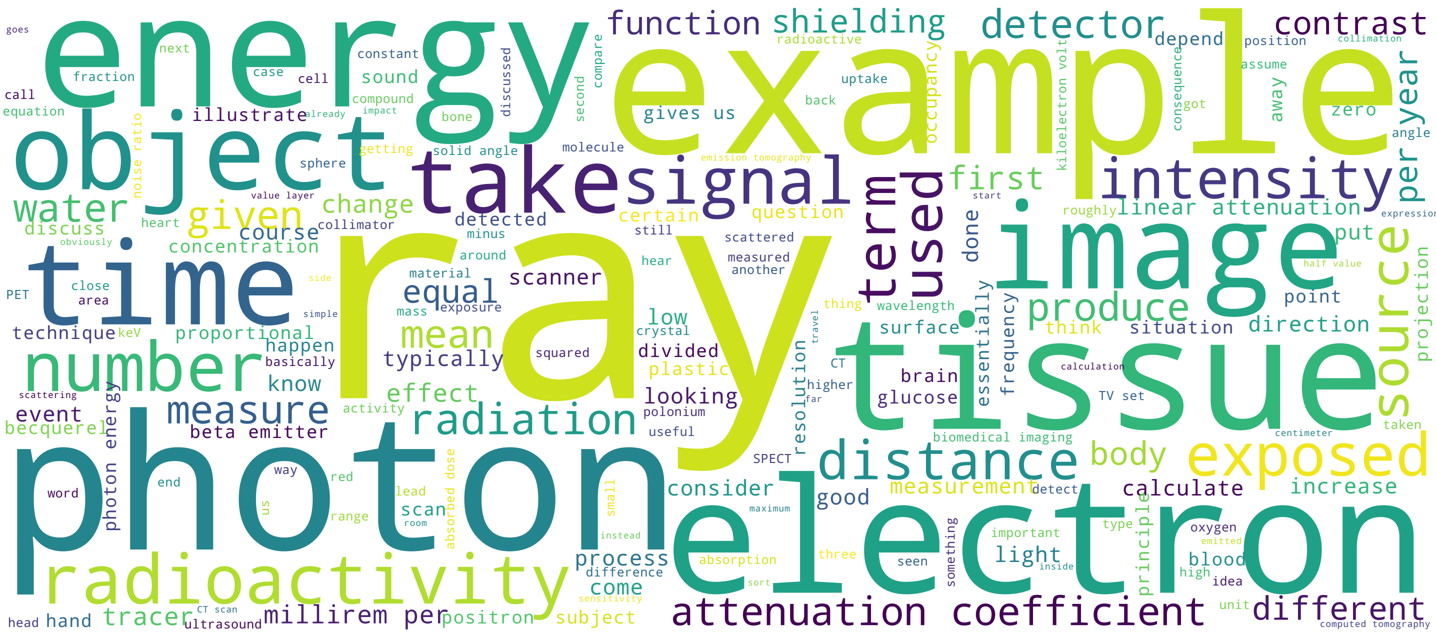
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

3.6 Radiation protection: A primer

Fundamentals of Biomedical Imaging

Prof. Rolf Gruetter



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EPFL

So now that we have discussed the effects of x-ray, of ionizing radiation on our tissues, we've discussed the possible repair mechanisms and how we quantify the radiation. Now comes the question, how do we protect ourselves against x-rays. And I want to do this here as a general primer of radiation protection. It by no means replaces a regular radiation protection course. But it gives you the basic principles and the governing principles that are behind it. And as you will see, they are fairly easy to understand. So the absorbed dose depends on the intensity of the radiation, and the activity here is given, that's a term that is useful to know, is given in becquerel. And a becquerel is very simple it's 1 decay per second. So instead of saying 1 decay per second, it was decided to call it 1 becquerel. So for radioactive materials, we typically in SI units express it in becquerel. And now we have three basic elements of radioprotection. Number one is time. Don't be exposed to it for a long time. In practice for biomedical imaging the term that has been used is occupancy. And occupancy is basically, we take a room and we calculate what percentage of time of a working day do you spend in that room?

