Producing Radioactive Isotopes

A more efficient approach is to artificially manufacture radioisotopes. This can be done by firing high-speed particles into the nucleus of an atom. When struck, the nucleus may absorb the particle or become unstable and emit a particle. In either case, the number of particles in the nucleus would be altered, creating an isotope. One source of high-speed particles could be a cyclotron. A cyclotron accelerates particles around a circular race track with periodic pushes of an electric field. The particles gather speed with each push, just as a child swings higher with each push on a swing. When travelling fast enough, the particles are directed off the race track and into the target.

A cyclotron works only with charged particles, however. Another source of bullets are the neutrons already shooting about inside a nuclear reactor. The neutrons normally strike the nuclei of the fuel, making them unstable and causing the nuclei to split (fission) into two large fragments and two to three "free" neutrons. These free neutrons in turn make additional nuclei unstable, causing further fission. The result is a chain reaction. Too many neutrons can lead to an uncontrolled chain reaction, releasing too much heat and perhaps causing a "meltdown." Therefore, "surplus" neutrons are usually absorbed by "control rods." However, these surplus neutrons can also be absorbed by targets of carefully selected material placed in the reactor. In this way the surplus neutrons are used to create radioactive isotopes of the materials placed in the targets.

Isotope Production Methods

There are numerous strategies for producing isotopes for research and applications.

Production with Reactors

Radioisotopes can be produced in reactors by exposing suitable target materials to the intense reactor neutron flux for an appropriate time. In light-water moderated, swimming pool-type reactors, the compact core is accessible from the top of the pool. Target materials to be irradiated are sealed in capsules, loaded in simple assemblies and lowered into predetermined core locations for irradiation. Afterwards, the irradiated targets are loaded in appropriate shielding containers and transported to hot chemistry labs for processing. In uranium, heavy-water moderated, tank-type reactors, sophisticated assemblies containing numerous target capsules are used for target irridiations. For both approaches, the quality and specific activity of the radioisotopes produced depends on both the target and the irradiation conditions.

A wide range of isotopes are made at reactors, from as light as Carbon-14 to as heavy as Mercury-203, with irridiations lasting minutes to weeks. For example, Mo-99 -- the parent to the widely used medical diagnostic radioisotope Tc-99m -- is usually produced via neutron-induced fission of targets with U-235 using a 4 to 8 day irradiation time.

The High-Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory for DOE uses highly-enriched uranium fuel elements to generate a power of 85 MW and a maximum neutron flux of about $2.6x10^{15}$ neutrons/cm^2s^2. Irradiation cycles of 26 days are used to produce isotopes such as Se-75, Cf-252, W-188/Re-188, and Ni-63.

For more information on isotope production with reactors, please click here to read this IAEA report, a "cookbook" on both the irradiation and subsequent chemical procedures to successfully make isotopes in reactors. Also visit our Isotope Reports page and More Information page. For information on particular facilities, please visit our Isotope Production Sites page.

Production via Accelerators

Accelerators are used to bombard production targets with beams of charged nuclei impinge on targets to produce a wide range range of isotopes, including many proton-rich nuclei (F-18, C-11) that are not available at reactors. Beams of protons and deuterons are primarily used, but alpha particles and heavier ion beams can also in principle be used. Possible alternatives involve bombarding a primary target to produce neutrons or photons, which them impact the production target to form the isotopes of interest. The range of particle energies and intensities vary between facilities -- 10 - 100 MeV for commercial cyclotrons dedicated for isotope production, with higher energies available at some research accelerators. For example, the Brookhaven Linac Isotope Producer (BLIP) at Brookhaven National Laboratory uses a 200 MeV, 150 microAmp proton beam from the Alternating Gradient Synchrotron to bombard samples for the production of Ge-68/Ga-68, Sr-82/Rb-82, as well as Zn-65, Mg-28, Fe-52, Rb-83. Another is the Isotope Production Facility (IPF) at Los Alamos National Lab that uses the 100 MeV, 250 microAmp proton beam from the LANSCE linac to produce Ge-68/Ga-68 and Sr-82/Rb-82, as well as smaller amounts of Al-26 and Si-32.

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