World Nuclear Association Annual Symposium
5-7 September 2001 - London

Modular Helium Reactor Technology: Making Nuclear Waste Transmutation Practical

Francesco Venneri, Mike Fikani, Alan Baxter, Carmelo Rodriguez

To meet world power demands, the use of nuclear power must continue to grow as a safe, emission free, reliable, and economical source of energy. However, at the rate waste is produced by the existing fleet of nuclear reactors in the U.S., new repository capacity equal to the statutory capacity of the yet-to-open Yucca Mountain would be needed about every 20 years. Therefore, the ability to expand, or even maintain the nuclear power capacity in the U.S. will be limited, unless either additional disposal capacity is identified, or waste volume, proliferation risk, and toxicity dose are significantly reduced.

Based on this motivation, methods to reduce nuclear waste volume and toxicity have been proposed that involve a large fleet of systems using liquid metal-cooled, fast breeder reactor technologies. However, the use of these technologies has been questioned. Critics argue that significant amounts of new waste and ample opportunities for plutonium diversion would be created, that estimated deployment times are too long to be of any benefit, and that estimated costs are prohibitive.

A far preferable option for the destruction (transmutation) of waste from reactors is based on the use of thermal Modular Helium Reactor systems (MHRs). An essential feature of the MHR transmuter is the use of ceramic-coated fuel particles that are strong and highly resistant to irradiation, thereby allowing very extensive destruction levels ("deep burn") in one pass. The ceramic coatings are also durable and impervious to moisture for long periods of time, providing an attractive residual waste form. In addition, the fixed moderator (graphite) and neutronically transparent coolant (helium) provide inherent safety features for the destruction of nuclear waste that cannot be replicated in any other design.

- Early plutonium destruction tests and recent engineering developments in the use of modular helium reactor technologies indicate that transmutation of nuclear waste in these systems could be practical and economically viable in the near term.

- Waste destruction would be performed rapidly without the need for multiple reprocessing of large amounts of weapons-usable plutonium or other fissionable materials, thus eliminating long-term proliferation risks associated with repeated handling of plutonium, and limiting the generation of secondary waste.

© World Nuclear Association 2001

- The MHR technology could be available for deployment in a short time, thus making a positive contribution to the solution of waste treatment in a timely manner. Credibility for this is strengthened by two considerations: (1) utilities in the U.S. and abroad are considering MHR technologies for the next generation of nuclear reactors, and (2) MHR technologies are currently being developed in Russia for the destruction of weapons-grade materials while generating electric power.

In the Deep Burn Transmutation, MHR-based, the destruction of reactor waste is logically carried through one burn-up cycle, achieving virtually complete destruction of proliferation materials, and roughly 95% destruction of all transuranic waste. While it would be possible to reduce the residual waste inventory further through repeated processing and recycle in the MHR system, there is little advantage in doing so since: (1) virtually all proliferation materials would already be destroyed, and (2) more high level secondary waste is produced with each additional reprocessing stage.

A brief outline of the Deep Burn, MHR-based, Transmutation concept

The transmutation of nuclear waste involves treating reactor spent fuel and bombarding it with "customized" neutron radiation to fundamentally change its characteristics and make it significantly easier to dispose of.

- The initial treatment of nuclear waste is the traditional and well proven UREX (Uranium Extraction) process, extensively described in previous documents, including the DOE-sponsored transmutation roadmap.

- In the MHR nuclear waste destruction concept, the thermally fissile component of the nuclear waste (made into "driver" fuel) fissions and generates the neutrons necessary to achieve the conversion of the thermally non-fissile component into fissionable isotopes ("transmutation" fuel) and their subsequent destruction.

- The two fuels are fabricated with the same ceramic coated particle technology already developed for commercial MHR systems, sized to favour immediate fission (driver fuel), or absorption-followed-by-fission (transmutation fuel).

- Contrary to some perceptions, in the right environment thermal neutrons are perfectly capable of transmuting both major and minor actinides: Cross sections and specific destruction rates are large.

- 80% of the nuclear waste destruction is done in MHR reactors (critical systems) of very similar design to systems currently proposed for high efficiency energy production (including "prismatic" and "pebble bed" variants). This extensive transmutation is achieved using the principle that "fresh fuel burns old fuel" in cores that are zoned with fuels of different ages.

- After the neutron self-generating ability of the driver fuel is exhausted, the transmutation fuel is extracted from the MHR critical system and is irradiated in a second-stage MHR system without further reprocessing, thereby avoiding the problems associated with the handling of volatile actinides (Americium and Curium).

- The extra neutrons required to implement the second transmutation stage (where 20% of the overall destruction is accomplished) could be generated by an accelerator-driven spallation target housed in the center of MHR subcritical cores. Alternatively, a large fraction of the necessary neutrons could be obtained using 20% enriched uranium, thereby substantially reducing the use of subcritical systems.

- As the final residual wasteform, ceramic-coated exhausted fuel is very durable and remains impervious to moisture well beyond the life of metal containers currently contemplated for spent fuel disposal.

© World Nuclear Association 2001