Joint ICTP-IAEA School on FPGA-based SoC and its Applications for Nuclear and Related Instrumentation

25 Jan to 19 Feb 2021

Introduction into Radiotracer techniques for Industrial and Environmental Applications

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Radiation Protection
&
Safety Aspects for
Radiotracer applications

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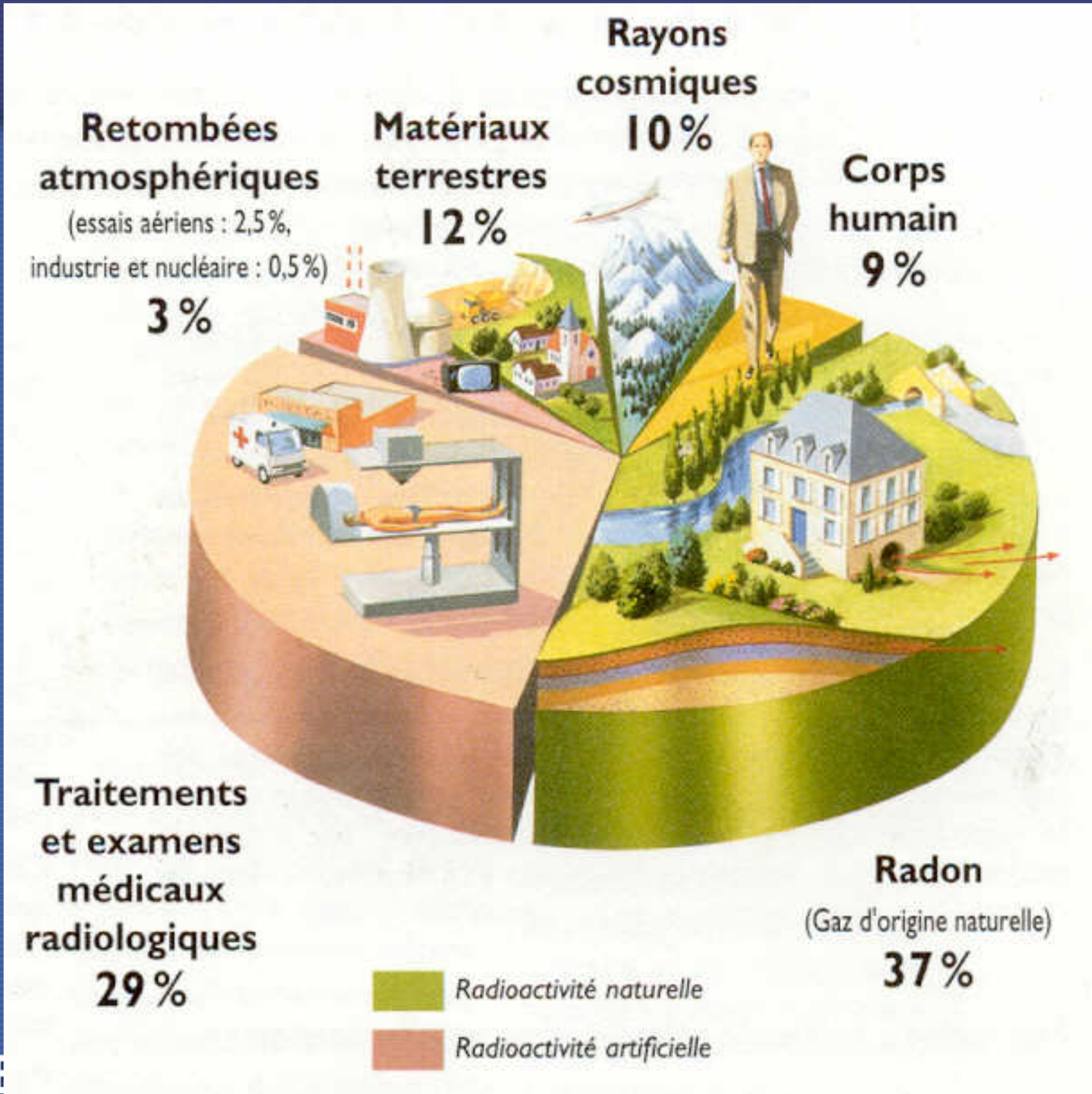
FACTS



Rayons cosmiques 10%
Retombées atmosphériques (essais aériens : 2,5%, industrie et nucléaire : 0,5%) 3%
Matériaux terrestres 12%
Corps humain 9%
Traitements et examens médicaux radiologiques 29%
Radon (Gaz d'origine naturelle) 37%
Radioactivité naturelle
Radioactivité artificielle

