Brazil looks to HALEU

By increasing its capabilities to produce high-assay low enriched uranium fuel or HALEU, Brazil is hoping to position itself for a leading role in the global nuclear industry. **Leonam dos Santos Guimarães** and **José Augusto Perrotta** examine the opportunity

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TRADITIONALLY, FUEL FOR RESEARCH REACTORS and targets for use in the production of radioisotopes are made with highly enriched uranium (HEU), that is, above 20% in the assay content uranium-235. This material has been supplied mainly by the USA and Russia from military surplus, under the International Atomic Energy Agency's (IAEA's) Nuclear Non-Proliferation Treaty safeguards. But HEU use has become subject to additional political and legal restrictions and no new HEU has been produced, which makes future supplies uncertain.

In support of non-proliferation, most IAEA Member States are committed to converting research reactor fuel and targets for radioisotope production to high-assay low-enriched uranium (HALEU) below 19.75%.

Brazilian research reactors — including the largest radioisotope producer in the country, which is IEA-R1, at the São Paulo Institute of Energy and Nuclear Research (IPEN) — have already successfully made the transition to HALEU.

HALEU's long-term availability and accessibility is a key to ensuring the continued operation of research reactors and the production of radioisotopes. Currently, the only commercial supplier available is Russia and this offers a risk to security of supply for both fuel and targets. Political considerations similar to those affecting HEU supply may also affect the future supply of HALEU at 19.75%. If no action is taken, there is a risk that the supply of this critical material will not be guaranteed for some time after 2030, according to a May 2019 report from the Euratom Supply Agency (ESA).

This presents a great opportunity for Brazil, which has already produced batches of HALEU for IEA-R1 (UF_6 with 19.75% uranium-235 enrichment). They were initially produced at the enrichment facilities of Aramar, at the Brazilian Navy Technology Center (CTMSP) in São Paulo in the early years of this past decade. More recently, in August 2017 CTMSP produced batches of HALEU for the manufacture of fuel and targets for the production of molybdenum-99, a radioisotope widely used in medicine, for the future Brazilian Multi-purpose Reactor (RMB).

CTMSP has also provided HALEU for manufacture of 19 plate-type fuel elements by IPEN for its MB-01 research reactor.

This experience makes domestic production possible as an alternative that will guarantee the future availability of HALEU for Brazil's own needs and, eventually, be available for export.

Advanced reactor opportunity

Even more importantly, several nuclear power development strands are considering the use of HALEU. New fuel concepts are emerging for small modular reactors (SMRs) and advanced reactors, and almost all consider the use of HALEU.

The demand for nuclear fuel can roughly be broken down into the following categories:

- Small modular reactors based on LWRs that mainly use UO_2 with enrichment <5%;
- Small modular reactors based on high temperature reactors that mainly use HALEU;
- Small modular reactors based on molten salt reactors that mainly use HALEU;
- Small modular reactors with sodium or lead coolant that mainly use HALEU or mixed oxides (MOX); and
- Advanced reactors with capacity > 300MWe. These are mainly fast reactors, cooled with sodium or lead. Most use MOX fuel but some use HALEU.

The lack of HALEU production capacity for these applications could delay or even completely prevent development of new types of SMR. How the nuclear industry will power the next generation of reactors and advanced commercial nuclear technologies is an important topic of discussion among industry experts. An expanded national production capacity may allow Brazil to play a global leading role.

In order to ensure a secure supply of HALEU, the current infrastructure of the nuclear fuel cycle aimed at nuclear commercial reactors using low-enriched uranium (LEU) to up to 6% — mining, processing, conversion, fuel enrichment and manufacturing — will have to be further developed and made more robust. New transport solutions will also have to be developed.

And compared with the material needed for research reactors and targets for radioisotope production, the industrial investment required in infrastructure for the production of HALEU for commercial reactors would be substantial. It is only realistic if there is sufficient demand and if prices are both high enough for sellers and acceptable to potential customers.

It is very difficult to make reliable predictions of HALEU's demand for future commercial reactors based on the information currently available.

Currently, there is no consolidated assessment of HALEU's needs, but the potential projects would imply an increasing demand for commercial reactors using this type of fuel.

According to a 2016 assessment by the Organization for Economic Cooperation and Development / Nuclear Energy Agency (OECD/NEA), up to 21GWe of SMRs could be added by 2035 in an optimistic scenario. This represents 3% of the total global installed nuclear capacity. However, the projections did not take into account the potential for further development of SMR technologies and regulatory frameworks that might lead to major changes in the nuclear power plant market. SMR designs can be based on 'traditional' LWRs or advanced reactor technology (Generation IV) such as HTRs or MSRs, or fast reactors. Many SMRs envisage longer fuel cycles or very long-life cores, which requires further enrichment of the fissile material.

The demand for HALEU for use in advanced reactors is becoming an interesting aspect of the global nuclear fuel cycle. It may also be an option for existing LWRs, in to developing safer, so-called accident-tolerant fuels.