Notes

Summary

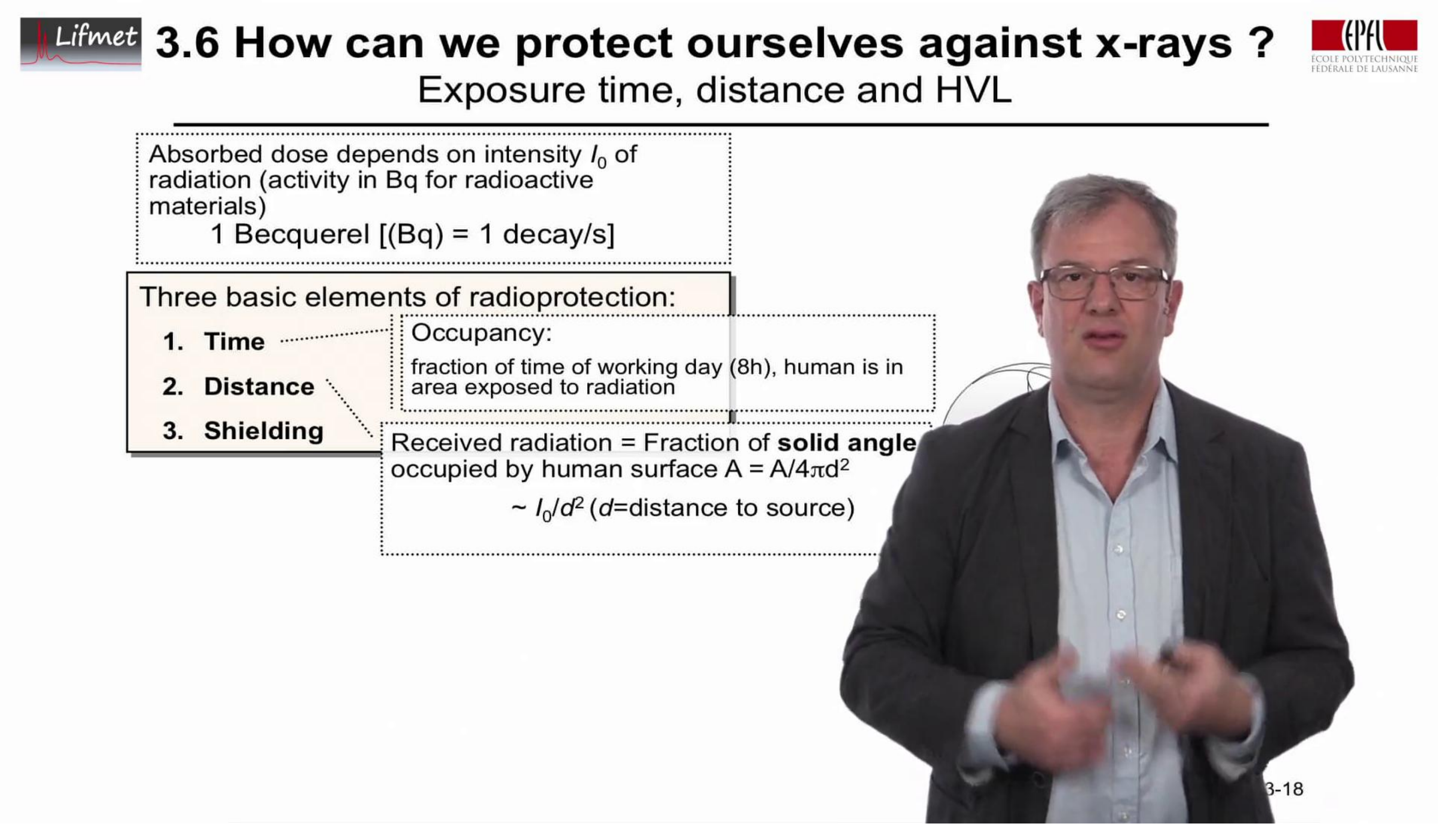
0m 04s

So if your office is next to an x-ray imaging device your occupancy is, you roughly work eight hours per day in that room, your occupancy will be close to 100%. If it's a corridor where you pass through once a day for example, your occupancy is essentially something like 20 seconds divided by 8 hours times 60 seconds. So it is very small. So for corridors, we have less considerations to do, because you walk through there, your exposure-- remember the exposure is determined by the absorbed dose and the absorbed dose is number of-- is the energy per kilogram deposited in your body. The second factor is distance. The further away you are, the less exposed you are to the radiation. We have an object that releases a certain number of becquerel, of decays, of events. It does that in all sorts of directions. The radioactivity doesn't know in which direction to go. And so the radiation that our body absorbs is proportional to the fraction of the solid angle that we occupy. So in other words, we have the fraction, we can express it as the surface of a sphere, with the radius of the distance between us and the source and our surface area.