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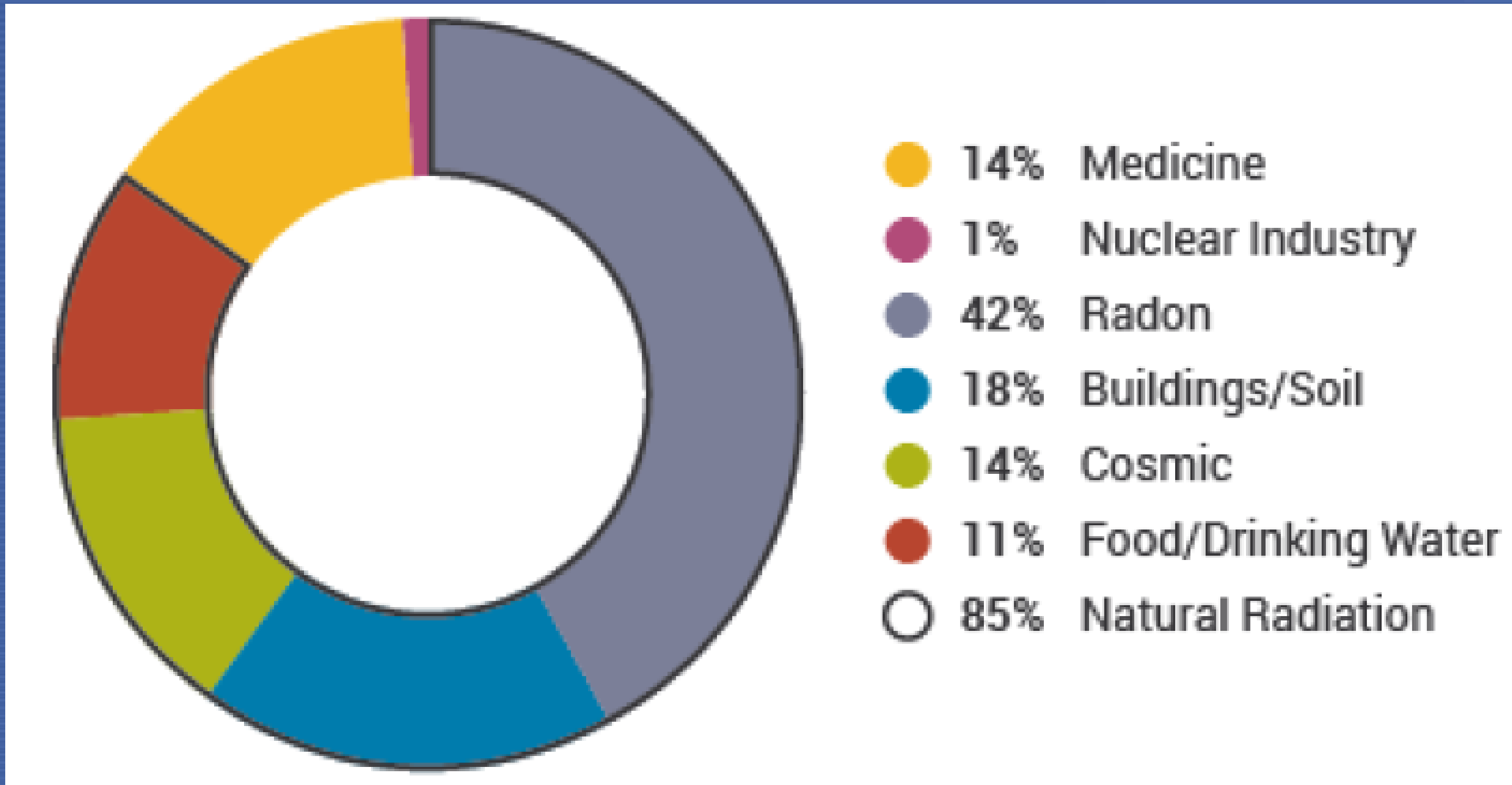
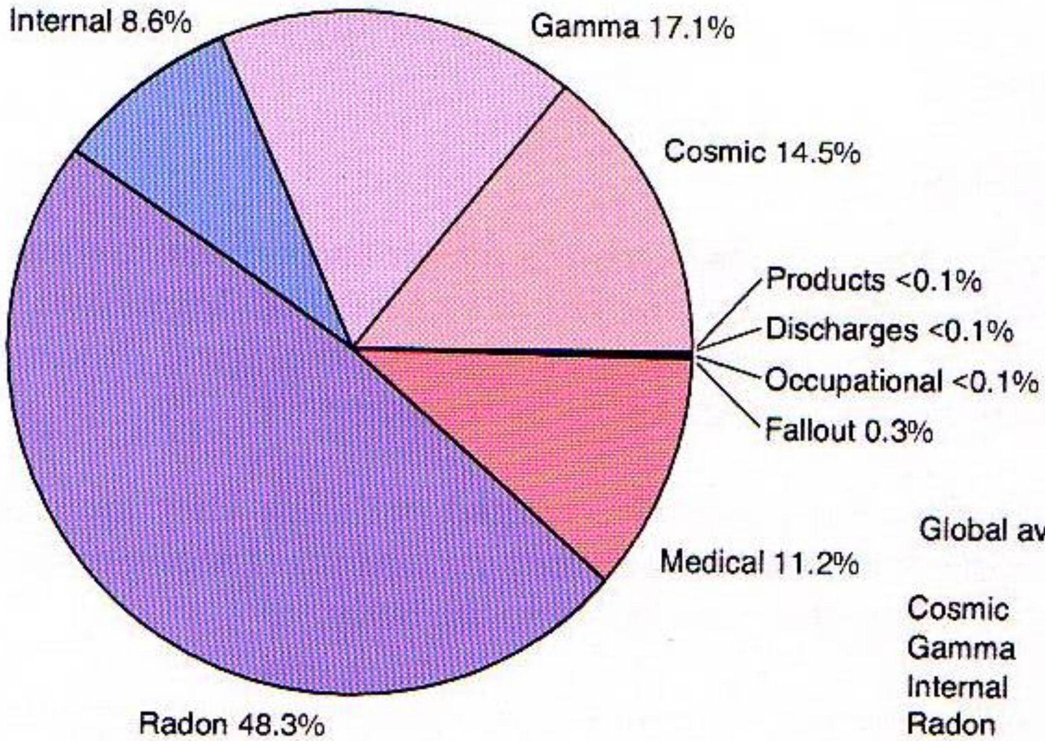
Routine Sources of Radiation



Radiation can arise from human activities or from natural sources. Most radiation exposure is from natural sources. These include: radioactivity in rocks and soil of the Earth's crust; radon, a radioactive gas given out by many volcanic rocks and uranium ore; and cosmic radiation. The human environment has always been radioactive and accounts for up to 85% of the annual human radiation dose.

Components of Radiation Protection



Global average doses	msv
Cosmic	0.39
Gamma	0.46
Internal	0.23
Radon	1.3
Medical	0.3
Fallout	0.007
Occupational	0.002
Discharges	0.001
Products	0.0005
Total	2.69

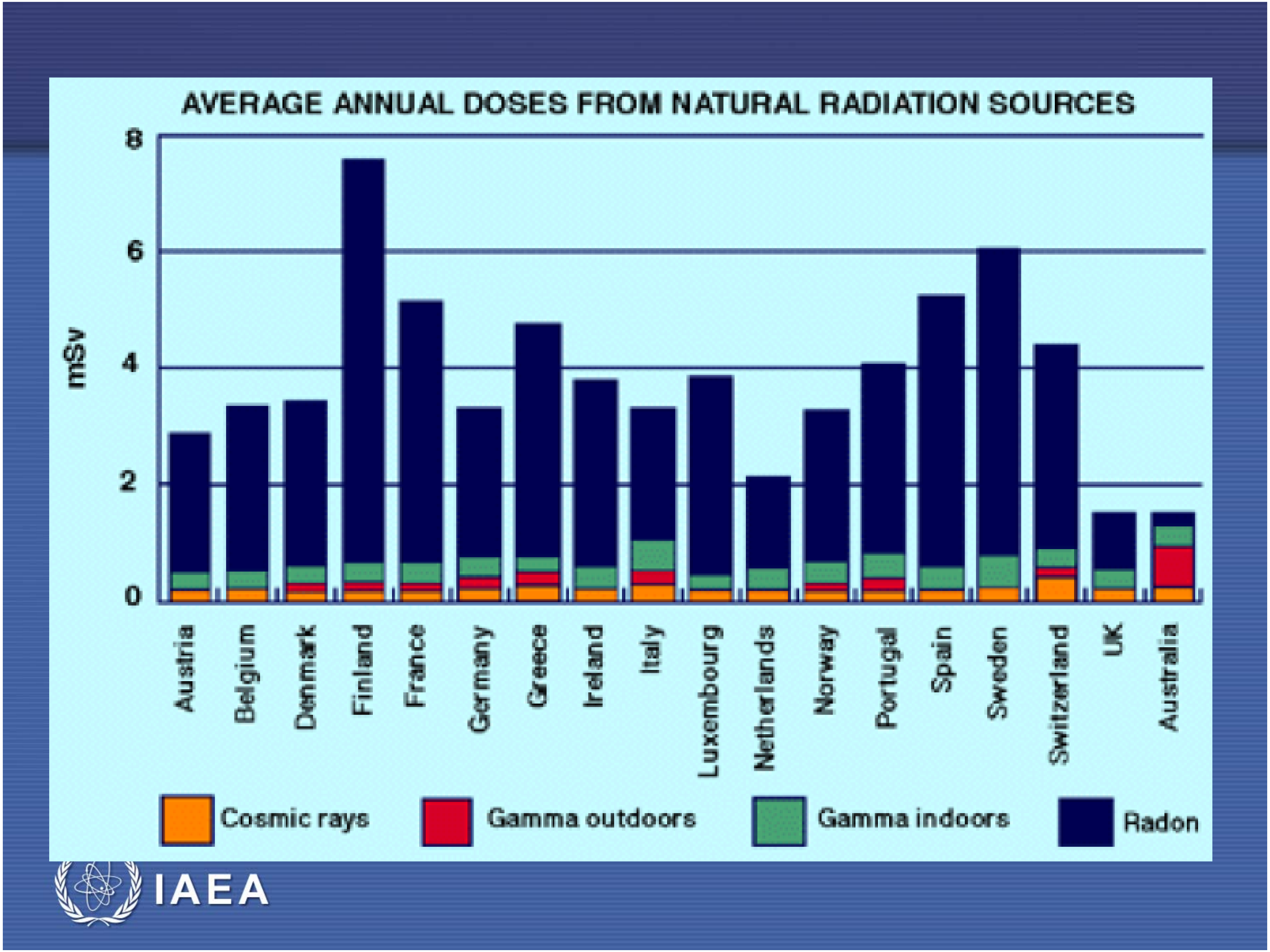
The average yearly global radiation dose from all sources of radiation is 2,7 millisieverts, made up of the components shown in the diagram.

