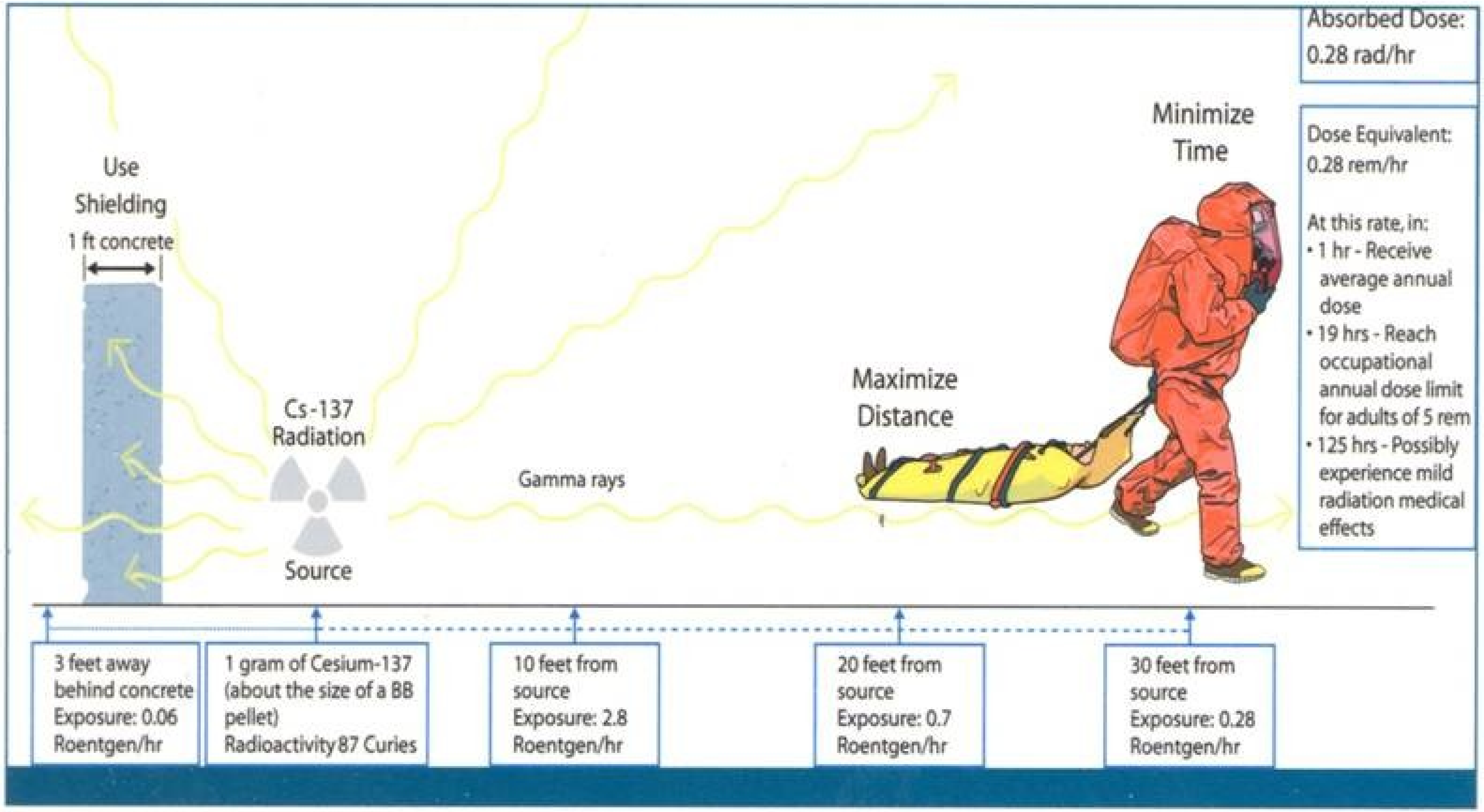


Radiological Exposure Device
150 Ci of
Iridium-192 Source Under Seat

Properties of Nine Key Radionuclides for RDDs

Isotope	Half Life [yrs]	Spec. Activ. [Ci/g]	Decay Mode	Alpha [MeV]	Beta [MeV]	Gamma [MeV]
Am-241	430	3,5	**α**	5,5	0,052	0,033
Cf-252	2,6	540	**α**	5,9	0,0056	0,0012
Cs-137	30	88	**β**	-	**0,19;** 0,065	**0,60**
Co-60	5.3	1100	**β**	-	0,097	**2,5**
Ir-192	0,2/72d	9200	**β**	-	**0,22**	**0,82**
Pu-238	88	17	**α**	5,5	0,011	0,0018
Po-210	0,4/140d	4500	**α**	5,3	-	-
Ra-226	1600	1	**α**	4,8	0,0036	0,0067
Sr-90	29	140	**β**	-	**0,20; 0,94**	-

Response to Radiological Events



Minimizing radiation exposure

Courtesy RST Inc.

Current CB(RN) PPEquipment

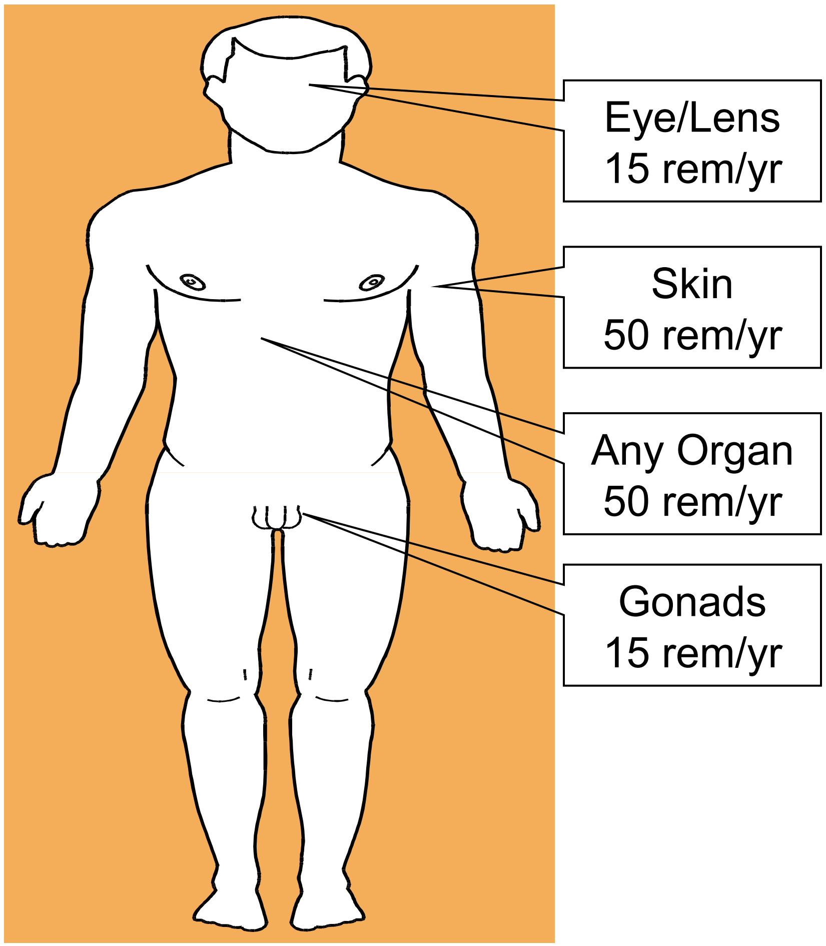
- All fabrics and skin block α-particles
- Inhaled or ingested α-particles are hazardous
- Provides Low Energy α and ß-particles protection only
- Impermeable PPEs are heat sinks and limit operations
- Protection against x and γ-rays is „Zero“ and High Energy ß-particles is also negligible

Radiation Safety
"ALARA"

"**A**s **L**ow **A**s **R**easonable **A**chievable" exposure

- ALARA is a basic requirement of current radiation safety practices. It means that every reasonable effort must be made to keep the dose to workers and the public as far below the required limits as possible.
- Is to minimize the risk of radioactive exposure or other hazard while keeping in mind that some exposure may be acceptable in order to further the task at hand
- ALARA have to meet Occupational Dose Limits

Occupational Dose Limits



Whole Body
Total Effective Dose Equivalent
5 rem/yr (0,05 Sv)

- Recovery and Restoration
- Rescue operations
- Saving life
- Preventing serious injury
- Actions to prevent the development of catastrophic conditions.
- In principle, **no dose restrictions are recommended if, and ONLY IF**, the benefit to others clearly outweighs the rescuer's own risk.
- Every effort should be made to avoid deterministic effects on health (i.e., effective doses **below 100 rem** and below **10 times** the maximium single year dose limit(50 rem/yr).

Radiation Protection

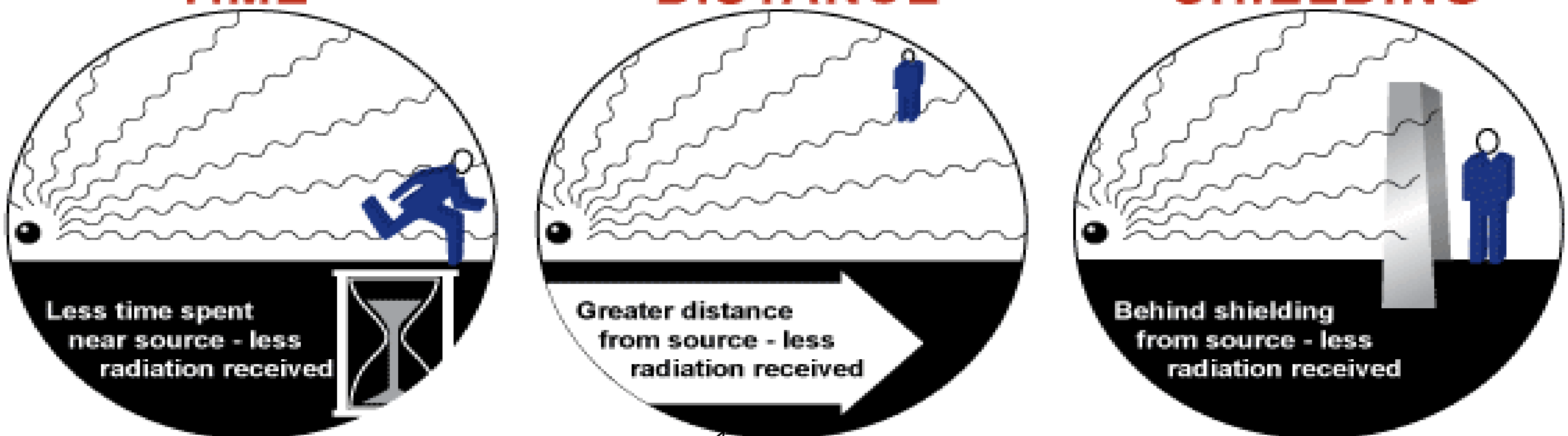
- **Radiation protection**, sometimes known as **radiological protection**, is the science of protecting people and the environment from the harmful effects of ionization radiation, which includes both particle radiation (α, ß±, n^0) and high energy electromagnetic radiation (x, γ,cosmic-rays).