Notes

Summary

1m 33s



So in other words, the received radiation that our body receives is proportional to the intensity of the object, the intensity of the source in becquerel, ***I**o* divided by the distance squared. So the further away we are, the better. So as a reminder here, it's a solid angle on a sphere; it's *4**π*** for a unit's sphere. The surface area that we occupy, we as a human being, is fixed. We do not change our surface if we go further away. So the fraction of the solid angle, the total solid angle that we occupy decreases with 1 over *d* squared. So that's the second element. Don't be exposed to it for a long time. Stay away from it as long as you can. But there, the distance, if you double the distance, you have a quarter of the radiation that you're exposed to. So if you have radioactive sample in your hand, hold it like this, as compared to this, and this mark is already a tenth of the radiation that you're exposed to, roughly. And the final element is shielding. So if you cannot avoid being exposed to it, you're going to have a long exposure, if you cannot get away from it, then use shieldings. So we use shielding in certain x-ray procedures to shield the parts of the body that are not subjected to the procedure.

Notes

Summary

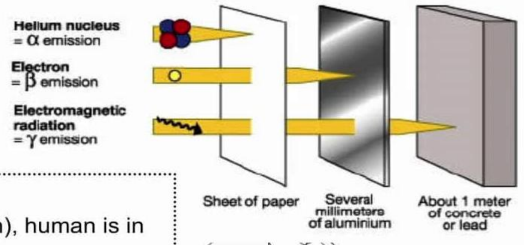
2m 57s

3.6 How can we protect ourselves against x-rays ?

Exposure time, distance and HVL

Absorbed dose depends on intensity I_0 of radiation (activity in Bq for radioactive materials)

1 Becquerel [(Bq) = 1 decay/s]



Three basic elements of radioprotection:

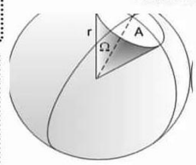
1. **Time**
2. **Distance**
3. **Shielding**

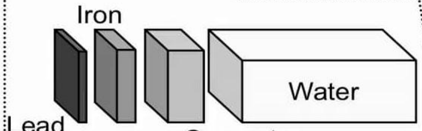
Occupancy:

fraction of time of working day (8h), human is in area exposed to radiation

Received radiation = Fraction of **solid angle** occupied by human surface A = $A/4\pi d^2$

$\sim I_0/d^2$ (d=distance to source)





10-fold reduction:
5 10 20 100 cm

Depends on energy and type of radiation

HVL	Iron or steel	Brick	Concrete	Dirt	Ice	Wood (soft)	Snow
(cm)	1.8	5.1	5.8	8.4	17	22	52