Everyone is exposed to natural radiation:

cosmic rays + Earth‘s natural radioisotopes (uranium-thorium and K-40) + artificial radiation (Xray, radiotherapy, nuclear medicine)

Annual **Effective dose** :

2,7 mSv /y = 0.3 µSv/h


AVERAGE ANNUAL DOSES FROM NATURAL RADIATION SOURCES
mSv
8
6
4
2
0
Austria
Belgium
Denmark
Finland
France
Germany
Greece
Ireland
Italy
Luxembourg
Netherlands
Norway
Portugal
Spain
Sweden
Switzerland
UK
Australia
Cosmic rays
Gamma outdoors
Gamma indoors
Radon
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Elements of Radioactivity & Radiation Protection

Quantity	Unit	What is measured	Amount
Activity	Curie (Ci) Becquerel (Bq)	The number of decays per unit time	1 Ci = 1,000 mCi 1 Bq = 27 x 10^{-12} Ci
Absorbed Dose	Rad Gray (Gy)	Amount of energy absorbed in 1 gram of matter from radiation	1 rad = 1,000 mrad 1 Gy = 100 rad
Dose Equivalent	Rem Sievert (Sv)	Absorbed dose modified by the ability of the radiation to cause biological damage	rem = rad x Quality Factor 1 rem = 1,000 mrem 1 Sv = 100 rem

Effective Dose

Effective dose is calculated for the whole body.

It is the addition of equivalent doses to all organs, each adjusted to account for the sensitivity of the organ to radiation.

Effective dose is expressed in millisieverts (mSv).

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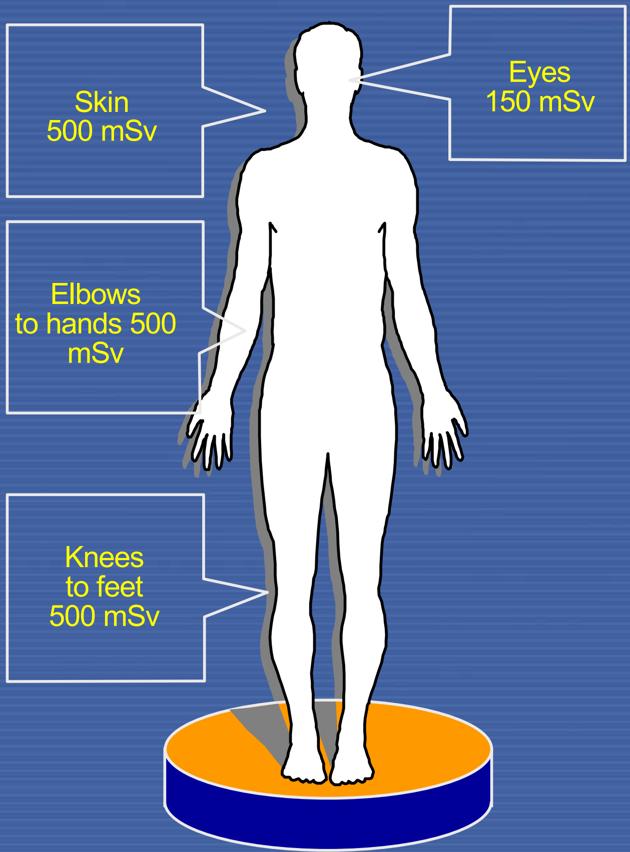
Occupational Dose



50 mSv in any single year

Workers

Effective dose

20 mSv/a over 5 years

50 mSv in any single year

Equivalent dose

to the lens of the eye 150 mSv/a

extremities (hands and feet) or the skin 500 mSv/a

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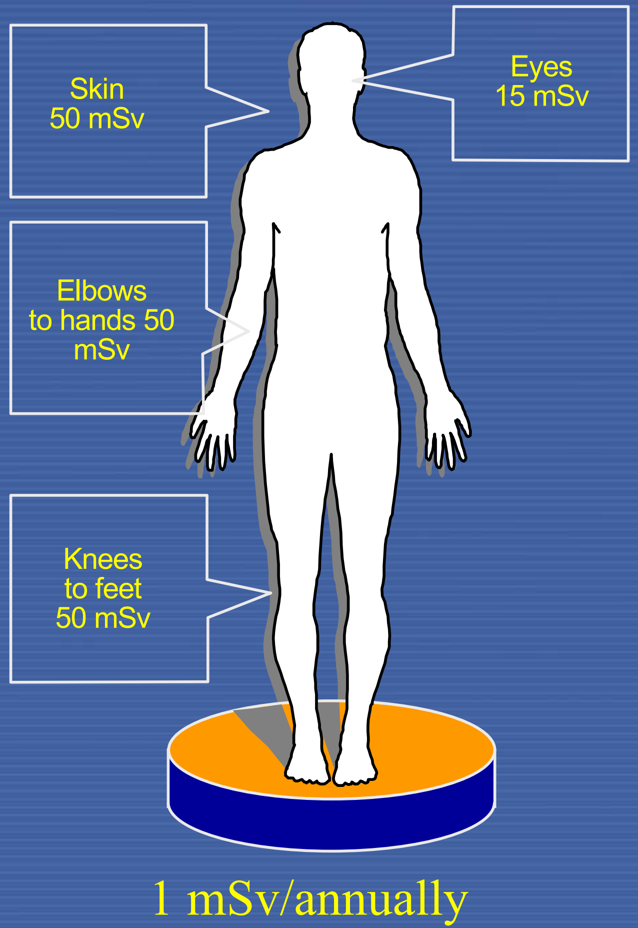
Dose Limits