- There are four factors that control the amount, or dose of radiation received from a source. Radiation exposure can be managed by a combination of these factors:

Amount-Time-Distance-Shielding

Three key concepts that apply to all types of ionizing radiation that maximize ALARA

TIME **DISTANCE** **SHIELDING**



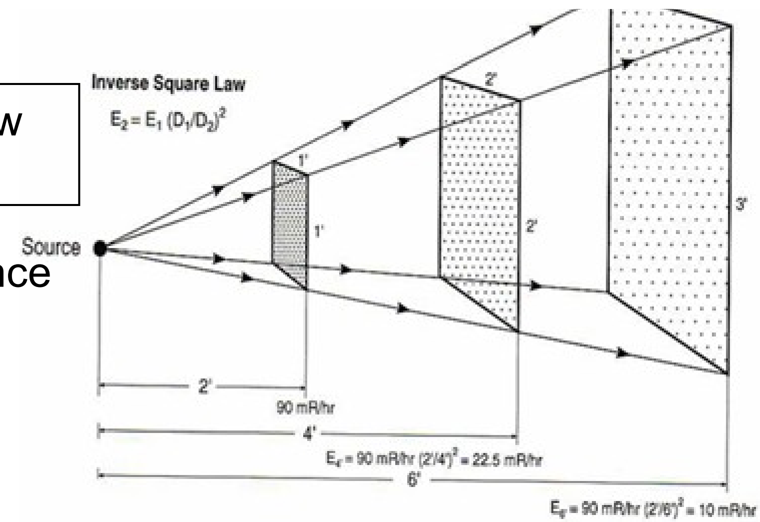
Dose = Dose Rate x Time

The radiation dose is directly proportional to the time spent in the radiation

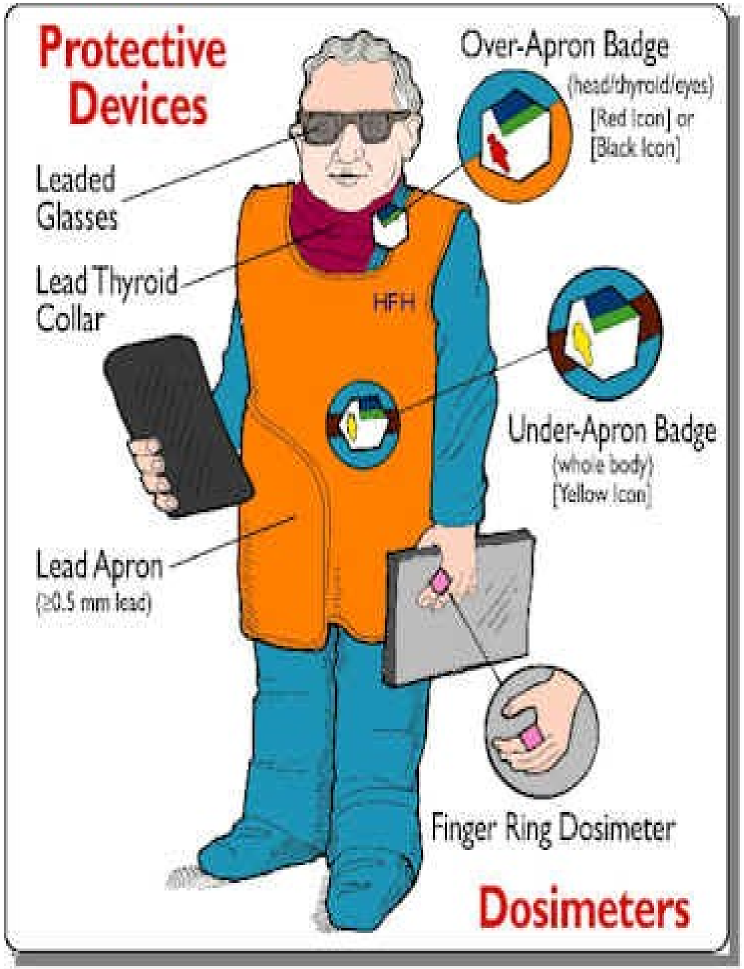
Inverse Square Law

$E_2 = E_1 [D_1 / D_2]^2$

Double the Distance Quarter the Exposure



Radiation Safety



Courtesy of Sorenson, 2000

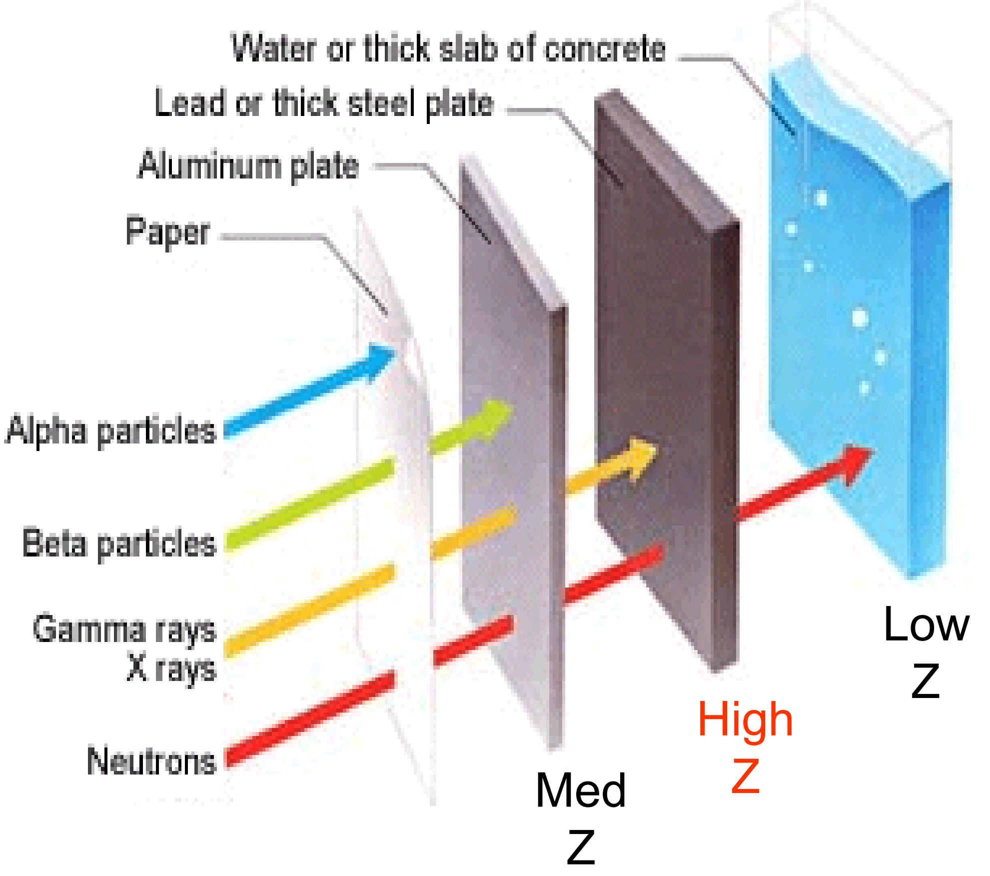
- Dose Limits
- Source (amount/energy)
- Time
- Distance
- Shielding
- Dosimetry

Shielding

- Shielding against x and γ-rays is the ***Half Value Layer (***HVL), the thickness of the material required to reduce radiation to ½,

$$HVL = \frac{0.693}{\mu}$$

- The ***Tenth Value Layer (***TLV), ***the thickness required*** to reduce the radiation to 1/10 of it´s initial value.



Z is Atomic Number

Percentage Transmission of X-rays through Various Thickness of Lead at Different kVp

	60 kVp	80 kVp	100 kVp	120 kVp	N120 kVp	N250 kVp
0.25 mm Pb	4.28%	11.95	16.73	20.16	30.11	77.52
0.5 mm Pb	0.42	2.55	4.96	6.31	10.05	60.50
1.0 mm Pb	0.01	0.27	0.86	1.09	1.63	37.13
2.0 mm Pb	0.00	0.01	0.05	0.06	0.16	14.20

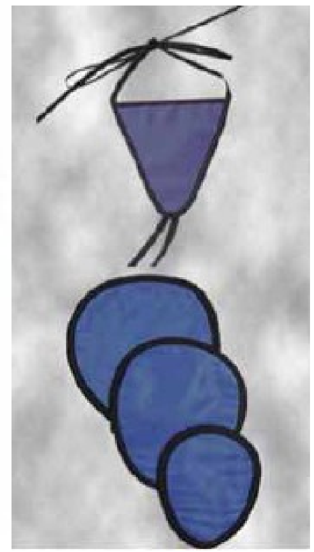
Shielding

- The **photoelectric effect** overwhelmingly dominates **energy transfer and absorption**;
- The effectiveness of radiation shielding varies significantly with the photoelectric attenuation coefficients of the constituent materials, the thickness of the garments, and the energy spectrum of the radiation.
- The purpose of radiation shielding is to protect individuals working with or near x-ray machines and with radioisotopes from harmfully radiation. Personnel shielding is accomplished using 0,25, 0,35 and 0.5 mm lead (Pb) equivalent aprons, thyroid collars, skirts, vests, gauntlets, portable chest shields, glasses, pull-down shields, leaded drapes, etc.
- A lead apron will reduce your exposure by approximately 95%. For example, if your exposure to radiation is 10mR/hr at a given distance without any shielding, wearing a lead (Pb) apron will reduce this to 0.5 mR/hr.
- Shielding: Pb apron 0.5 mm stops 99.9% of x-rays at 75 kVp and 75% of 100 kVp x-rays.

Personal Radiation Protection Apparel

Aprons, Skirts, Vests

Thyroid Shield

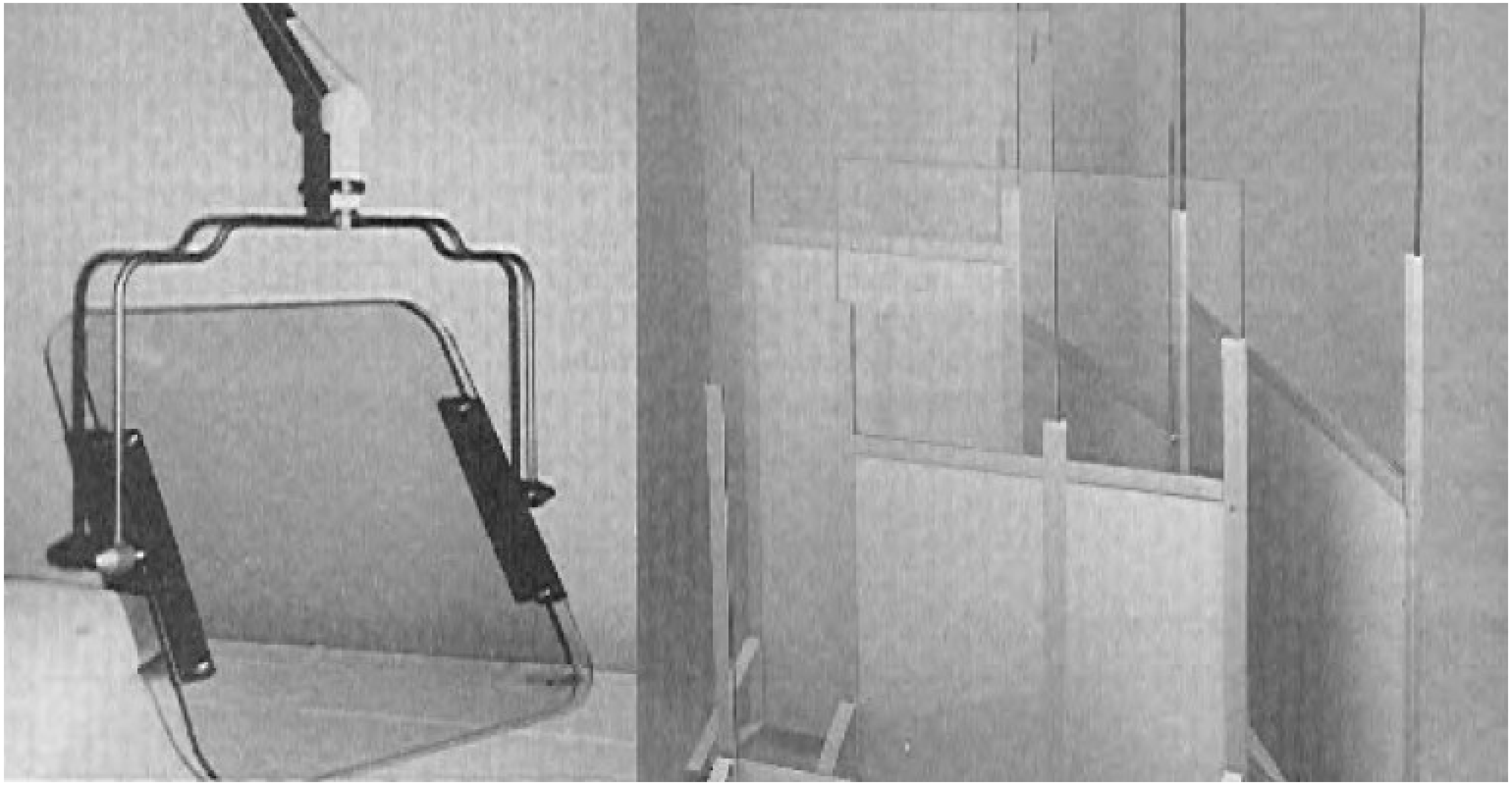


Reproductive organ shields

Glasses

Gauntlets

Shielding Panels/Walls



Lead Aprons in Nuclear Medicine

- In nuclear medicine, where the energies of the ambient radiation are much higher than in radiography, the lead apron is of limited use, and is often considered too restrictive for day long wear.
- A 0.25 mm lead apron will provide a dose reduction of about only 40% for low energy gamma emitter Tc-99m (140 keV). A 0.5 mm lead apron weighs about 12 kgs and will provide a dose reduction of about 70%;
- Lead apron is less effective in reducing radiation levels from a mixed beta and gamma emitter such as I-131, (360 keV) 52.6%; and
- Lead apron is not very effective in reducing radiation exposures from a high energy gamma emitter such as F-18, (511keV) 18.2%
- Lead apron for a pure beta emitter such as Y-90, is more effective