Half-value layers

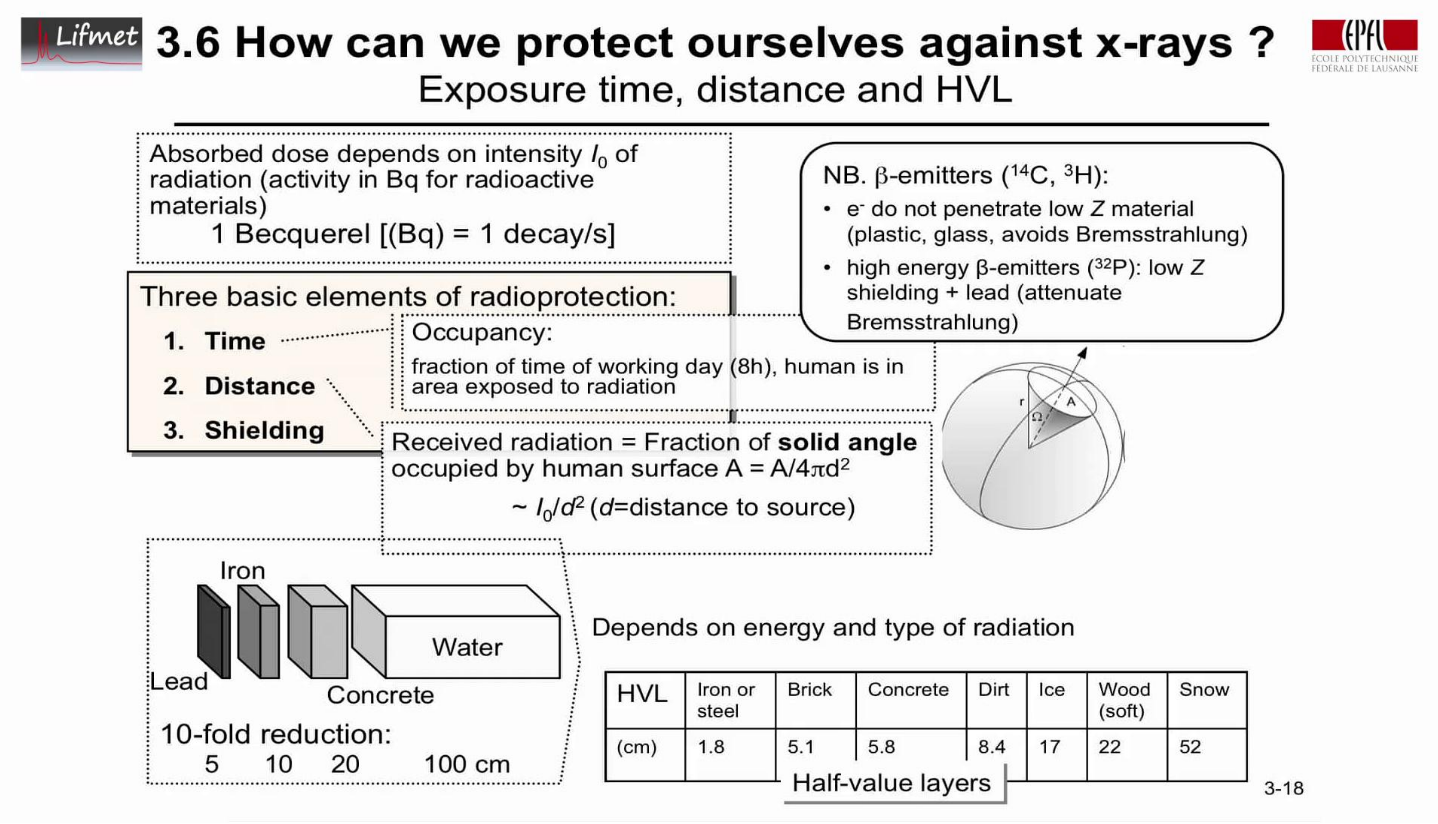
3-18

Now for shielding, we can have lead, we can have iron, we can have concrete, and water. And the thicknesses that you see here is the measure of the thickness needed to produce a ten-fold reduction in x-ray exposure. So we have for lead, a ten-fold reduction is achieved for 5 centimeters of lead. Iron we need 10 centimeters. Concrete, 20, and if it's water, we need 1 liter of water to produce the same effect. So we have different materials at our hands. This depends on the energy and type of radiation. So to give a sense of the half value layers, here is the number for materials. Iron or steel is close to 2 centimeters, bricks are 5 centimeters, concrete, 6, dirt 8, ice, 17 centimeters, soft wood, 22 centimeters, and snow, in our area if that's of interest, 52 centimeters. So an increased half-value layer means a decreased efficiency as a shielding material. Now we have to consider the different types of radiation as I will illustrate in shortly. We cannot just assume, well, we've got our radiation and we will just take one type of shielding. We have to consider what kind of source it is. Here are alpha emissions, beta emissions, gamma emissions-- the different ways of shielding these different radiations.