Members of the public

Effective dose

1 mSv/a

in special circumstances 5 mSv in a single year provided that 1 mSv/a over 5 years is not exceeded

Equivalent dose

to the lens of the eye 15 mSv/a

extremities (hands and feet) or the skin 50 mSv/a

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Personnel Monitoring Equipment

- **TLD - gamma, X, neutron and beta radiation**

- **Film - gamma, X and beta radiation**

- **OSL - gamma, X, neutron and beta radiation**

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Personal Monitoring

- Policy for assigning dosimetry to individual workers
- Workers provided with personal dosimeter
- Type of dosimeters
- Dosimeter service

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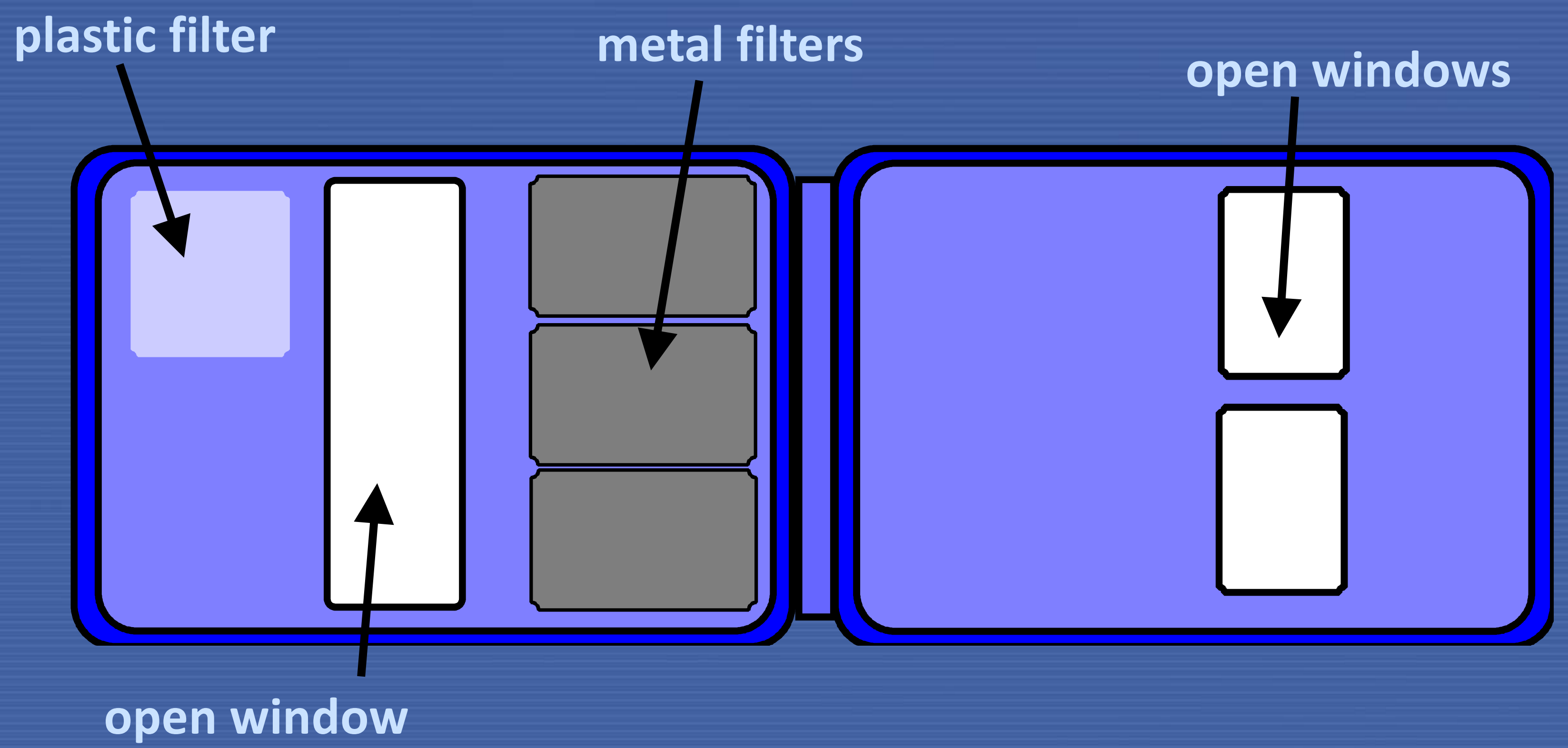
Film Badge



The holder creates a distinctive pattern on the film indicating the type and energy of radiation to which it was exposed (discrimination). Cumulative doses from beta, X, gamma and thermal neutron radiations are calculated by measuring the optical densities (darkness) of film under the filters and comparing the results with calibration films that have been exposed to known doses.

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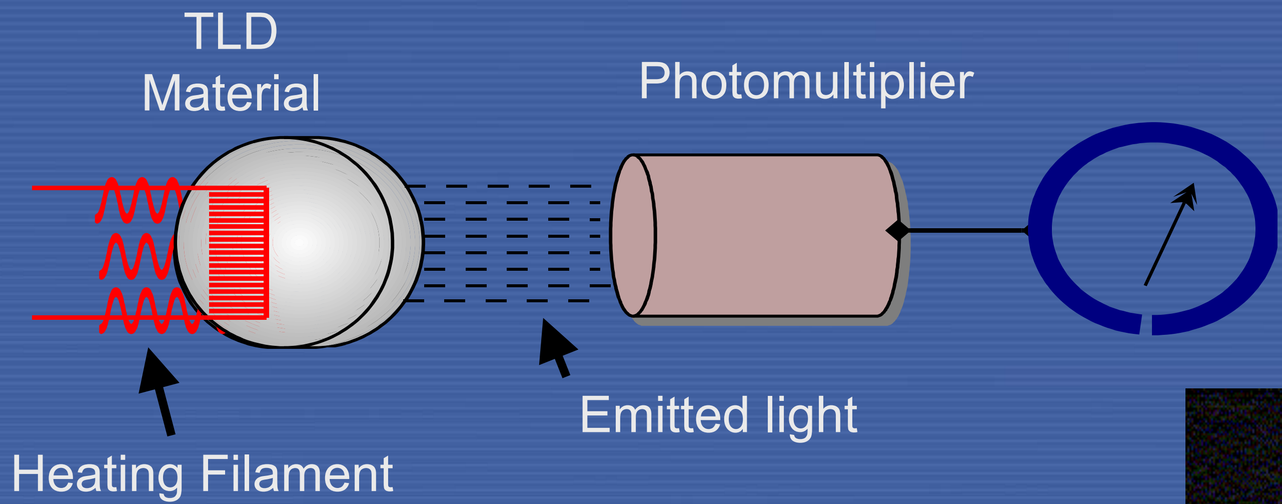
Thermoluminescence (TLD)