  99.8%;

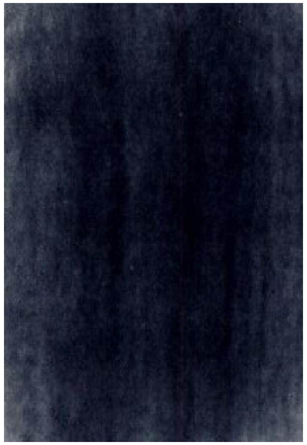
Syeda Ahmed, et all.;J Nucl Med. 2007; 48 (Supplement 2):470P

Lead Protective Materials

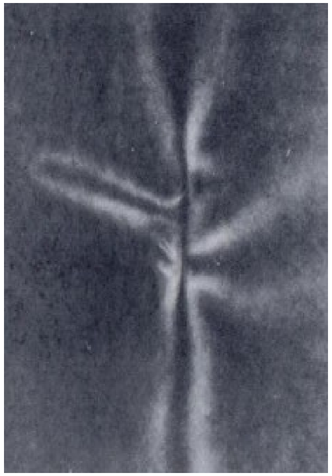
- Lead and lead composites are the most common shielding materials used to protect against X-rays and γ-rays;
- Radiation shielding aprons and coverings have been manufactured from lead Pb or PbO (~ 40%) powder-loaded polymer or elastomer sheets (vinyl, PVC, butyl or styrene butadiene rubber);
- Typical garment lifetime for these materials is approximately 10 years, However, aging, damage, embrittlement, as well as cracking, can drastically shorten this period of lifetimes.
- A typical Pb-based radiation shielding garment may contain approximately 0.5 m^2 of shielding material with a thickness of 1.5 mm, with a mass of about 4.5 kg.
- This is for 58 % heavier as a garment composed of 0.5 mm pure Pb, with the same protection (approx. 2.6 kg per 0.5 m^2).
- Those who wore aprons with weight of 6-7 kgs for more than 10 hours a week missed more time from work owing to back pain.

Defects in Lead Protective Aprons

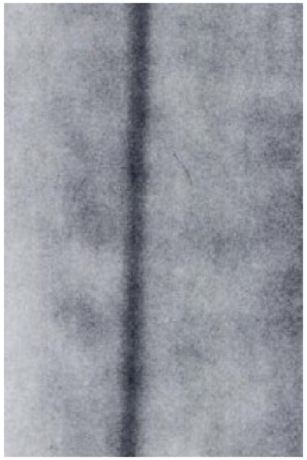
No defects

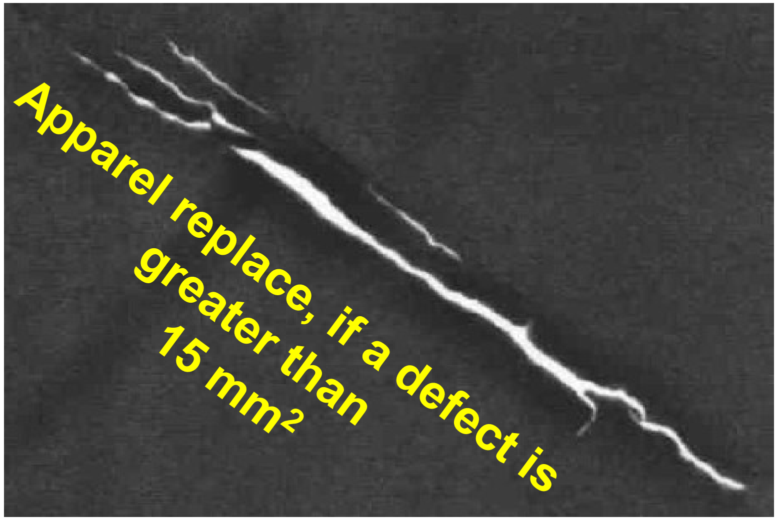


Bunching caused by folding

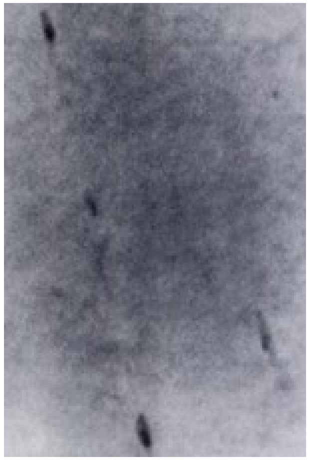


Low density strip defect





Peppering of small holes



Radiology 1982, 152; pp.217-218

Lead Apparel-Concerns

- Weight
- Embrittlement
- Mechanical sensitivity
- Microsized fillers
- Aging
- Attenuation limits
- Lead is toxic
- Disposal

ght-weight Apparel

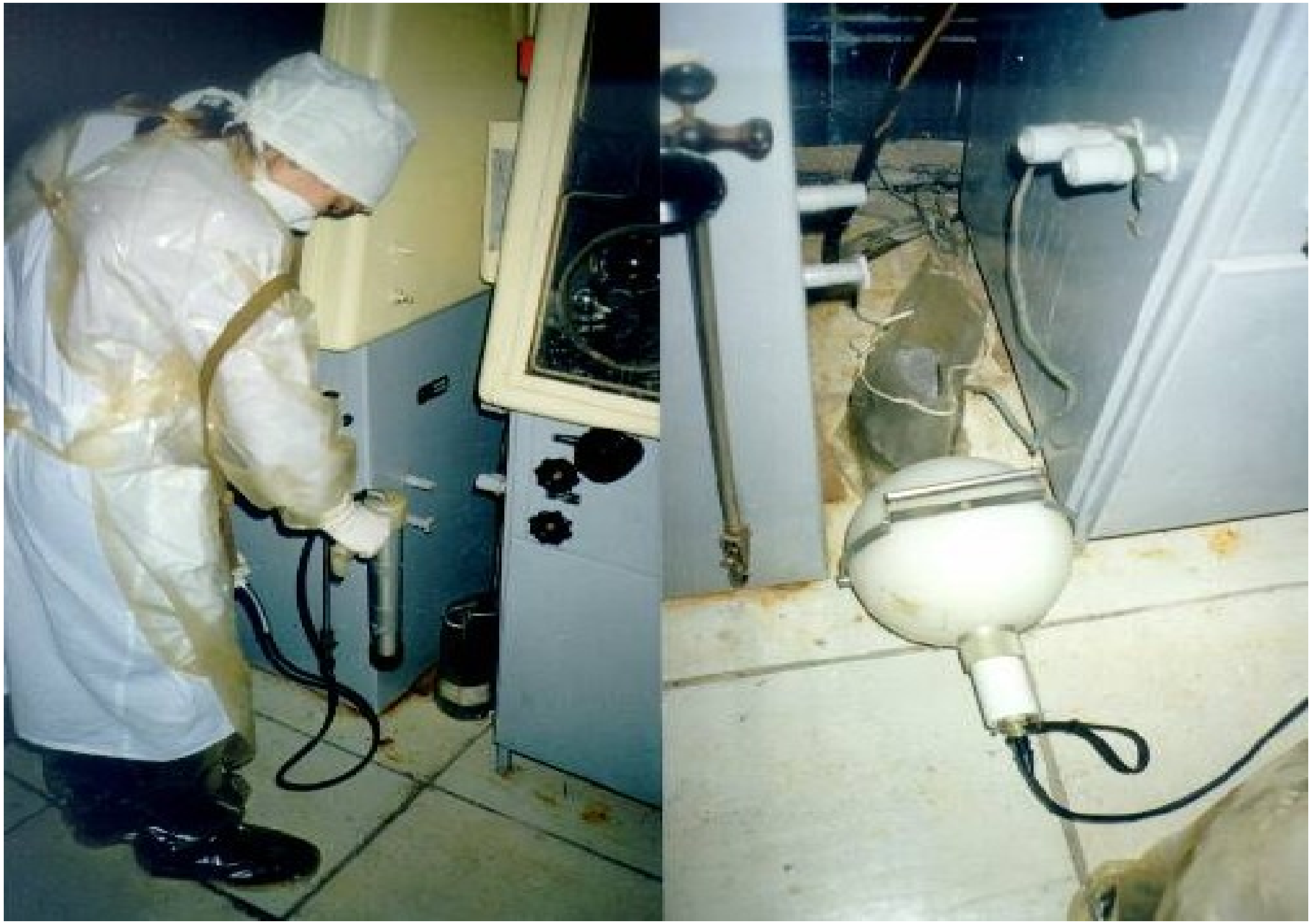
- ~30 % lighter
- Reduced lead content
- Non-lead composite
- Nano-sized fillers
- Attenuation improvement
- Mechanical improvement
- Thermo conductivity
- Whole body apparel
- CBRN protection
- Recycling

Elements incorporated into some commercial radiation-shielding garment materials

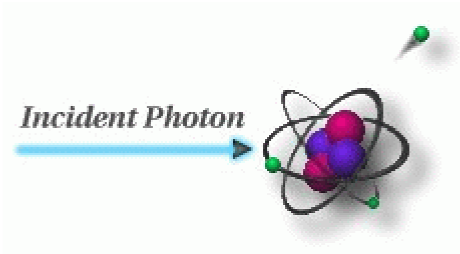
ELEMENT	ATOMIC NO.	Density (g/cm^3)	K absorption edge (keV)
Cadmium (Cd)	48	8.65	26.7
Indium (In)	49	7.31	27.9
Tin (Sn)	50	7.30	29.2
Antimony (Sb)	51	6.69	30.5
Cesium (Cs)	55	1.87	36.0
Barium (Ba)	56	3.5	37.4
Cerium (Ce)	58	6.66	40.4
Gadolinium (Gd)	64	7.90	50.2
Tungsten (W)	74	19.3	69.5
Lead (Pb)	82	11.36	88.0
Bismuth (Bi)	83	9.75	90.5

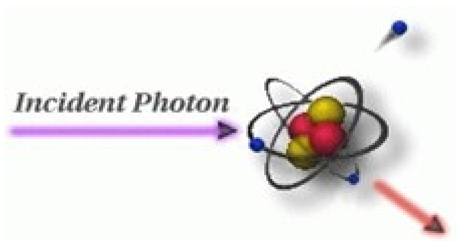
McCaffrey *et al.:*Med. Phys. 34 ,(2) February 2007

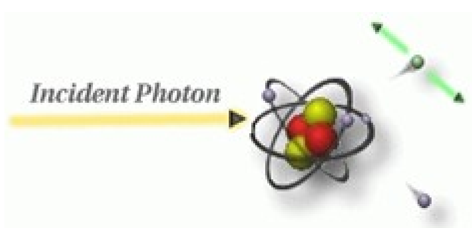
??? ZERO Protection ???

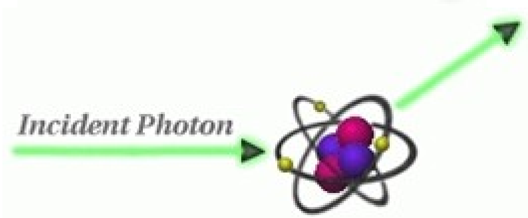


Radiation Interaction with Mass









- **Photoelectric** absorption of x-rays occurs when the x-ray photon is absorbed, resulting in the ejection of electrons from the outer shell of the atom, and its ionization. Photoelectron absorption is dominant for atoms of high atomic numbers and attenuation coefficient μ value is proportional to atomic number $\mu \propto Z^3$
- **Compton scattering** occurs when the incident x-ray photon is deflected from its original path by an interaction with an electron. The scattered x-ray photon loses energy due to the interaction but continues to travel through the material along an altered path.
- **Pair production** can occur when the x-ray photon energy is greater than 1.02 MeV, but really only becomes significant at energies around 10 MeV.
- **Thomson scattering**, also known as Rayleigh, coherent, or classical scattering, occurs when the x-ray photon interacts with the whole atom.

Gamma and X-rays Attenuation

- Gamma (γ) and X-rays radiation consists of highly energetic photons with high frequency. They can be stopped by a sufficiently thick layer of material with high atomic number "Z", such as Lead (Pb-82) or depleted Uranium (U-92).

