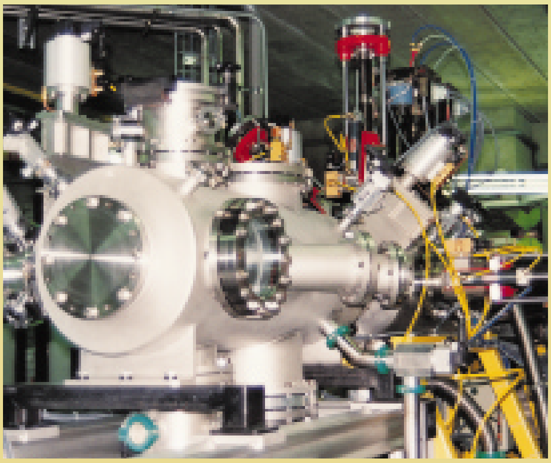

Ganil/ULP

***Heavy ions.*** *Irradiation chamber in the line located in experiment hall D1 at the Large National Heavy Ion Accelerator (Ganil, CEA-CNRS). It features a small (2.5 cm²) but very homogeneous usable beam section of ions with energies ranging from 0.1 to 95 MeV per nucleon and a widely variable flux that provides average doses of a few cGy to several thousand Gy. Another area (G4) is dedicated to the irradiation of large-size biological samples.*

# Ionizing Radiation an

*To study the effects of ionizing radiation on living matter, researchers have at their disposal a broad range of radiation sources. These sources are chosen according to either the type of radiation required, or the applications to be tested. The first of these two variables determines how the radiation interacts with the matter, and thereby its biological effects. The choice must also take into account certain experimental constraints, e.g., those coming from the path length of the radiation takes in the matter.*

## Reproducing conditions of natural, accidental or therapeutic exposure

The objectives of experimentation in radiobiology are wide-ranging. Experiments are designed to reproduce the different types of exposure to natural radiation, such as that from radon to which populations living in granite regions, and miners extracting uranium ore are particularly exposed, or solar ultraviolet radiation. Some are intended to reproduce the effects of accidental exposure: accidents with gamma ray sources, or criticity accidents. While others are designed to evaluate the effects of therapeutic exposure such as radiotherapy in the treatment of cancer or the use of lasers in medicine, for example for the correction of certain

### Electromagnetic or particulate radiation

**Electromagnetic radiation** can be either **X rays**, used for example for medical diagnosis or **gamma rays** emitted by naturally-occurring or artificially-made **radioactive** atoms. This radiation resembles light, radio waves, microwaves, or the **ultraviolet** (**UV**) rays emitted by the sun.

**«Particulate» radiation** is composed of particles charged either positively (**positrons, protons, alpha ions or heavy ions**), or negatively (**electrons**), or uncharged particles (**neutrons**). They account for most **cosmic rays**.

### Energy deposition at a microscopic scale: from less than 1 to several hundred keV/µm

Radiation loses all or part of its energy to the matter it goes through, in a discontinuous and random manner.

The level of energy transfer at a microscopic scale *(see Physical tools for studying radio-induced lesions)* is often expressed in terms of **lineal energy transfer** (**LET**). The average value of *LET* ranges from less than 1 kiloelectronvolt per micrometer (keV/µm) (1 µm = 0.001 mm) for electromagnetic radiation, to several hundred keV/µm for heavy ions. The values for neutrons cover the whole of the range.

Given the wide range of values for energy deposition for the same **dose**, the **biological effect** will vary according to the type of radiation. For example, comparing the effects of alpha and gamma rays is rather like comparing the effect on a target of a cannonball with that of buckshot. The energy transferred may be the same, but the kind of damage inflicted will be different.

Thus for alpha particles, as the dose decreases the number of hit cells decreases, but not the degree of impact on those cells, whereas for gamma rays the quantity of energy deposited per cell goes down, but not the number of cells hit.

### Rays and radioactivity

**radioactivity**: the process by which certain **(radio)nuclides**, which are unstable owing to the numbers of their nucleons (protons and neutrons) and (or) their energy state, undergo spontaneous disintegration with release of energy, generally yielding new nuclides. By this process, one or more types of radiation are emitted

**lineal energy transfer** (***LET***): energy transferred from a particle to the medium traversed per unit length. This magnitude is expressed in kiloelectronvolts per micrometer (keV/µm)

**neutron radiation**: the neutron carries no charge and so is stopped only by a nucleus. The penetration of the radiation depends on the energy of the neutrons, the *LET* of which is high. An adequate thickness of concrete, water or paraffin will stop them. Light elements will stop neutrons, because the mass of the nucleus is close to that of the neutron