Detects Beta, Gamma, X-Ray, and Neutrons

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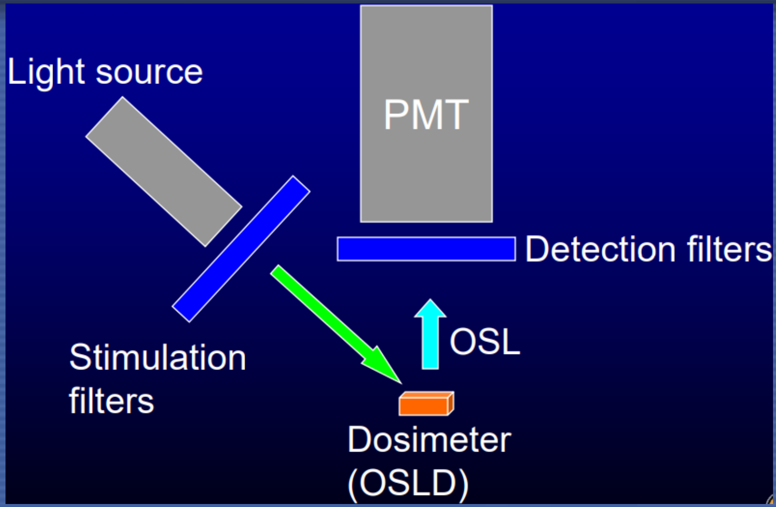
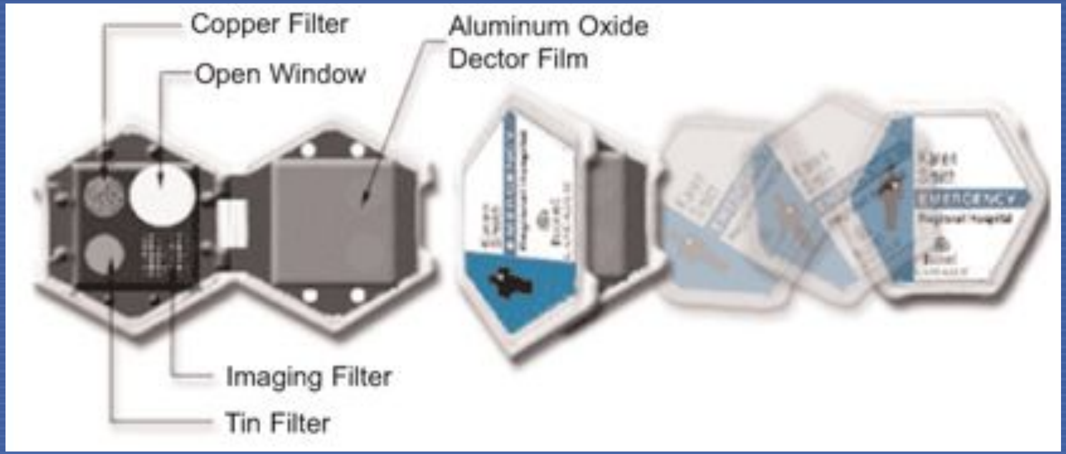
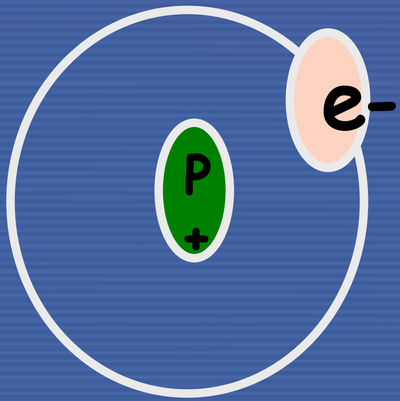
Optically Stimulated Luminescence (OSL)





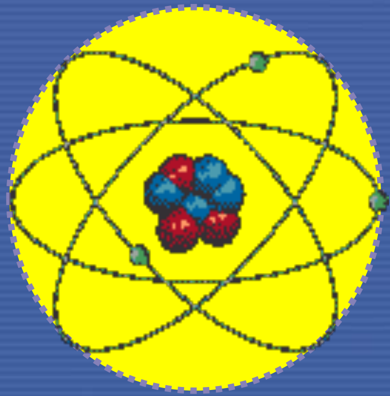
ideal for monitoring employees working in low-radiation environments and for pregnant workers. OSL dosimeters offer advantages that include the ability to be re-read and a high sensitivity (low minimum measurable dose), and they have become popular because of these favourable properties.

Stable vs. Unstable Atoms



STABLE

"Non-Radioactive"



UNSTABLE

"Radioactive"

If there are too many or too few neutrons for a given number of protons, the nucleus will not be stable.

Particules Radiation

The power of penetration depends on the nature of the radiation

α is stopped by the skin (≈ 0,07mm).

No external irradiation.

β can penetrate deeper than a (≈ 10mm) but generally don't reach deep organs (dépend upon the energy of the particule b)

Neutron case of fission and for e few industrial sources, high penetration because high energy.

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Power of penetration

STOP

α → Paper – some cm Air

β → 1cm Plexiglas

Attenuation

γ and *X* → Lead or Concrete

neutron → Polyethylene, Water

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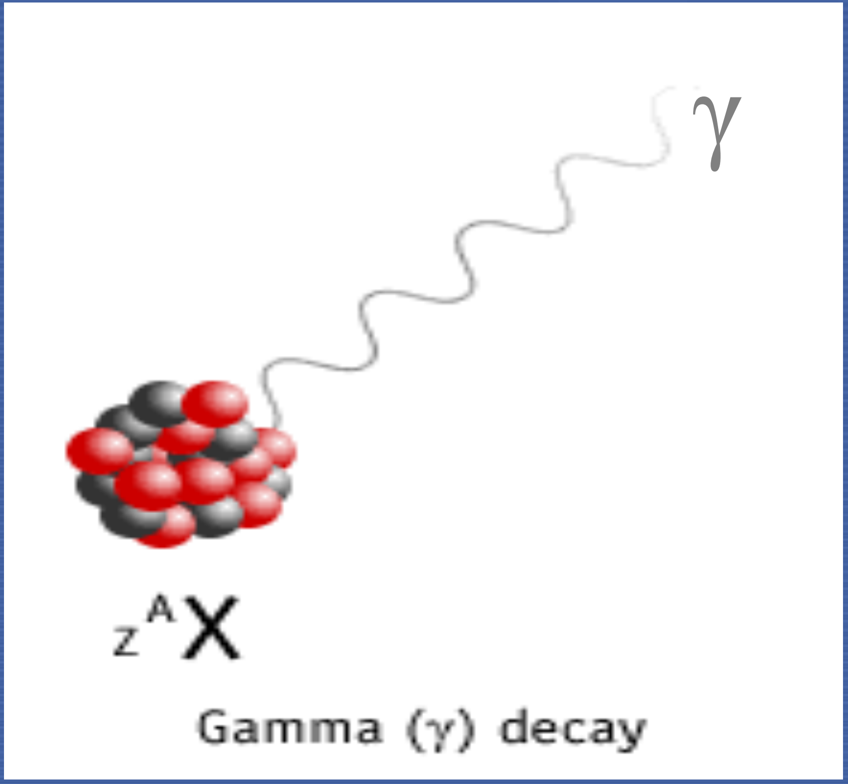
Gamma-ray