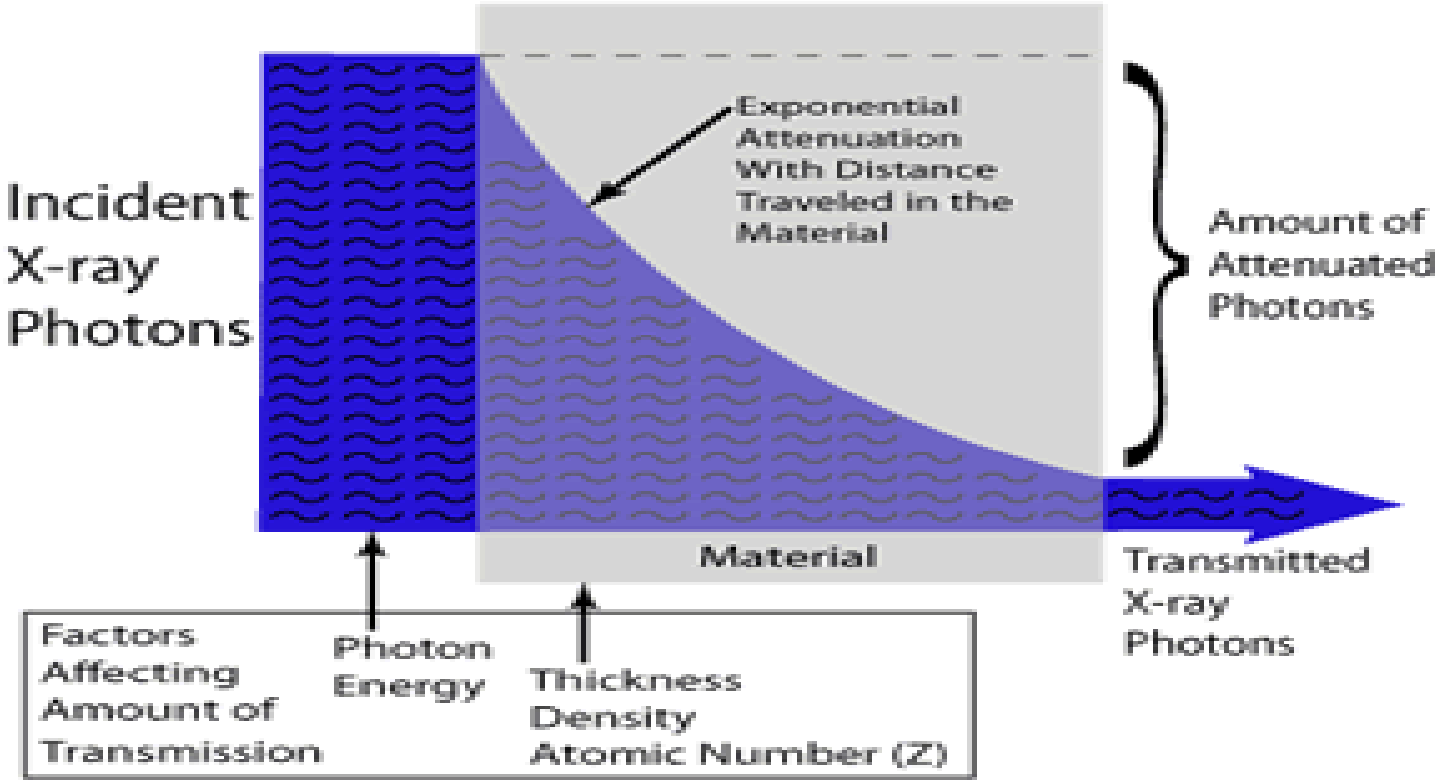
- Photoelectric Effect of <u>attenuation coefficient μ</u> is proportional to atomic number "Z"

$$\mu \propto \mathbf{Z^3}$$

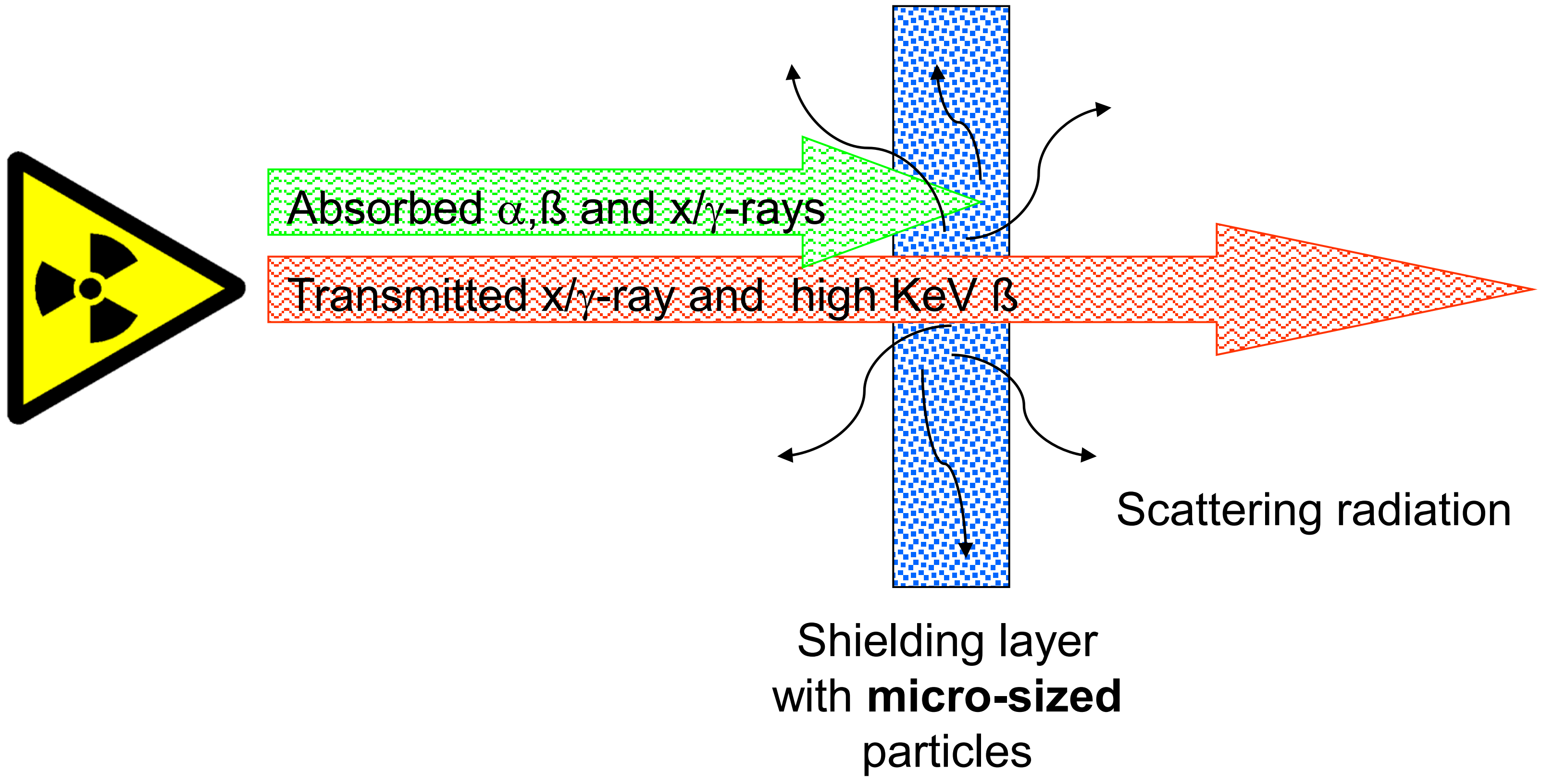
- **E.g. Pb aprons (Z = 82) absorbs γ and X-rays ~ 1,000 more rather than soft tissue with approx. Z ~ 8**

Attenuation

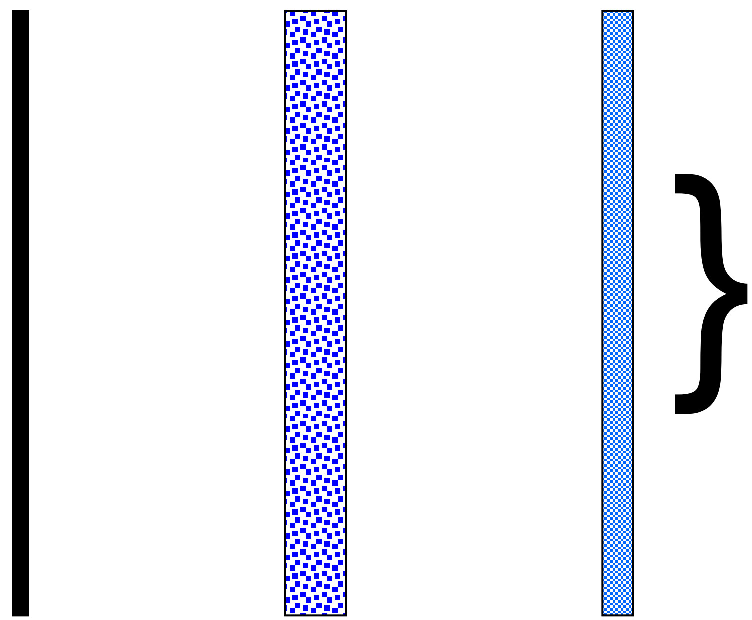
μ(total) = μ(photoelectric) + μ(Compton)