Notes

Summary

4m 17s



HVL	Iron or steel	Brick	Concrete	Dirt	Ice	Wood (soft)	Snow
(cm)	1.8	5.1	5.8	8.4	17	22	52

And here I wanted to illustrate this with beta emitters. like C14 or tritium. They do not penetrate low Z material. So the shielding that one should use if one has beta emitters should be plastic or glass, the low Z material so that we avoid Bremsstrahlung, We have a minimum in Bremsstrahlung in there. If we have high energy beta emitters such as phosphorus-32, this is used for DNA labeling for example. Then what you do is first, you have a low Z shielding, so you try to-- the electrons-- the beta emitters, that's are our electrons, they have to lose their energy, so you want to use low Z shielding and then complement this with lead shielding because as these high energy beta emitters are losing their energy in the plastic, they are producing Bremsstrahlung which are then x-rays. So you're transforming beta and make those into gamma emitters in this process, so you need to think of using lead there as well. So our take home message, it does depend on the type of radiation. And now we will demonstrate a few of the sources and also some rather surprising presence of radioactivity in our environment.

Notes

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5m 58s

Okay, so we will first demonstrate the effectiveness of certain material to eliminate radioactivity. This is strontium, a beta emitter. You can hear from the sound how active it is. Now I'll put the paraffin block in-between. And here the paraffin block is a perfect way to eliminate the beta emissions. If you take plastic here, also this plastic is fairly good. On the other hand, aluminum, even though high Z material, it's not very good at stopping this radioactivity from strontium. Now we'll take americium. This has a lower activity and we can hear the sound. If we listen to the frequency of the sound that gives us the counts of the particles that are detected. And I'll put the plastic in-between. And this source is not effectively blocked by plastic. On the other hand, if I use lead, then we can eliminate the source of radioactivity here to a large extent. We have in older watches, the hands that makes them glow in the dark is made by radium. Radium is radioactive. And here you can hear it, these are the hands of the watches. Some old watches, they should not be being sold or being in use today, but this is an illustration. We'll find radioactivity actually in very surprising places.

Notes

Summary

7m 29s

And this is for those of you who do camping. These are the things that you light on. And as you can see from the activity, this is radioactive. There is radioactive material used. There's of course, more nasty materials that are being used such a polonium in fire detectors and the old CRT TVs.

Notes

Summary

8m 58s

What are typical radiation exposures ?

Natural, artificial and some examples

Natural	mrem/yr	mSv/yr	%total
Radon	200	2.0	55%
Cosmic	27	0.27	8%
Terrestrial	28	0.28	8%
Internal	39	0.39	11%
Total	**300**	**3**	**82%**

Other			
Occupational	0.9	<0.01	<0.3
Nuclear Fuel Cycle	<1	<0.01	<0.03
Fallout	<1	<0.01	<0.03
Misc.	<1	<0.01	<0.03

Artificial			
Medical X ray	39	0.39	11%
Nuclear Med.	14	0.14	4%
Consumer products	10	0.1	3%
Total	**63**	**0.63**	**18%**

Useful to know:

100 Röntgen equivalent man (REM) = 1 Sievert

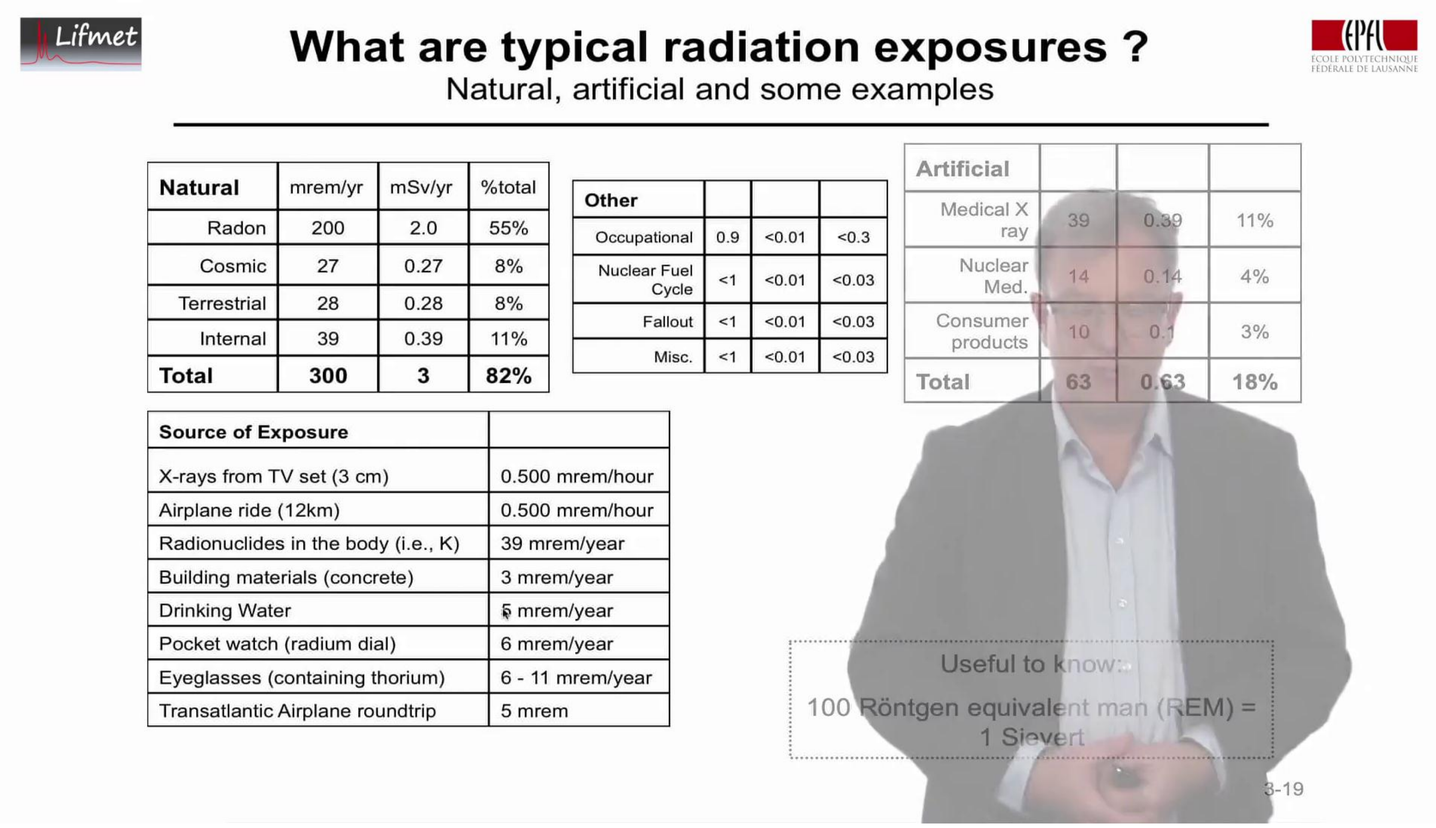
3-19

So finally, to put all this into perspective, the radiation exposures we have in biomedical imaging. It will be useful to have some idea what are typical radiation exposures. So we have taken here some tables of first, some natural radiation. We have radon, typically in our basements in rocky environments. They're expressed here in millirem per year and millisievert per year. Radon is by far the biggest source of natural radiation. We have cosmic radiation, 8% terrestrial radiation, and then we also have some internal sources. Very often, the usage of units is not uniform. We have roentgen equivalent man or REM. And a 100 roentgen equivalent man is 1 sievert. Sievert is the official SI unit for quantifying radiation. Then we have artificial sources. We have here an example of medical x-ray. This is in millirem per year and this is in sievert, millisiervert per year, nuclear medicine and consumer products. That is a contribution. So we have artificial exposure, natural exposure. By far the most exposure that we are exposed to is the natural sources. Now if you look at occupational other sources, we have occupational radioactivity. We have the nuclear fuel cycle.

Notes

Summary

9m 21s



We have nuclear fallout from surface testing of atomic bombs. We can measure the radioactivity, the consequences of these tests done by the various countries, predominantly in the 60s. These effects, although they can be quantified, they are very low. They are less than a millirem per year here in this column. To give you another idea, sources of exposure. So in the old days when we had-- maybe you still have an old CRT computer monitor or TV, that is where the electrons are accelerated, and they produce the image on the screen, the big, thick TV screens. These TV sets, at three centimeters from that TV set, you're exposed to 1/2 millirem per hour of radiation. Thus we have electrons that impact on the surface. If you're in an airplane at 12 kilometers height, then you're exposed to roughly the same radioactivity. It's a 1/2 millirem per hour. We have radionuclides in the body, for example, postassium, for example, from bananas. There's a lot of potassium, so that's 39 millirem per year. So we compare this radioactivity with-- this is primarily potassium here, this source. You can compare these numbers here, with these numbers here and do the calculation. We have concrete that has radioactivity in there.