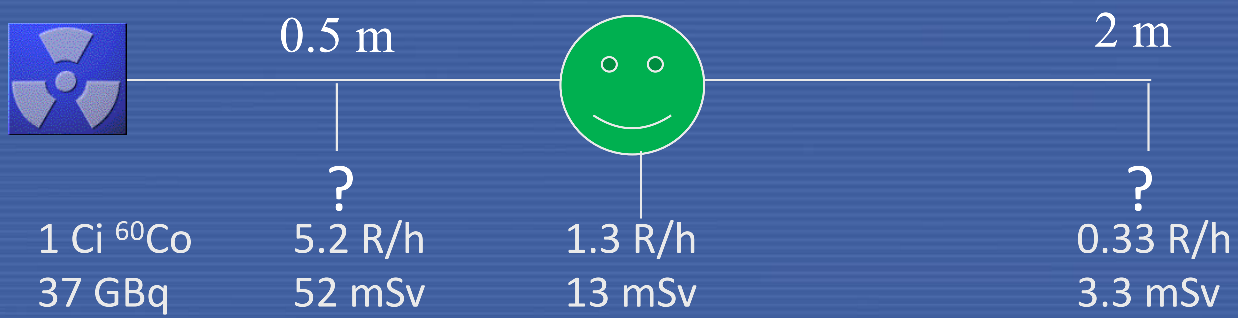
Electromagnetic Radiation

- γ : very penetrant, never completely stopped by a shileding but can be stronglly attenuated
- X : same as g but with lower energies.

Gamma-ray emission constant

(Inverse square law)

$$\text{Dose rate} = \text{gamma emission constant} \times \frac{(\text{old distance})^2}{(\text{new distance})^2}$$



^{60}Co: $\gamma = 1.32$ R/h/Ci/m

^{137} Cs: $\gamma = 0.35$R/h/Ci/m

Conversion from:

Radioactivity to radiation

Radiation to radioactivity

Irradiation: Distance

The received « doses »(D) varies with the square of the distance!

- *If: d (distance) is multiplied by 2*

  D (Dose) is divided by 2^2 (2x2) = 4

- *If: d is multiplied by 10*

  D is divided by 10^2 (10x10) = 100

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The gamma-ray field from a particular Co-60 source is 10 mR/h at 0.5 m.

What is the dose at 3m?

Answer:

Dose (3m) = Dose (0.5m) x $(\text{old distance})^2 / (\text{new distance})^2$

$= 10 \times (0.5)^2 / (3)^2$

$= 0.28$ mR/h

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Example

- ---- We are using 400 mCi of Au-198.
- ---- Distance from the radioactivity is 50 cm
- ---- We are working with the activity for 5 min (exposure time)
- (Consider this as a point source)

- What total dose will we received at the end of 5 minutes**?**

Gamma-ray emission constant = 0.291 R/h/Ci/m

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Radiation Safety & Protection

- How can I ensure my safety?

A — As

L — Low

A — As

R — Reasonably

A — Achievable

- Time
- Distance
- Shielding

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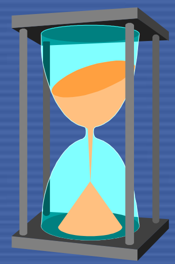
Does not eliminate radiation exposure

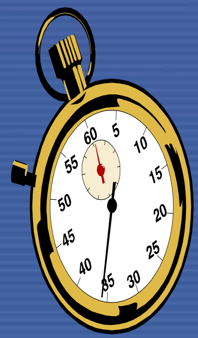
Provides guidelines to limit the risk of bodily injury

What Safety Precautions Should I Take?

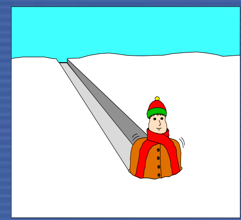
Apply the three corners stones

Minimize time



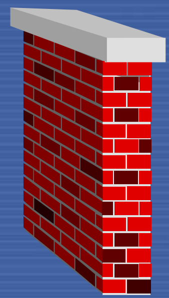


Maximize distance



Maximize shielding

(the heavier material the better)



Very Small DOSE = Very Small RISK

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Follow safety precautions

Procedures for Conducting a Field Radiotracer Applications in Industry

Following sequential procedure/steps are conducted by the "Radiotracer Team" for conducting field radiotracers:

1. Plant visit and feasibility assessment

On receiving a request from an industry, a member of the "Tracer Team" visits the experimental site/plant for assessing the feasibility of conducting the experiment and detail discussions with the plant engineers. If it is feasible to conduct the radiotracer, the user industry is asked to fill-up the PART-A of the safety planning form (SPF), which contains information such as name and contact details of the industry, purpose of radiotracer experiment, availability of conventional techniques for given application, information about reactor/system etc. Industry has to certify that "no alternative technique is available for this application" and undertaking for abiding all the safety rules/regulations during the experiment.

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2. Selection of radiotracer and amount of radiotracer required

After the feasibility assessment the suitable radiotracer is selected and amount of activity required for the tracer experiment is estimated. Subsequently, the PART-B of the SPF is filled by scientists/engineers responsible for conducting the radiotracer experiment, which contains information about radiotracer, transportation details, number of experiments to be conducted, number of people involved, similar kind of experiments done earlier etc. The PART-C is filled by the concerned Health Physicist.

3. Approval from Regulatory Authority

Since the field radiotracer experiments are conducted in public domain, it is also required to take approval of National Regulatory Authority for conducting the experiment on case to case basis. In addition to this, the necessary approval for transport of radiotracer to the experiment site is also obtained. Accordingly, an application is raised furnishing all the details and relevant information to competent authority.

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4. Preparation of work area and execution of tracer test

The area/location where the radiotracer experiment is conducted is prepared for the execution of the experiments.

After the injection of radiotracer is performed:

- *Injection of radiotracer conducted by well-trained and qualified radiotracer practitioners*
- *Monitoring/detection of radiotracer*
- *Waste management*

The radiotracer injected into full-scale industrial reactor gets diluted/dispersed within the reactor under investigation and downstream flow circuit. In addition to this, the injected radiotracer also decays completely within a period equal to 6-7 half-lives of the radiotracer used. As the radiotracer used in industry are short-lived (a few hours) and get highly diluted within the plant and thus do not produce any disposable waste.