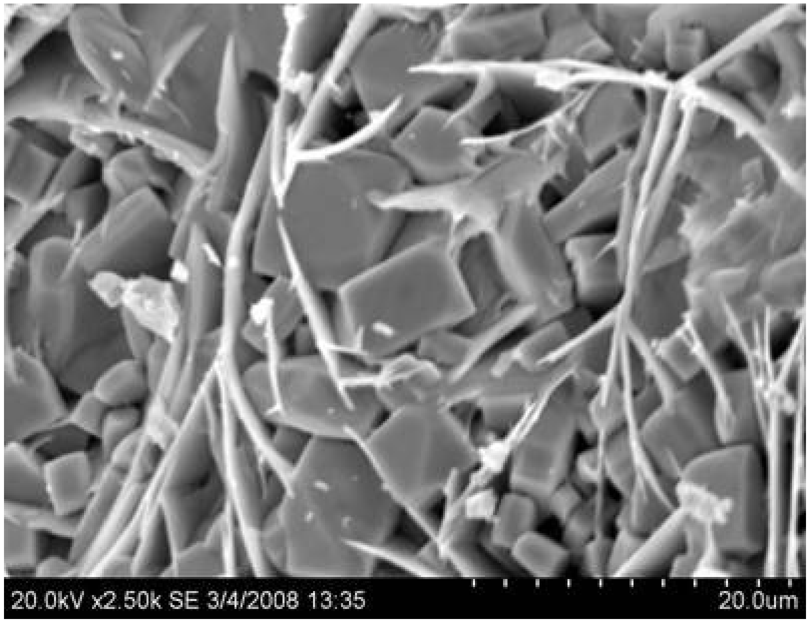


Shielding through Pb composite



Pb-equivalent shielding fabrics





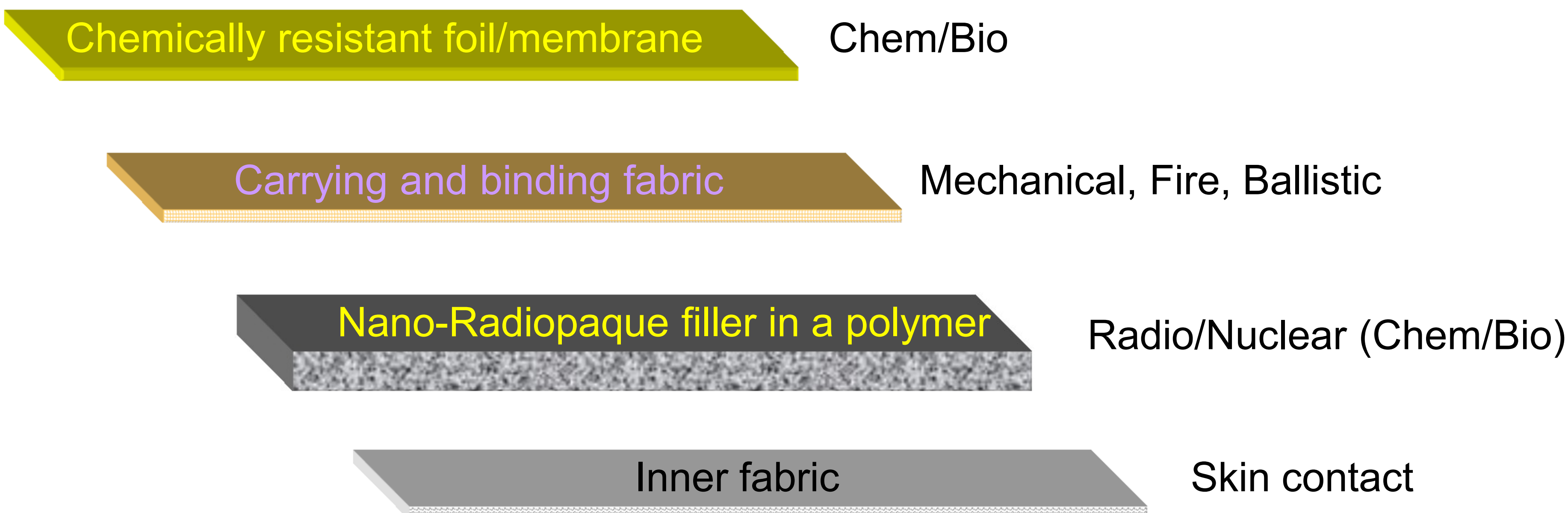
Pb Sheet 0,25; 0,35; 0,5; 0,75; 1,0 mm

Pb/PbO micro-sized in vinyl or butyl rubber composite

Nano-particle composite

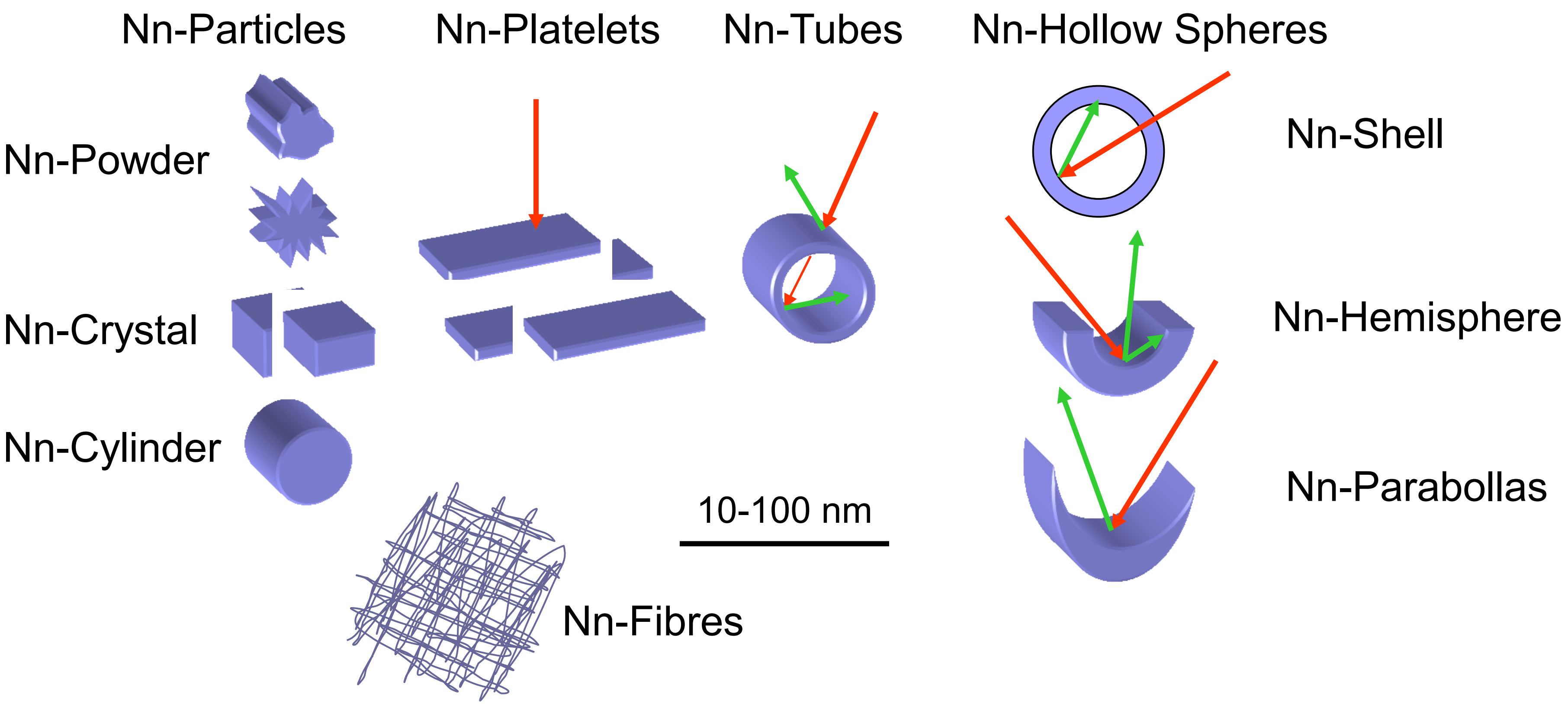
Multiple Hazard Protection Composite Material

