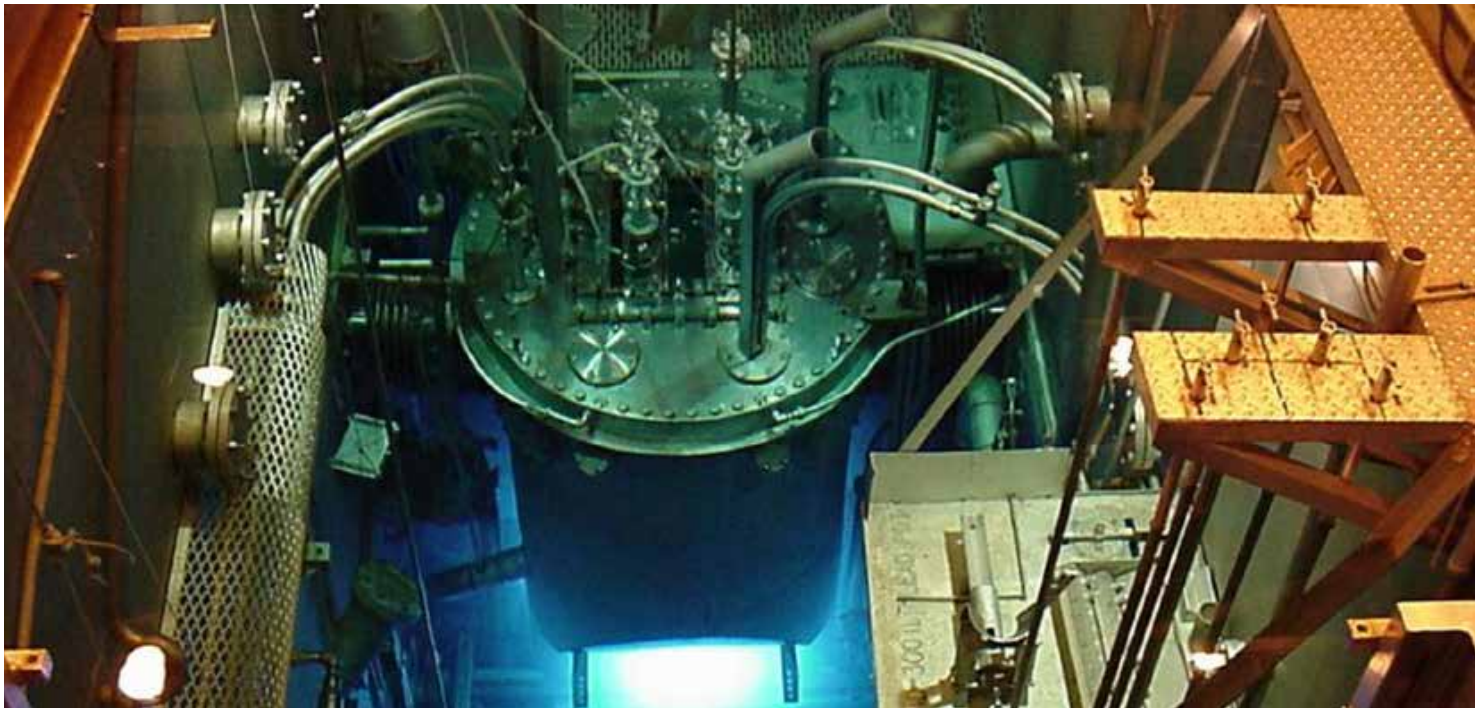
How research reactors help make medical imaging possible

By Aleksandra Peeva and Nicole Jawerth



The SAFARI-1 research reactor in operation.
(Photo: Necsa)

More than 80% of the medical imaging used each year to diagnose diseases like cancer is made possible by the pharmaceutical drugs produced, for the most part, in research reactors. These radiopharmaceuticals contain the radioisotope technetium-99m (^{99m}Tc), which comes from the radioisotope molybdenum-99 (^{99}Mo) that is primarily produced in research reactors.

"While ^{99}Mo or even ^{99}mTc can be produced using other approaches, research reactors are particularly cost-effective and well-suited to this, especially for commercial, large-scale production," said Joao Osso, Head of the IAEA's Radioisotope Products and Radiation Technology Section. "This is because they can produce large amounts of ^{99}Mo with the right characteristics that make it easy to extract ^{99m}Tc using a generator in a hospital, thereby keeping supplies of radiopharmaceuticals flowing consistently and reliably for more patients."