5. Analysis of radiation hazards

After completion of the field radiotracer experiment, PART-D of the SPF is filled by the accompanying Health Physicist or members of the "TRACER TEAM". Wherever, the Health Physicist is involved (sediment transport, effluent dispersion and flow rate measurements in canals etc.), a detailed Radiation Surveillance Report is prepared by him and submitted to competent authority for their review.

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Safety Rules and Instructions while working with Radioactive material

- Eating, drinking, smoking, snuffing is prohibited.
- Use of handkerchief not allowed.
- No mouth pipetting of radioactive solution.
- Must worn personnel dosimeters (TLD, DRD).
- Must wear protective clothing.
- No direct handling of radioactive material is permitted. Suitable remote handling tool must be used.
- Trays lined with absorbent material be used to handle radioactive material.
- Manipulations must be carried out speedily to minimise exposure.
- Shielding must be used whenever possible.

Ten Principles & Commandments of Radiation Protection

1.	Time	Be quick
2.	Distance	Stay away from RAM
3.	Dispersal	Disperse & Dilute RAM
4.	Source reduction	Use as little as possible
5.	Source barrier	keep RAM in Shield
6.	Personnel barrier	Shield the person
7.	Decorporation (internal & surface irradiation only)	Get it out of you & off you
8.	Effect mitigation	Limit the damage
9.	Optimal technology	Choose best technology
10.	Limit other exposure	Do not compound the risk

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Survey and monitoring instruments

- Confirm dose rates estimated for control area
- Determine the boundaries of control area
- Search for background/residual contamination /radioactivity in the working area where tracer is to be introduced into the system
- Confirm working of instruments by standard source. Have minimum two measuring instruments preferably working on two different principles.

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Risk Assessment
Case Study: Movement of catalyst in FCCU

Tracer used	^{140}La
Half life	40 hrs
γ-emission constant (RHM)	1.253R/h
Activity	50mCi (1.85GBq)
Physical form	Powder
Dose on 180mm lead container	0.5mSv/h
No. of persons involved	3

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Dose assessment

Type of operation	Equipment	Time (Sec)	Estimated dose(mSv)
Opening container	Manual	60	0.01
Removal of Al. cup containing activity	2m cee-vee tong	30	0.01
Removal of lid of Al. cup	0.3m tong	30	0.01
Loading of capsule into inj. Apparatus	2m cee-vee tong	30	0.005
Breaking of capsule	In built hammer	10	0.17
Flushing the activity by N_2	N_2Gas cylinder	2min	0.01
		Total	0.215
Exposure per person 0.07mSv			

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Transportation of radioactive materials

All containers must be duly identified according to internationally adopted safety rules. A label must be placed outside transport container. Labelling must identify warning and state the hazards, classify the material in a hazard class, be readily recognizable.

What are different labels used on the external surface of packages containing radioactive material?

a. White-I
b. Yellow-II
c. Yellow-III
d. all of them

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Radiation hazard warning signs

Hazardous levels of ionising radiation are signified by the trefoil sign on a yellow background. These are usually posted at boundary of a radiation controlled area or in any place where radiation levels are significantly above background due to human intervention

Red ionizing radiation warning symbol (ISO 21482) was launched in 2007, and is intended for IAEA Category 1, 2 and 3 sources defined as dangerous sources capable of death or serious injury, including food irradiators, teletherapy machines for cancer treatment and industrial radiography units. The symbol is to be placed on the device housing the source, as a warning not to dismantle the device or to get any closer. It will not be visible under normal use, only if someone attempts to disassemble the device.

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Radioactive White-I Very low radiation level means:

5 µSv/h maximum on surface

Radioactive Yellow-II Low radiation level means:

0.5 mSv/h maximum on surface;

10 µSv/h maximum at 1 meter

Number 7 at bottom of the label indicates the UN hazard class description for radioactive materials.

A transport index number should be written inside the empty box above number 7.

This number states the actual radiation level in mSv/h measured at 1 m distance.

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Radioactive Yellow-III- radiation level means

In the picture bellow, yellow-III identifies higher radiation levels, i.e.

2 mSv/h maximum on surface and

0.1 mSv/h maximum at 1 m distance.

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RADIONUCLIDE: Tc-99m

Physical characteristics:

Half-life: 6.02 hours

Type decay: Isomeric Transition gammas: 0.141 MeV (89.1 %)

Hazard category:

C- level (Low hazard) : 100 µCi to 10 mCi

B - level (Moderate hazard) : > 10 mCi to 1 Ci

A - level (High hazard) : > 1 Ci

External radiation hazards and shielding:

The gamma exposure rate at 1 cm from 1 mCi is 720 mR/hr. The exposure rate varies directly with activity and inversely as the square of the distance. The half-value layer is 0.3 mm of lead. To facilitate control of the radiation exposure from mCi amounts of this radionuclide, the use of 4 mm thickness of lead will attenuate the radiation emitted by a factor of about 10000.

Hazards if internally deposited:

The annual limit on oral intake (ALI) of Tl-99m corresponding to a whole-body guideline gamma exposure rate of 500 mrem/year is 8.0 mCi.

Dosimetry and bioassay requirements:

Film badges are required if 5 mCi are handled at any one time or 1 mCi levels are handled on a frequent (daily) basis.

Urine assays may be required after spills or contamination incidents.

Special problems and precautions:

1. Always use a syringe shield for drawing up of doses and injecting. Survey frequently.

Handle stock solution vials in shields or use tongs or forceps. Change gloves often.

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NUCLIDE: I-131

Physical characteristics:

Half-life: 8.04 days Type decay: beta -

Beta maximum energy 0.806 MeV (0.6 %)

Gamma 0.248 MeV (6.10 %) 0.364 MeV (81.25 %) - 0.637 MeV (7.26 %) - 0.723 MeV (1.80 %)

Hazard category:

C- level (Low hazard) : 1 to 100 µCi

B - level (Moderate hazard) : > 100 µCi to 10 mCi

A - level (High hazard) : > 10 mCi

External radiation hazards and shielding:

Exposure rate at 1 cm from 1 mCi is 2.2 R/hr.

Amount of lead required to reduce the exposure rate by a factor of 10 (1 TVL) is approximately 1.1 cm.

Hazards if internally deposited:

Contamination on the skin or inhalation from air containing iodine vapors will result in internal deposition. Iodide solutions are easily oxidized and the elemental iodine will become airborne. About 70% of activity inhaled is deposited in the body and about 30% of that is deposited in the thyroid. Continual presence of 0.07 µCi in the thyroid gland will result in that gland receiving the maximum dose recommended by the NCRP, i.e. 15 rem/year. Inhalation of 1 µCi results in a dose of 1.9 rem to the thyroid. The Annual Limit of Intake of I-131 corresponding to a whole body exposure rate of 500 mrem/ year is 9 µCi.