Polymer with radiopaque fillers is sendviched between layers of fabric

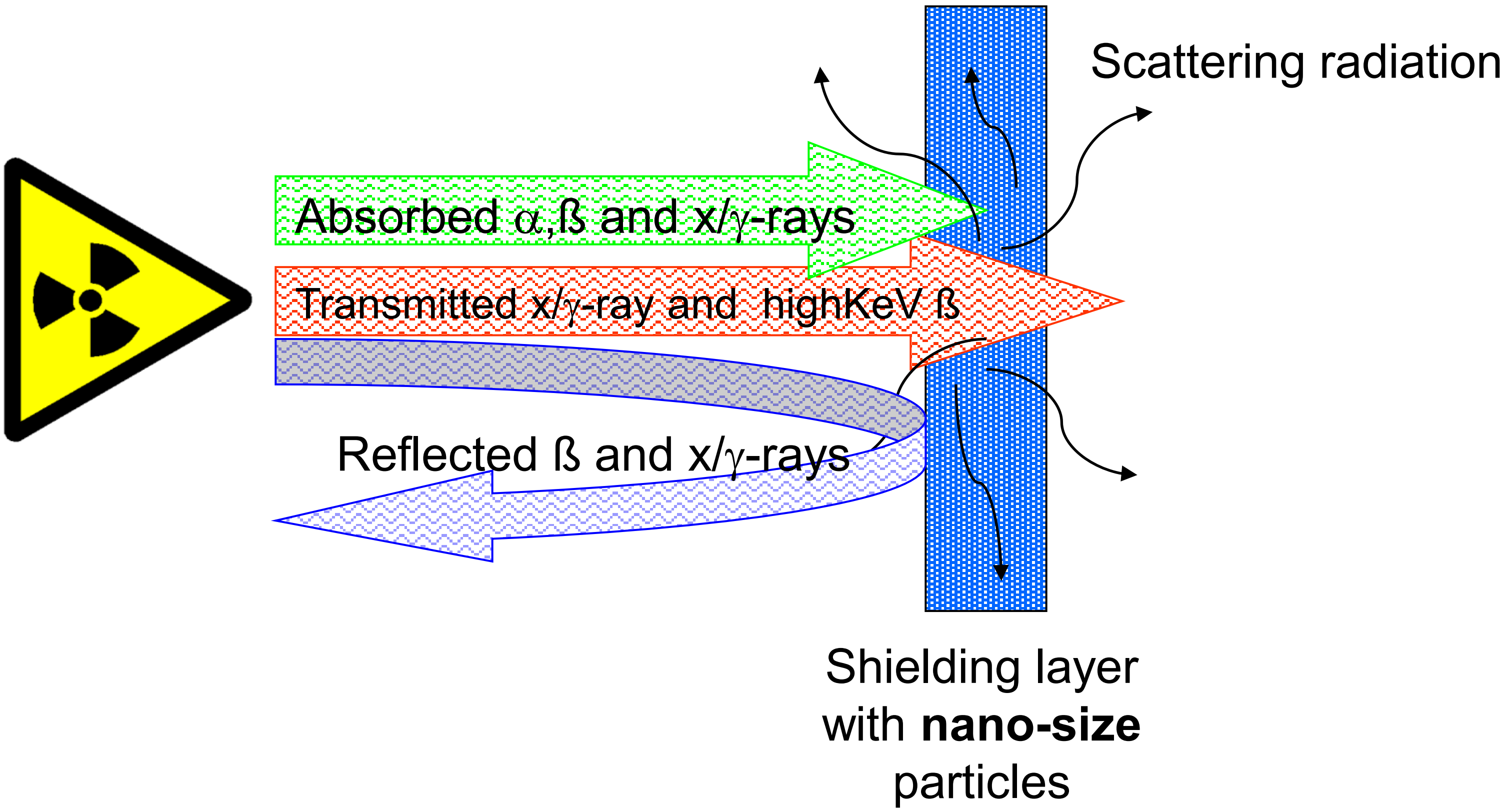


Absorption and deflection of Rays

- Different shape of nano-particles

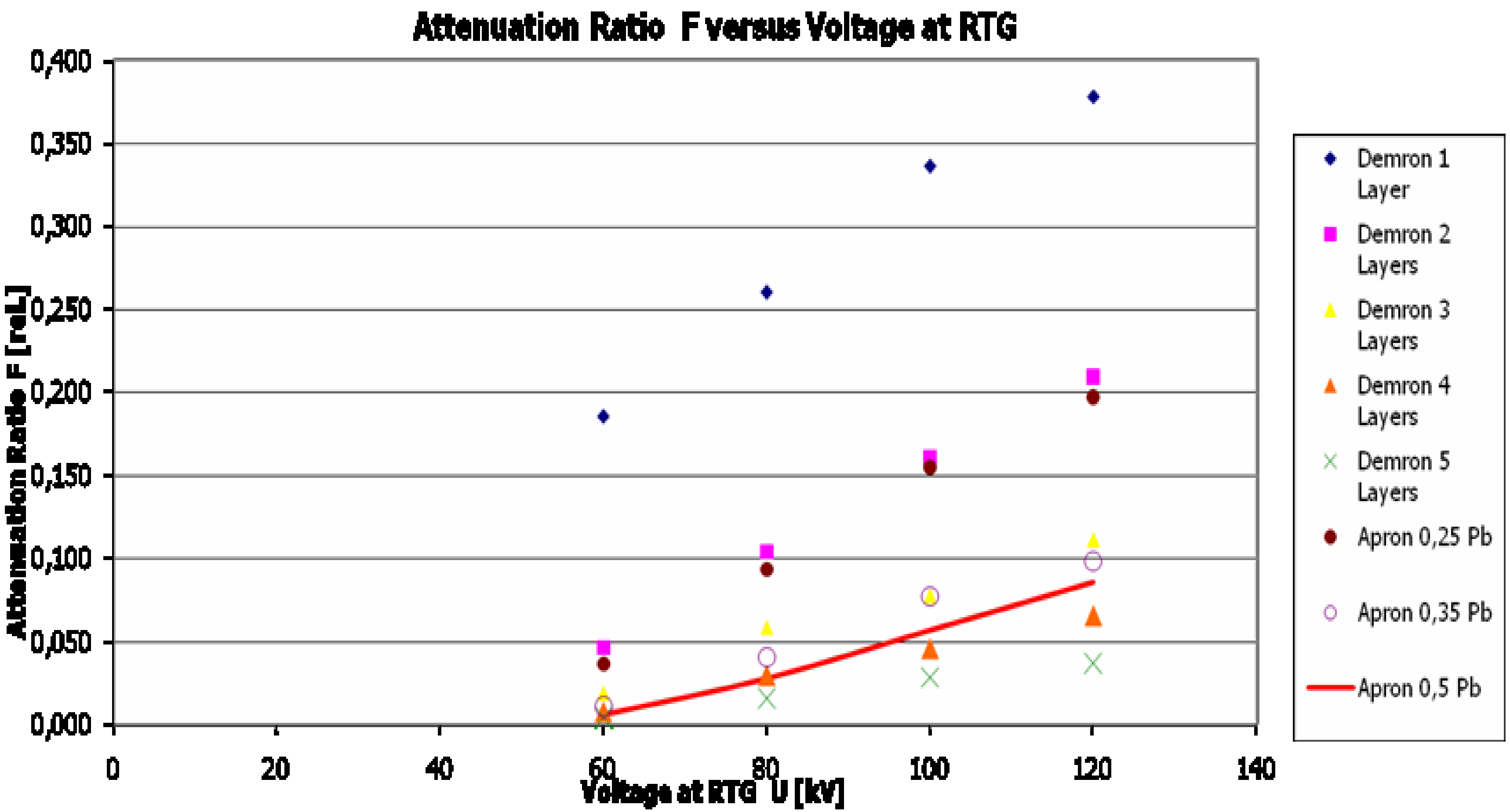


Shielding composite with nano-particles

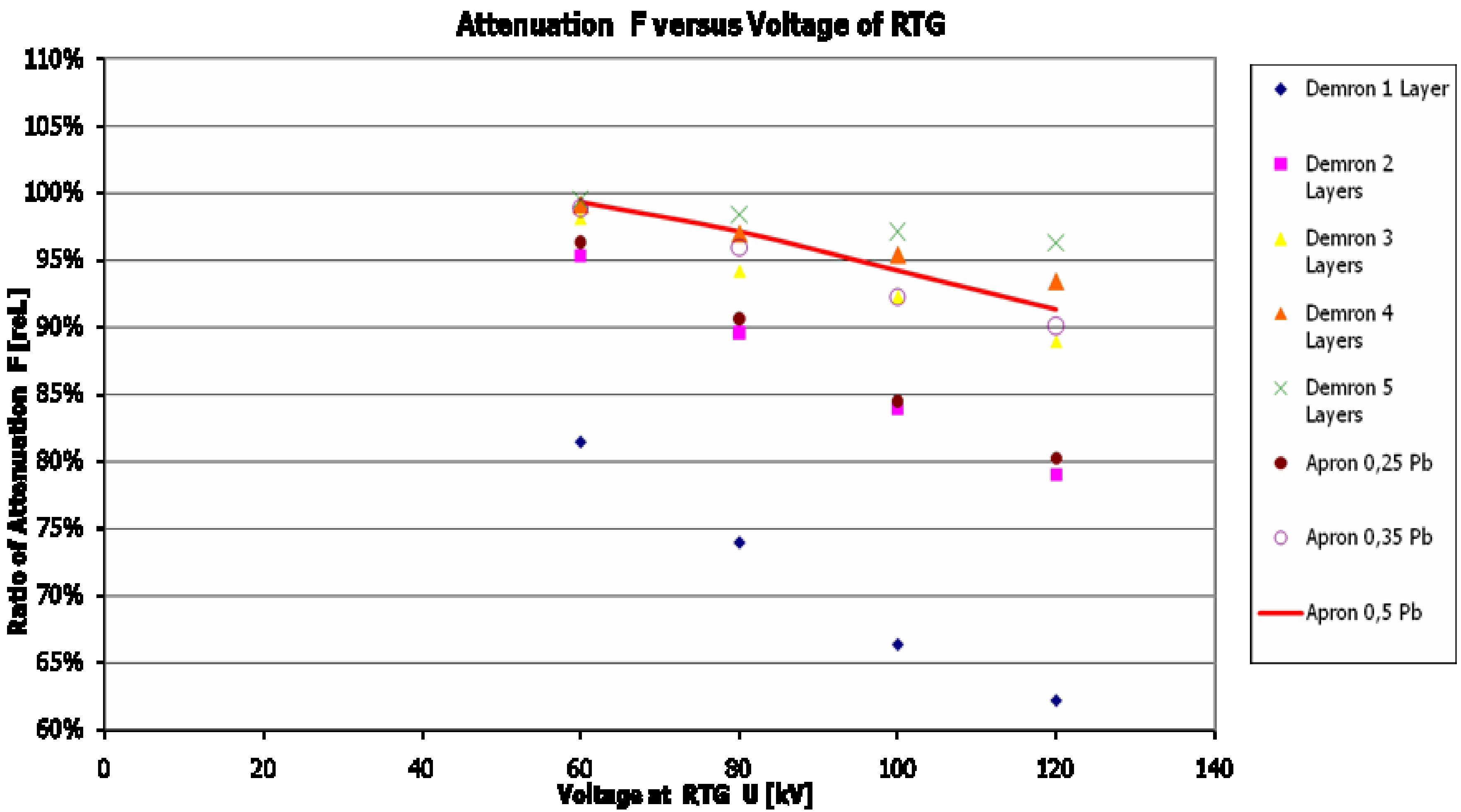


True CBRN Protective Ensemble

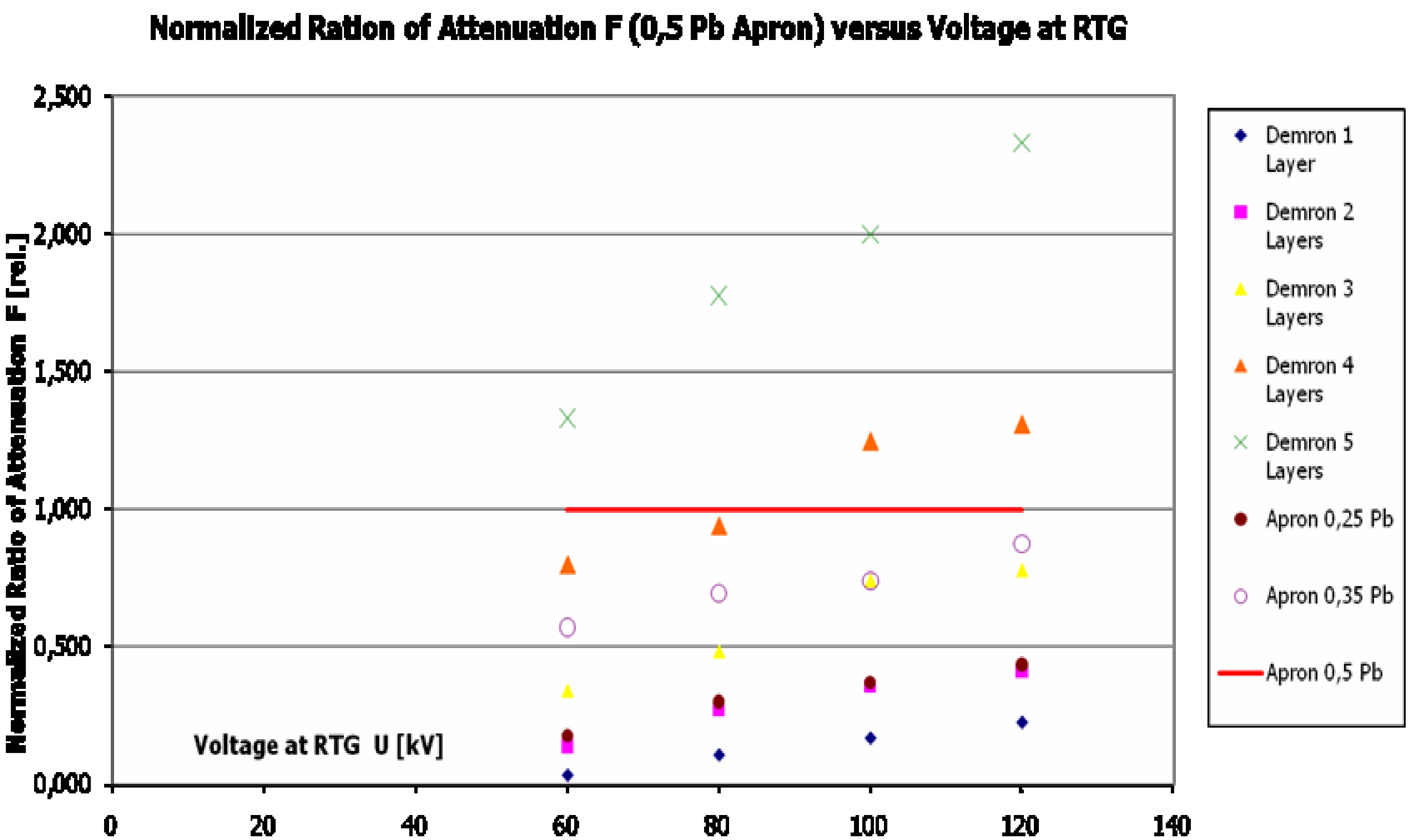
Courtesy RST Inc.



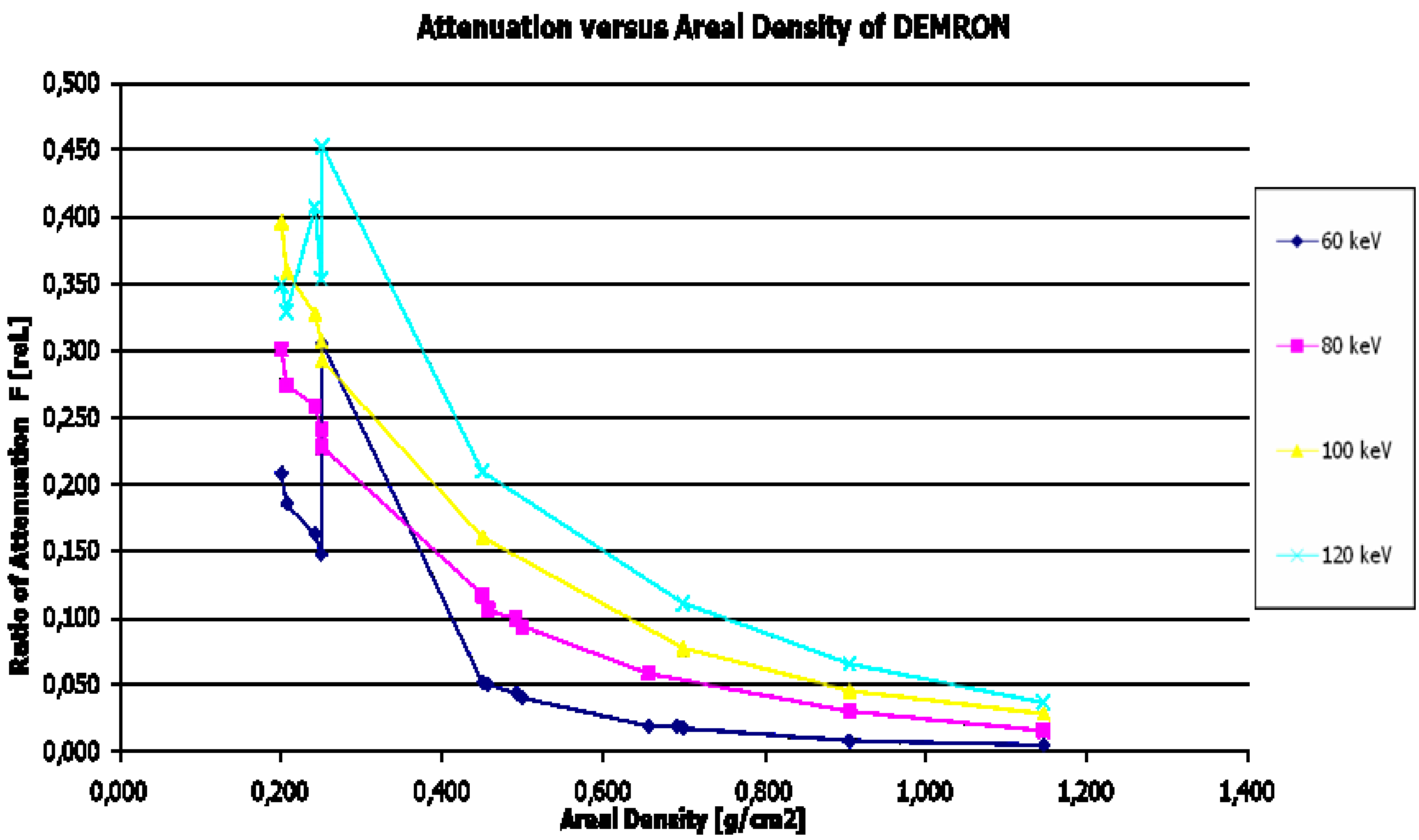
Attenuation Ratio F versus Voltage at RTG
Attenuation Ratio F [rel.]
0,400
0,350
0,300
0,250
0,200
0,150
0,100
0,050
0,000
0
20
40
60
80
100
120
140
Voltage at RTG U [kV]
Demron 1 Layer
Demron 2 Layers
Demron 3 Layers
Demron 4 Layers
Demron 5 Layers
Apron 0,25 Pb
Apron 0,35 Pb
Apron 0,5 Pb