Notes

Summary

10m 53s

What are typical radiation exposures ?

Natural, artificial and some examples

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Total	**63**	**0.63**	**18%**

Source of Exposure	
X-rays from TV set (3 cm)	0.500 mrem/hour
Airplane ride (12km)	0.500 mrem/hour
Radionuclides in the body (i.e., K)	39 mrem/year
Building materials (concrete)	3 mrem/year
Drinking Water	5 mrem/year
Pocket watch (radium dial)	6 mrem/year
Eyeglasses (containing thorium)	6 - 11 mrem/year
Transatlantic Airplane roundtrip	5 mrem

Chest x-ray, dental x-ray, head & neck	5-20 mrem
Lumbar spinal x-rays	130 mrem
Pelvis x-ray	44 mrem
Hip x-ray	83 mrem
CT (head and body)	1,100 mrem

Useful to know:

100 Röntgen equivalent man (REM) = 1 Sievert

3-19

We have some radioactivity in drinking water. If-- I presume nobody owns these watches anymore, I had one from my grandfather. The old pocket watches had the hands that glow in the dark this was done with radium and there you would be exposed to six millirem per year of radioactivity. Very often eye glasses contain thorium for whatever reason. There you're exposed to 6 to 11 millirem per year. And if you take a trans-Atlantic round trip, then you're roughly taking up a radioactivity of 5 millirem. Now compare this to medical procedures: chest x-ray, dental x-ray, head and neck. We're up around 5 to 20 millirem. Lumbar spinal x-rays, pelvic x-rays and hip x-rays, they're on the order of 50 to 100 millirem. And if you do a CT scan of head and body, then you're exposed to 1.1 rem of radiation. So that is quite a bit, and that is one of the reasons why we cannot put too many x-ray procedures on the same patient per year. It's interesting to note that these are sort of general tables I felt was useful to illustrate the different dosages here. We have some compounds that are quite dangerous but they are used.

Notes

Summary

12m 21s

What are typical radiation exposures ?

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Building materials (concrete)	3 mrem/year
Drinking Water	5 mrem/year
Pocket watch (radium dial)	6 mrem/year
Eyeglasses (containing thorium)	6 - 11 mrem/year
Transatlantic Airplane roundtrip	5 mrem

Chest x-ray, dental x-ray, head & neck	5-20 mrem
Lumbar spinal x-rays	130 mrem
Pelvis x-ray	44 mrem
Hip x-ray	83 mrem
CT (head and body)	1,100 mrem

Useful to know:

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3-19

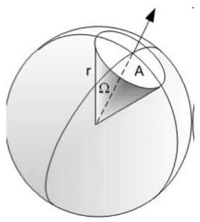
If you might remember a few years back, it is now believed that it was the Russian Secret Service that poisoned this former agent of theirs in the UK with polonium. So they got him to swallow something that contained the polonium and he died of the radiation damage. Polonium is a very nasty substance. It releases very high energetic beta particles. It gets warm. But you do have polonium in, for example, some smoke detectors. They're being used there and on the older CRT screens, the old TV sets, it was used as an anti-ionizing agent to prevent [char] from building up on the surface of the TV set. So these are some examples. A more recent example of where we have to deal with these terms here like millirem or sievert, were the tragic events that surrounded the catastrophe of Fukushima in recent years.

Notes

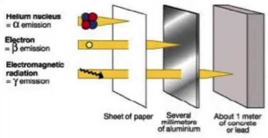
Summary

13m 55s

Credits



Solid angle
https://commons.wikimedia.org/wiki/Category:Solid_angle



Penetrating powers of radioactive rays
http://www.radiationgames.net/0Nzm/CellTissueHumanBody6/O3aaklm/Radiation.htm

And here are some links that you can look at. This is where you can calculate the dosage for certain exposures if you're interested in doing so.

Notes

Summary

15m 00s