It will probably still be some time before these developments result in significant demand for HALEU. But prototypes or lead test assemblies (LTAs) will be required in smaller volumes in the near future. If these LTA programmes are successful, the volume of HALEU needed to support reload quantities for a large long-term LWR will be significant — around 40tU per reload with 16% uranium-235 enrichment.

The US Nuclear Energy Institute assessed its national demand for HALEU in 2018. The NEI surveyed advanced reactor developers and fuel designers using HALEU to identify their annual needs by 2030. The annual demand for less than 1t of HALEU in 2018 is expected to increase to around 185t/yr of HALEU by 2030, in enrichment ranging from 13% to 19.75%.

Of course, these figures should be treated with caution, but they show that the nuclear industry may need HALEU in the short term for new developments. The expected volumes would quickly exceed the current requirements established for research reactors and other purposes such as medial isotope production. That requires investment in production infrastructure. ■

Building on 60 years in the fuel cycle

Brazil is in a unique position to develop HALEU, according to José Augusto Perrotta, RMB's technical coordinator at the Energy and Nuclear Research Institute (IPEN). IPEN is part of Brazil's National Nuclear Energy Commission (CNEN) based in São Paulo and has more than 60 years' experience working in the fuel cycle.

This work started in the 1960s with studies on obtaining and purifying uranium concentrate (yellowcake). U_3O_8 and UO_2 manufacturing technology were developed and fuel was manufactured for the subcritical RESUCO (oxide sub-critical reactor) in São Paulo.

In 1965 dispersion-based fuel technology was developed and fuels were produced for the Argonauta reactor at the Nuclear Engineering Institute (IEN) in Rio de Janeiro. These were dispersion of U_3O_8-Al with U_3O_8 powder enriched at 20% by weight imported from the USA. IPEN improved this technique and manufactured fuel reloads for its IEA-R1 reactor in the 1980s, when it was not possible to import fuels from the USA due to restrictions.

Pilot conversion plants were developed, and the material produced was used in developing enrichment technology in conjunction with the Brazilian Navy in the 1980s. Uranium recovery techniques using high purity ammonium diuranate and conversion to ammonium uranyl tricarbonate allowed the manufacture of U_3O_8 and UO_2 powder and manufacture of sintered UO_2 pellets that were used to fuel IPEN\MB-01. This zero-power critical facility was Brazil's first domestically designed and manufactured reactor, which achieved first criticality in 1988. This fuel technology was transferred by IPEN to the Brazilian Navy Technology Center in Aramar.

IPEN developed a technique to convert UF_6 to UF_4 and produce metallic uranium by magnesiothermic reduction. With this technology it was possible to further develop the powder metallurgy technique to manufacture plate-type fuels, using HALEU, including U_3Si_2-Al, UAlx-Al, UMo-Al and metallic uranium sheets.

IPEN has already produced more than 100 fuel elements for the IEA-R1 reactor, Perrotta says. In 2019, it produced 19 U_3Si_2-Al plate-type fuel elements for the IPEN/MB-01 reactor to simulate the core of the Brazilian Multi-Purpose Reactor (RMB). It can also produce UAlx-Al targets and uranium sheets that will be used by RMB in producing Mo-99.

The RMB reactor core is a 5x5 matrix, containing 23 MTR fuel elements, with two positions available for materials irradiation testing. In the heavy water reflector tank, there are positions for radioisotope production, neutron beam extraction and fuel irradiation testing. The fuel elements comprise 21 U_3Si_2-Al fuel plates, with 19.75% by weight of enrichment. This equates to 1.7kg of uranium per fuel element. The uranium targets for producing Mo-99 are UAlx-Al dispersion mini plates, with 19.75% by weight of enrichment, containing around 7.5g of uranium per mini plate. Both fuels and targets are HALEU.

RMB is expected to need 60 fuel elements per year to operate, and 1000-2000 uranium targets will be needed to produce Mo-99.

When the RMB comes online, scheduled for 2024 subject to continued funding, the reactor will contribute to the HALEU system with its use for fuels and materials irradiation testing for nuclear reactors.

IPEN is one of several institutions working in Brazil's nuclear fuel cycle that could help in producing HALEU.

Nuclear Industries of Brazil (INB) can produce yellowcake and purify it to nuclear grade for conversion to UF_6. However, it does not have a UF_6 conversion plant and is currently importing conversion services. INB operates a uranium enrichment plant, which can enrich up to 5% by weight. It has the technology to manufacture UO_2 powder and sintered UO_2 pellets, and assemble rods and fuel elements for the Angra 1 and Angra 2 PWRs.

CTMSP has a pilot plant, in the commissioning phase, for producing UF_6. It has isotopic enrichment laboratories, one that enriches up to 5% by weight and another that enriches up to 20% by weight. In December 2016, CTMSP inaugurated a new enrichment cascade to exclusively meet the needs of UF_6 at 20% to manufacture fuels and uranium targets for the RMB. It also has a laboratory for converting UF_6 to UO_2 powder and manufacturing sintered UO_2.

Combining these capacities, Brazil has the knowledge, technology and infrastructure to manufacture HALEU fuels for research reactors and to expand it for small modular reactors in the future. ■