From reactor to patients

Research reactors are reactors that, instead of generating electricity, are primarily used to produce neutrons for other applications. These neutrons can be used for various purposes, such as to produce ^{99}Mo by irradiating uranium-235 targets.

Being a radioisotope, ^{99}Mo is an unstable atom that undergoes decay. It takes 66 hours for half of any ^{99}Mo produced to decay — this is known as its half-life. The decay product of ^{99}Mo, also called its 'daughter product', is ^{99m}Tc.

To get ^{99m}Tc, the irradiated uranium-235 targets are moved to a processing installation, usually near a research reactor, to separate ^{99}Mo from the other fission products and purify it. The purified ^{99}Mo is then transported to a production facility for ^{99}Mo /^{99m}Tc generators — devices used to safely hold, transport and chemically extract ^{99m}Tc from ^{99}Mo directly on site at a hospital or other medical facility.

Inside a typical generator, aluminium oxide containing ^{99}Mo is washed with a saline solution. The ^{99}Mo clings to the oxide, whereas the ^{99m}Tc is removed by the solution. This produces a ^{99m}Tc solution that is then used to create different radiopharmaceuticals

ready to be injected into a patient's body. Once inside the body, the small amounts of radiation released by the decaying ^{99m}Tc are detected by a special camera outside the patient's body to create medical images for diagnosing diseases.

Short half-lives, constant production

As ^{99m}Tc has a half-life of six hours, it must be used quickly after it is extracted otherwise it loses its effectiveness. With ^{99}Mo's short lifespan and ^{99m}Tc's being even shorter, they have to be constantly produced to meet global demand.

One of the major global producers of ^{99}Mo, and of other radioisotopes, is the South Africa Fundamental Atomic Research Installation (SAFARI-1), which is part of the South African Nuclear Energy Corporation (Necsa) and is the leading medical isotope-producing research reactor on the African continent. In collaboration with the radioisotope supplier, NTP Radioisotopes SOC Ltd — a subsidiary of Necsa — the SAFARI-1 reactor has become one of the world's 5 largest suppliers of ^{99}Mo and is part of the medical radioisotope supply chain for more than 50 countries worldwide. It now produces around 20% of the global ^{99}Mo demand, and the ^{99m}Tc derived from generators using SAFARI-1's ^{99}Mo is used in more than 40 hospitals and other health facilities across Africa.

"Becoming a global player in the radiochemical and radiopharmaceutical community has been a matter of implementing management systems, maintenance programmes, personnel training and strategic plans in a well-structured and controlled way," said Koos du Bruyn, Senior Manager at SAFARI-1. This has also supported the reactor's secondary use for research and education and for industry.

With the IAEA's support, SAFARI-1 has undergone continuous development and improvements since it began operation in 1965, including its conversion from high enriched uranium fuel to low enriched uranium fuel in 2009 (learn more about this kind of conversion on page 26) and its transition from high enriched to low enriched uranium targets, which was completed in 2017. These activities have helped to ensure better utilization of the reactor and its successful transition to more commercial use.

Molybdenum-99 target plate and the holder used to irradiate the plates in a research reactor.
(Photo: Necsa)

"In the 1990s, we changed our operational approach and put more emphasis on maintenance and management, including building up a team of specialized staff who are highly skilled in a range of areas. This allowed us to go from being a low-use reactor to an extremely high-use and more sustainable facility," du Bruyn said. In the nine years between 1995 and 2004, the reactor was used more than in the previous three decades combined. Then only seven years later it achieved the same result. As of 2019, SAFARI-1's use has almost quadrupled since 1995.

In the last 15 years, SAFARI-1 has operated around the clock, nearly non-stop for around 300 days each year and is expected to continue supplying ^{99}Mo until at least 2030. However, as the reactor is ageing, a new 15 to 30 MW (thermal) multipurpose research reactor (MPR) is being considered to replace it. This process will take up to ten years from the start of feasibility studies to completion.

"If a new MPR is built, it will be equipped to flexibly operate over the next 60 or more years so we can adapt to potential changes, such as fluctuations in medical isotope markets and research requirements, as well as provide South Africa and the region with a critical nuclear fuel and material testing facility," du Bruyn said.

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