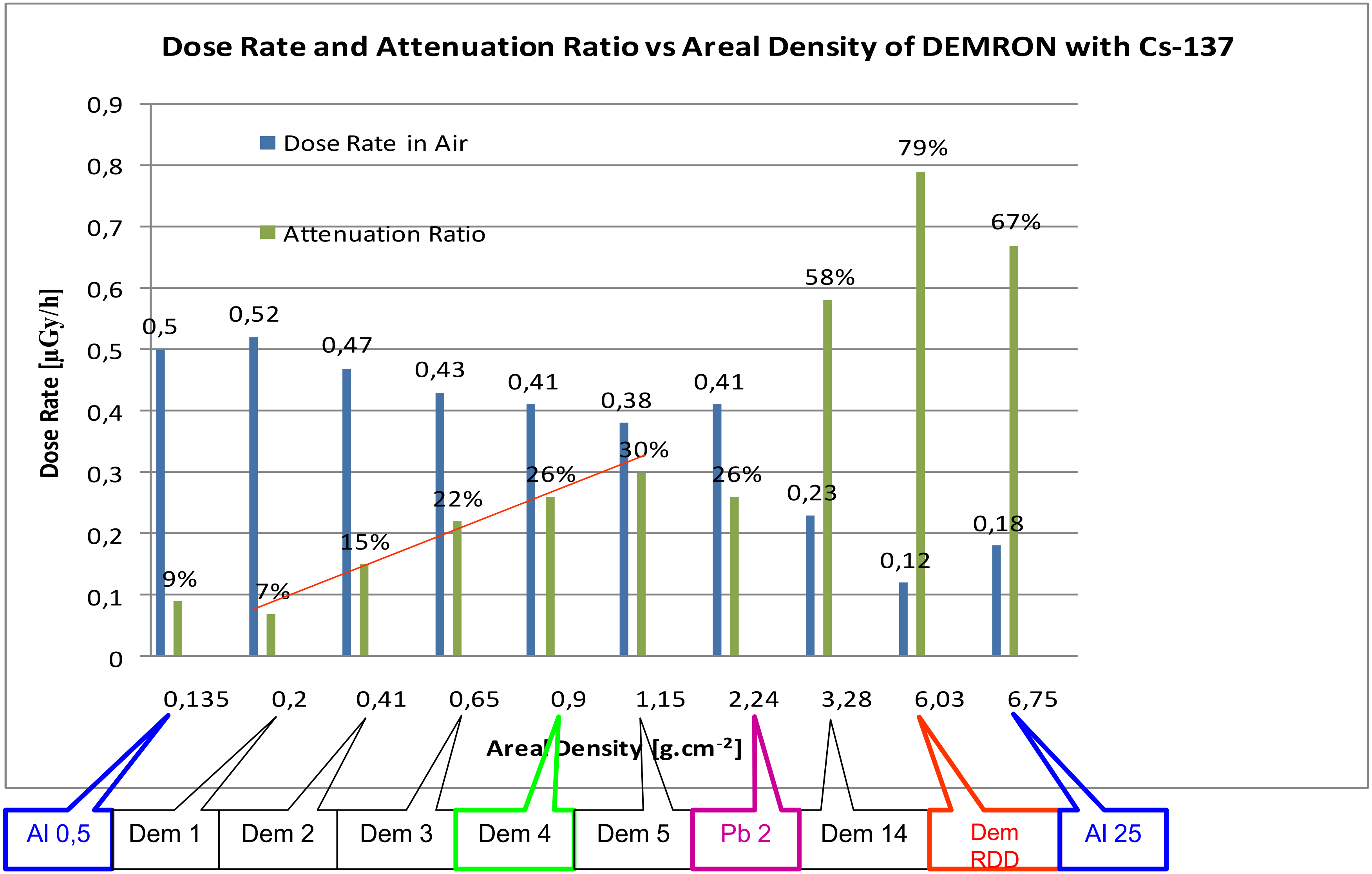
Attenuation F versus Voltage of RTG
Ratio of Attenuation F [rel.]
110%
105%
100%
95%
90%
85%
80%
75%
70%
65%
60%
0
20
40
60
80
100
120
140
Voltage at RTG U [kV]
Demron 1 Layer
Demron 2 Layers
Demron 3 Layers
Demron 4 Layers
Demron 5 Layers
Apron 0,25 Pb
Apron 0,35 Pb
Apron 0,5 Pb



Normalized Ration of Attenuation F (0,5 Pb Apron) versus Voltage at RTG
Normalized Ratio of Attenuation F [rel.]
2,500
2,000
1,500
1,000
0,500
0,000
Voltage at RTG U [kV]
0
20
40
60
80
100
120
140
Demron 1 Layer
Demron 2 Layers
Demron 3 Layers
Demron 4 Layers
Demron 5 Layers
Apron 0,25 Pb
Apron 0,35 Pb
Apron 0,5 Pb

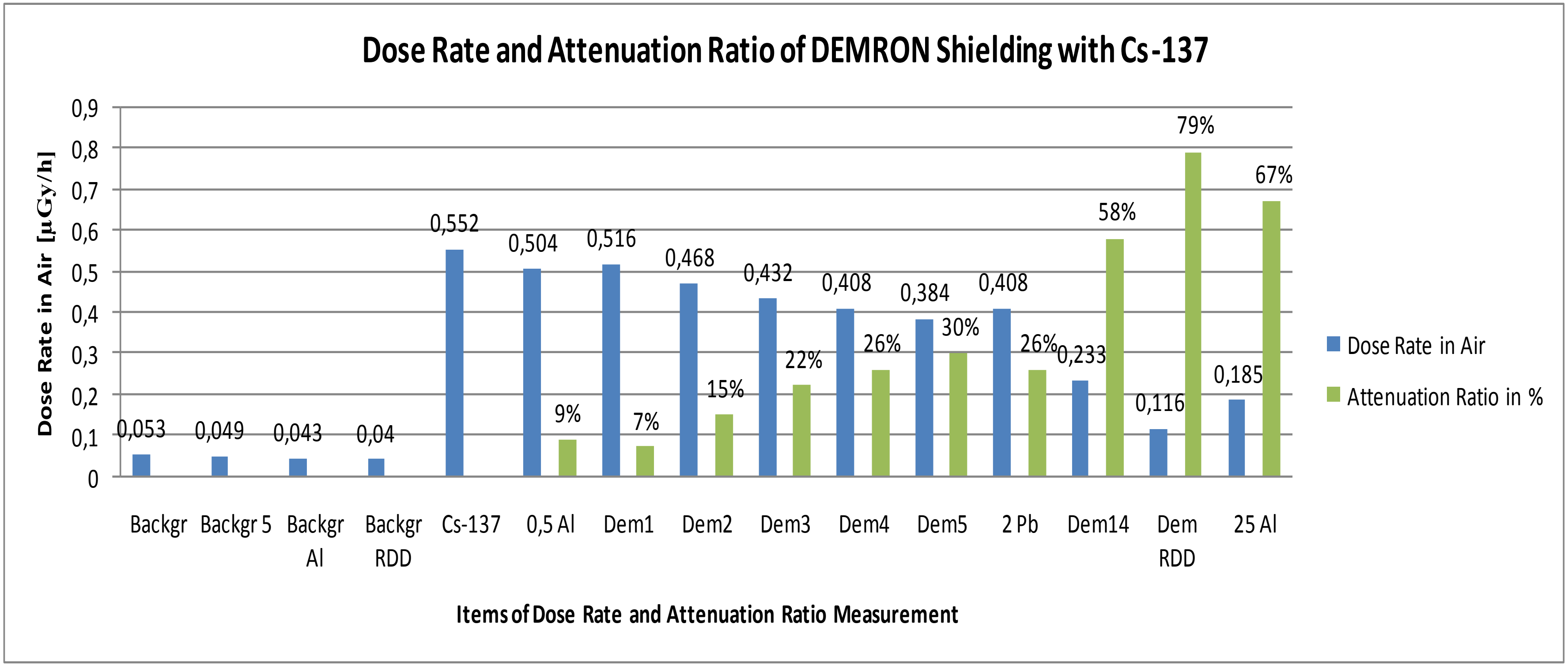


Attenuation versus Areal Density of DEMRON
Ratio of Attenuation F [reL]
0,500
0,450
0,400
0,350
0,300
0,250
0,200
0,150
0,100
0,050
0,000
0,000
0,200
0,400
0,600
0,800
1,000
1,200
1,400
Areal Density [g/cm2]
60 keV
80 keV
100 keV
120 keV



Dose Rate and Attenuation Ratio vs Areal Density of DEMRON with Cs-137
Dose Rate in Air
Attenuation Ratio
Dose Rate [µGy/h]
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,5
0,52
0,47
0,43
0,41
0,38
0,41
0,23
0,12
0,18
9%
7%
15%
22%
26%
30%
26%
58%
79%
67%
0,135
0,2
0,41
0,65
0,9
1,15
2,24
3,28
6,03
6,75
Areal Density [g.cm-2]
Al 0,5
Dem 1
Dem 2
Dem 3
Dem 4
Dem 5
Pb 2
Dem 14
Dem RDD
Al 25

Cs-137 (β)512 keV and (γ)662 keV



- During the measurement background dose rate fluctuated between 0,04-0,05 µGy/h and Cs-137 source gave dose rate of 0,552 µGy/h. Folding of DEMRON layers provide synergy effect in increasing of attenuation rate. 4 layers of DEMRON are surprisingly equivalent to 2 mm of Pb. Sample of multiply DEMRON layers as RDD shield provide effective attenuation of 79% against Cs-137 source.

Only True CBRN Anti-Radiological and Anti-Nuclear Protective Ensemble

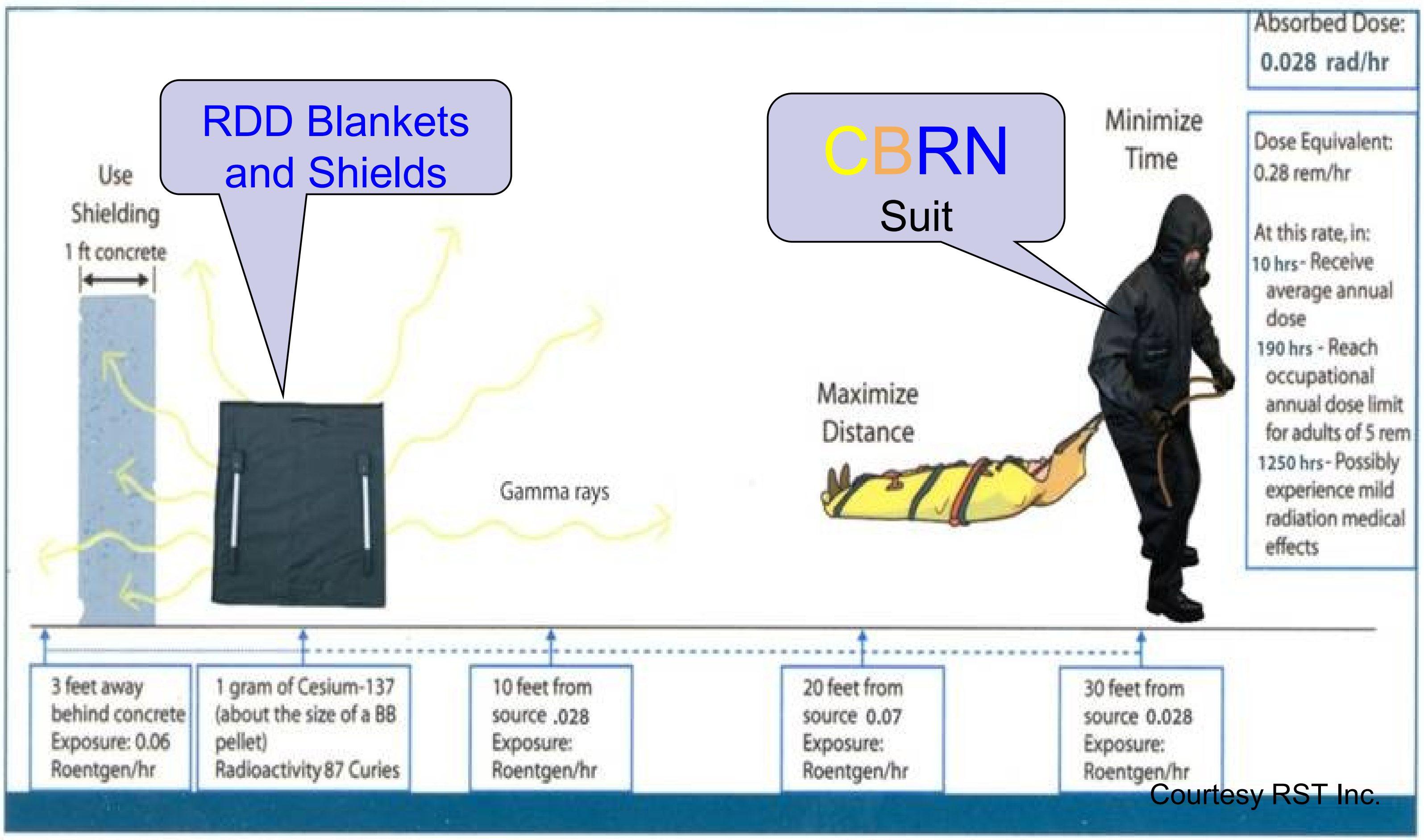
- CBRN Full Body Suit
- High Energy Nuclear/Ballistic Shield (IED, RDD, RED)
- Anti Ballistic/Nuclear Vest
- Anti Nuclear Blanket
- Radiological/HazMat Bags
- Casualty Bag

Courtesy RST Inc.