WORK IN PROPER FUME HOODS.

Dosimetry and bioassay requirements:

Film badges are required if 5 mCi are handled at any one time or mCi levels are handled on a frequent (daily) basis.

Arrange for a thyroid survey within 24-48 hours after the first procedure;

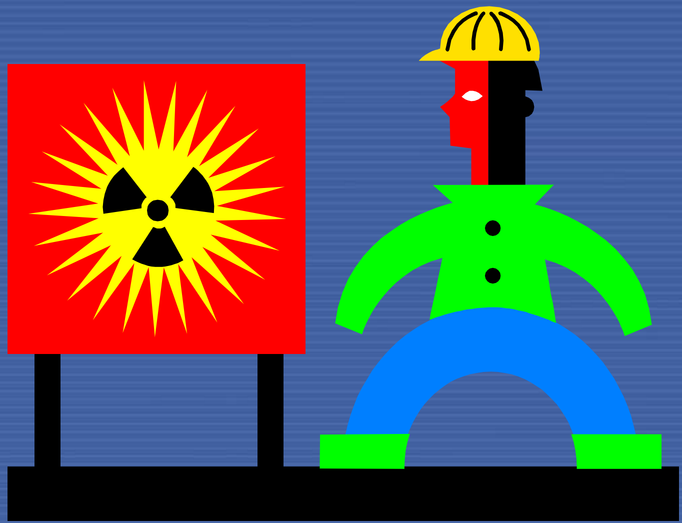
Special problems and precautions:

1.Segregate wastes to those with half-lives of 8 to 19 days. Wrap all waste items in plastic bags prior to placing them in waste.

2.Limit of soluble waste to sewer is 100 µCi / month / lab.

HEALTH EFFECTS

How will all this affect me?
How much will I be exposed???



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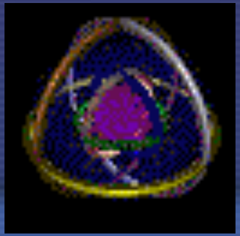
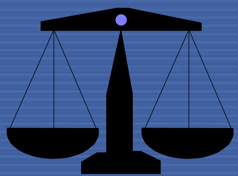
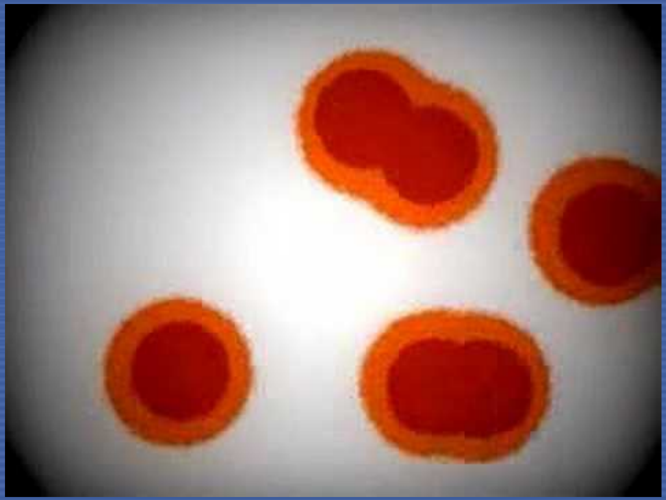
Radiation Effects



- Radiation Effect depends on
  - How much dose you receive
  - How quickly you receive the dose
  - What part of the body receives it, and
  - whether you receive any medical treatment.

- Radiation sensitivity depends on
- -- how rapidly cells divide





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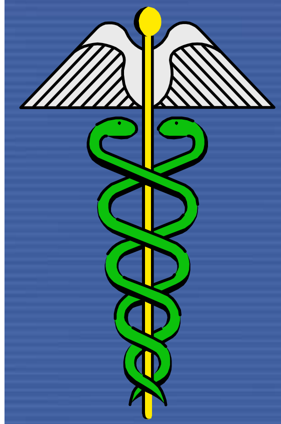
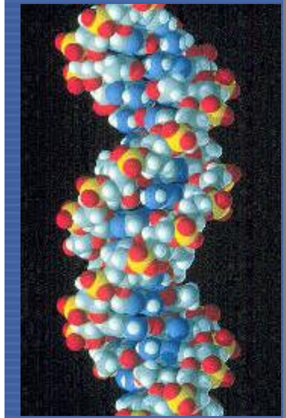
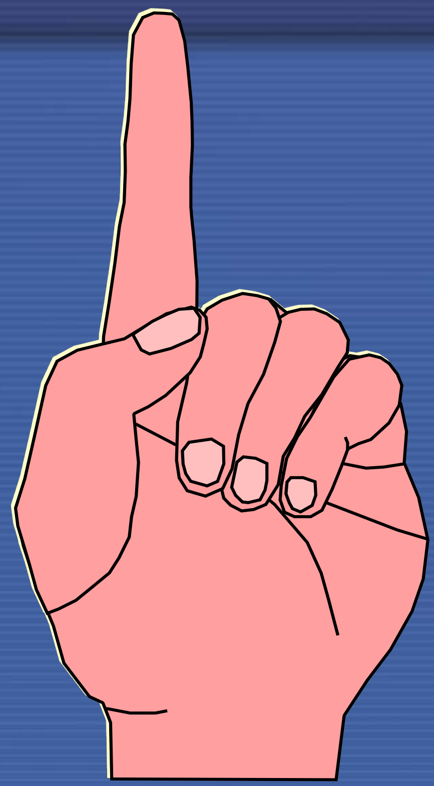
Acute Exposure Effects





AVG DOSE	DAMAGE
> 50 Sv	Death Within 2 -3 Days
> 5 Sv	Changes of death within 60 days
2Sv – 5Sv rem	Blood System Damaged
1Sv – 2Sv	Radiation Sickness / Hair Loss
250 – 500 mSv	Slight Blood Changes
2 mSv / 20 mSv	Annual Limit

Think ALARA



Please don't jiggle or play around with radioactivity

Radiotracers… no fear!
New developments make radiotracer applications safer and more reliable

- more sensitive detectors,
- lower radiation activity,
- improved radiation protection containers:
that's the look of radioisotope applications of future.

Dose rate that operating staff are exposed to in the vicinity of detector is considerably less than 1 µSv/h.
Every person on earth is exposed to a natural radiation dosage that is far higher.
In Germany, the average value of terrestrial radiation exposure is 350 µSv per year.

The consumption of 170 L. of mineral water in one year exposes us to, believe it or not, an average of 100 µSv, which is just about as much as a flight from Frankfurt to New York and back.

One CAT scan in the area of the abdomen exposes us to a dosage of 10 -25 mSv.

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Thanks for your attention!

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International Atomic Energy Agency

Further Information: nsil@iaea.org & physics@iaea.org