**alpha radiation**: composed of helium nuclei (two protons and two neutrons), it is weakly penetrating. A sheet of paper will stop alpha particles, and they travel no further than a few tens of micrometers in biological tissues. This radiation is therefore strongly ionizing (high *LET*), because these particles lose all their energy in a short track. The hazard presented by **radionuclides** that emit alpha particles is therefore that of internal exposure

**beta radiation**: beta particles are either electrons (beta minus radioactivity) or positrons (beta plus radioactivity). They have low *LET* values and are stopped by a few meters of air, a sheet of aluminium foil, or a few millimeters of biological tissue

**gamma radiation**: composed of photons with low ionizing power (low *LET*), but highly penetrating (more than X rays used in radiodiagnosis), it can travel hundreds of meters through air. Only thick concrete or lead screen will stop it sight disorders. More fundamental research is conducted to improve understanding of how radiation acts on matter, using in particular **heavy ions** or single energy **neutrons**.

## Appropriate experimental conditions

The irradiation possibilities depend on both the source characteristics and the nature of the biological sample.

The **radiation path in the matter** is an important criterion. The path length depends on the nature and energy of the radiation. X rays, gamma rays and neutrons are able to traverse the whole body, although there is a big difference between the dose deposited at entry and the one delivered on exit. **Beta** particles travel a few millimeters, but alpha particles come to rest after only some tens of micrometers. In this case to irradiate cells in culture these have to be grown on very thin supports, e.g., made of *Mylar*, because the ions would be stopped by the plastic walls of conventional culture flasks. Likewise the usable beam section, i.e., where the radiation is homogeneous, can be only of a few square centimeters. Hence experiments on animals, can be performed with certain sources only.

The radiation sources used are of various types, from the simplest «kitchen oven» irradiators to large irradiation rooms or complex machines. The first can be used directly around the clock by biologists and does not require the operators to be highly trained. For the second the physical characteristics of the radiation are better, but they need qualified personnel, given the risk of exposure. Experiments in the largest facilities are planned several months ahead after validation by a scientific committee (*see examples in photos*).

A. Gonin/CEA

***Gamma radiation. IBL 637 irradiator installed at CEA/Fontenay-aux-Roses. Using this particularly simple apparatus biological material, here cells in their culture medium, can be irradiated with a cesium 137 source.***

### Ionizing or non-ionizing radiation

The way radiation interacts with matter defines whether it is **ionizing radiation**, i.e., of sufficient energy to ionize certain atoms of the material traversed by ejecting electrons, or **non-ionizing radiation**, such as ultraviolet rays. Ionizing radiation can be either *directly* ionizing (this is the case for beams of charged particles: electrons, protons, alpha particles and heavy ions), or *indirectly* ionizing (X and gamma photons and neutrons).

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***Alpha radiation. At the beam output from the 7 MV tandem accelerator used for the irradiation of cell cultures at the CEA Radiotoxicology Laboratory at Bruyères-le-Châtel, the energy range, from 2 to 15 MeV, affords dose rates from 0.1 to more than 300 Gy/min. In addition, actinide sources, plutonium 239 or americium 241, cover an energy range of 4 to 5 MeV with dose rates of 0.05 and 0.2 Gy/min respectively.***

### It depends on what you mean by dose...

**absorbed dose**: quantity of energy delivered at a point per unit mass (inert or living), according to the definition given by the International Commission on Radiation Units and Measurements (ICRU). It is expressed in **grays** (Gy): 1 gray corresponds to an absorbed energy of 1 joule per kilogram of matter. *The dose absorbed at the organ* is obtained by averaging the doses absorbed at different points, according to the definition of the International Commission on Radiological Protection (ICRP)

**dose rate**: intensity of radiation (energy absorbed by the matter per unit mass and per unit time). The legal unit is the gray per second (Gy/s), but the Gy/min is commonly used

**radiation efficiency**: a type of radiation is said to be more efficient than another when the effect obtained at the same dose is greater, or when the dose required to produce a given effect is smaller

**dose equivalent**: quantity of absorbed dose weighted by **quality factors** that depend on the type of radiation, according to their biological efficiency for **stochastic** effects. For example alpha rays are considered to be 20 times more harmful than gamma rays. It is expressed in **sieverts** (Sv)

**effective dose**: this parameter was introduced in attempt to evaluate damage in terms of **stochastic** effects over the whole body. Calculated from the dose equivalent for each part of the body, the effective dose takes into account the different tissue sensitivities through **weighting factors** applied for each organ. It is expressed in sieverts (Sv)

**committed dose**: «lifetime» cumulated dose received by internal exposure in 50 years for workers and adults or until the age of 70 for persons aged below 20 after initial uptake of a **radionuclide**, unless the radionuclide has disappeared in the meantime by physical decay or biological elimination