Shielding of radiation source

Chem/Bio and Chem/Bio/Rad

Improving Radiation Protection



Minimizing radiation exposure

Thank you for your Attention

Pavel CASTULIK
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Radiation Events

Chernobyl's Nuclear Power Plant Catastrophe

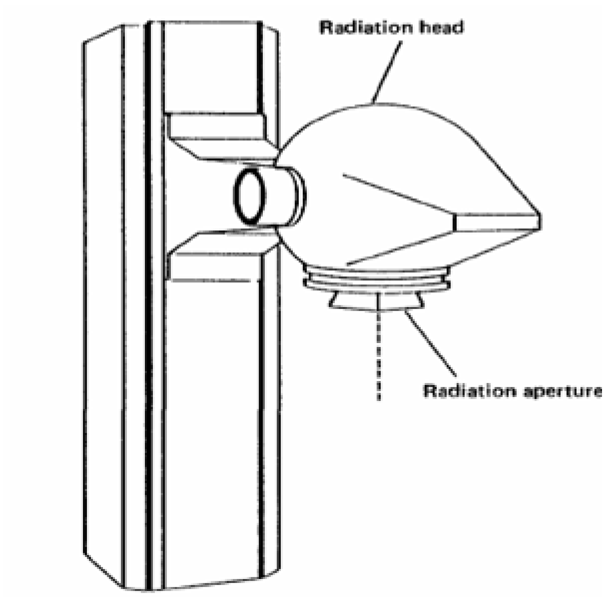
- 26 April 1986 at 1:23 a.m. the Nuclear reactor No. 4 was destroyed by two explosions
- Steam explosion and following fire of graphite, disseminate aprox, 5% of radiation material during 10 days
- Serious contamination of 200,000 km^2 with Cs-135

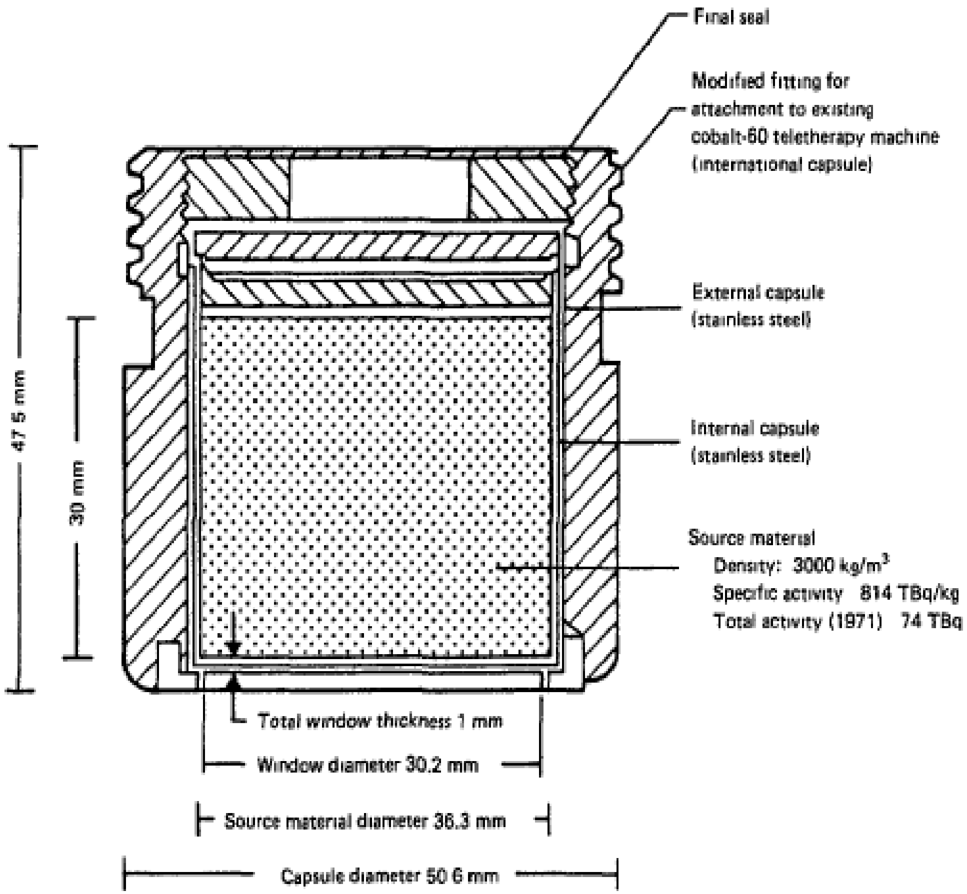
Goiania Cs-137 Case

- That happened with devastating results in Goiania, Brazil, in 1987, when scavengers dismantled a metal canister from a radiotherapy machine at an abandoned cancer clinic.
- The Caesium-137 teletherapy unit became totally insecure.
- Soon afterward, a junkyard worker pried open the lead canister and discovered a pretty blue, glowing dust: radioactive Cesium-137.
- In the following days, scores of people were exposed to the substance - some parents painted their children with it and sold tickets to neighbors to watch them dance.
- As a result, 112,000 people had to be monitored. Of those, 249 were contaminated; 28 suffered radiation burns and 4 people died.
- More than 67 square kilometers was monitored, large areas had to be decontaminated and 3,500 cubic meters of radioactive waste was generated.
- For years afterward, the region was stigmatized and its economy devastated .

The derelict of private clinic in Goiania from which the source of Cs-137 was taken

93 g of $^{137}CsCl$
50,9 TBq (1375 Ci)





Contaminated rubble removal

Radiation injury on palmar surface of the hand

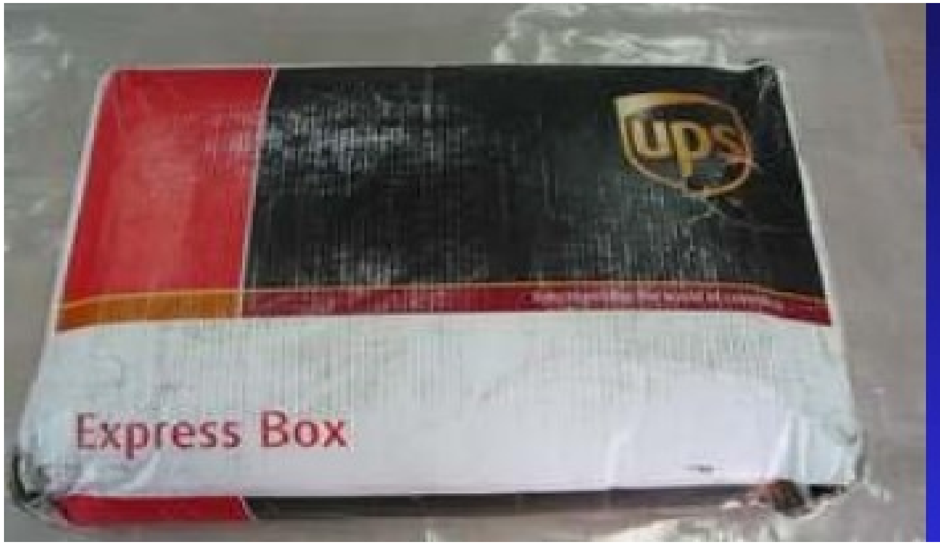
Radiation injury of the thigh
Lesion 100x120 mm

Albania
Radioactive Thermo-electrical Generators

Usually Sr-90, A= 104 Ci

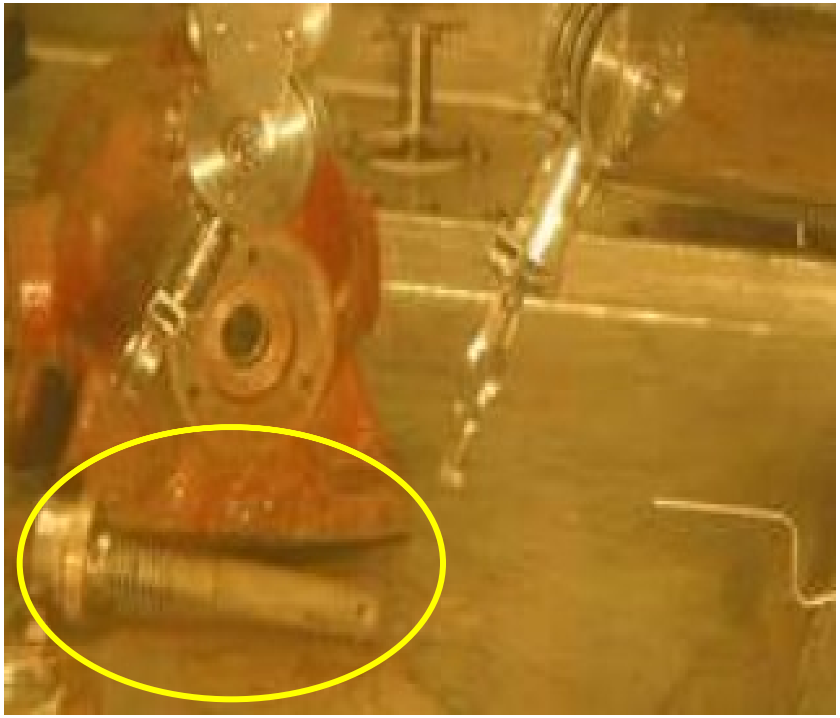
Air Mail Parcel UPS

- Mass 12 kg September 2007
- Dose rate on surface: 11 μSv/h
- Specific Activity: ^{232}Th – 45 kBq/kg
- Specific Activity: ^{226}Ra – 20 kBq/kg



Orphan sources

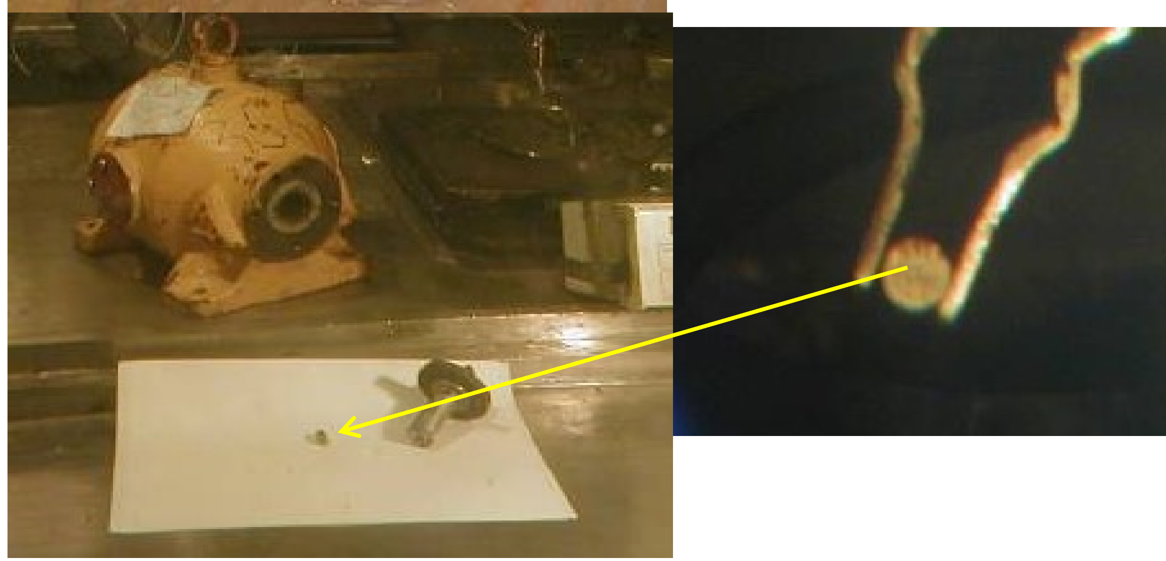
- Cs-137 0,6 Ci December 2006



^{137}Ceasium

- ^{137}Cs 3.0 Ci
- October 2003

- ^{137}Cs 0.7 Ci
- August 2003



HEU and Plutonium

Orphan sources-Jordan

Orphan sources-Georgia

Illicit Trafficking of radioactive materials

- UO_2 335 pellets, total weight 1628.5 g
- Uranium content 1435.5 g
- ^{235}U enrichment level 4,42 %
- ^{235}U isotope weight 63.4 g