ALFRED PROLIFERATION RESISTANCE FEATURES

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INTRODUCTION: The Advanced Lead Fast Reactor Demonstrator (ALFRED) project was conceived as a thorough demonstration program for the viability of the lead-cooled fast reactor (LFR) technology. Along with its indubitable advantages regarding level of safety, the reactor provides also key features for the non-proliferation.

1. OVERVIEW ON THE TOPIC

Eight technology goals have been defined for Generation IV systems [1] in four important areas:

- sustainability;
- economics;
- safety and reliability;
- proliferation resistance and physical protection.

Along with wide investigations regarding the safety, assessing the inherent proliferation resistance characteristics of nuclear systems [6] has received an increased attention at international level.

Some advanced reactor designs may offer non-proliferation advantages by reducing the plutonium production, limiting access to the reactor core, reusing the spent fuel and decreasing the need for uranium enrichment, or simply by requiring less fuel.

Most advanced reactors use fuel that is not weapons-usable. Many advanced reactor types produce waste that is less suitable for weapons production or require complex processes to extract fissile materials, adding by this a layer of proliferation resistance [6]. For instance, plutonium in spent fuel could be used for weapons only with using a reprocessing facility. As long as safeguards and verification measures remain robust, many designs are fairly proliferation resistant.

2. ALFRED AND THE NON-PROLIFERATION ISSUE

The Advanced Lead-cooled Fast Reactor European Demonstrator (ALFRED) project [3] is a key element for the demonstration and development of lead-cooled fast neutron (LFR) reactors. The project implementation is supported by FALCON (Fostering ALFRED Construction) Consortium, that consists of three organization members: Ansaldo Nucleare -Italy, ENEA -Italy and Institute for Nuclear Research (RATEN ICN) -Romania.

LFR technology leverages on the specific lead properties [2] such as:

- low neutron-moderating and -absorption capacity that is suitable for accommodating a fast neutron spectrum and retaining flexibility in fuel cycle services (e.g. burning minor actinides);
- chemical properties that make it substantially inert to water, air and the fuel in conjunction with its boiling temperature (higher than 1700 ^{0}C) that allow safe and efficient reactor operation at low pressure eliminating accidental scenarios with a high energy discharge to the environment in case of a leakage involving the reactor coolant boundary;
- good thermal capacity and natural circulation capability for mitigating thermal transients;
- retention capabilities of volatile fission products (e.g. cesium and iodine) in case of core degradation thus reducing the source term.

Use of lead brings some specific challenges, for instance, lead is opaque and toxic, necessitating specific operational and maintenance procedures and technologies, and its high melting temperature (roughly 327 ^{0}C) [2] requires provisions to maintain its liquid state during operation. Moreover, considering the lead tendency for corrosion and erosion [2], mitigation means through material passivation, coatings and oxygen control are needed.

ALFRED has all the components of Reactor Coolant System (RCS) located inside the Reactor Vessel (RV) providing for a compact configuration (see FIG 1) [5]. The RV is additionally surrounded by an external safety vessel (SV) to collect potential lead leaks through the reactor vessel, while ensuring a heat removal flow path inside the pool.

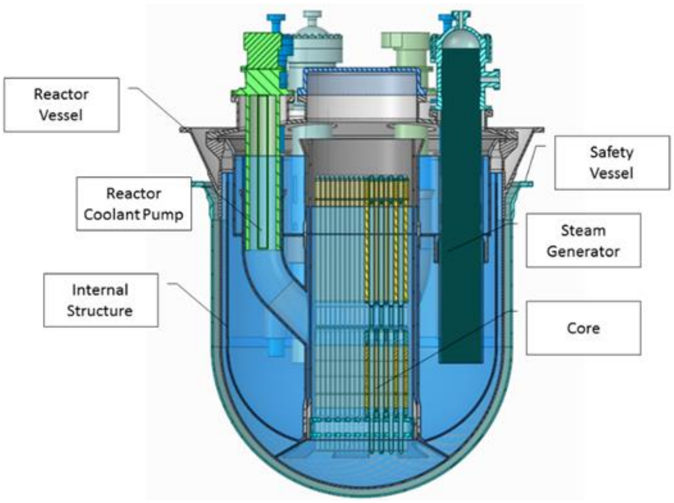

FIG 1. ALFRED section view [4]

The core provides for two independent and redundant shutdown systems based on diverse actuation principles as well as dummy positions. The core [4] is composed of wrapped sub-assemblies placed in a hexagonal lattice that includes:

- fuel assemblies (FA) composed of rod bundles containing mixed-oxide (MOX) fuel with a fraction of plutonium higher than 20 wt% (20.5 wt% in the inner region made of 56 FAs, and 26.2 wt% in the outer region with 78 FAs);
- dummy assemblies (102 dummy assemblies disposed into two external layers);
- control assemblies and shutdown devices for managing reactivity in normal and accident conditions. The control assemblies (12 control rods) are inserted from the bottom of the core and are based on bundles of absorber rods that can operate either actively or passively by buoyancy. The safety devices (4 devices) are positioned below the active region of the core and they can operate both actively and passively.

The positioning of the assemblies in the core is realized by a spike in the foot, which engages the lower core plate. Differentiated spikes can prevent the possibility of loading errors (e.g, fuel assemblies in the place of absorber assemblies) by design. A helium gap separates the pellets from the AIM1 cladding (a swelling-optimized variant of the 15–15 Ti class austenitic steels) designed to withstand the irradiation damaging associated to the design burnup and a maximum local temperature of 600 °C. The FAs are extended above the lead-free surface to simplify fuel handling during loading/unloading. The MOX fuel pellets are hollowed to decrease the thermal gradient and mitigate the maximum fuel temperature while accommodating the fuel swelling expected at the design burnup of 100 MWd/kgHM.

To overcome challenges related to lead intrinsic opacity, all core and reactor coolant system components [4], [5] are designed to be extractable so that the inspection and maintenance operations can be performed.

The proliferation resistance [6] is achieved by a combination of the following:

- Intrinsic features of the nuclear energy system (i.e., technology and design features);
- Extrinsic measures (e.g., organizational measures and international safeguards).

In ALFRED, the nuclear material is present in fuel-related items only, and therefore, the potential targets for diversion are the entire fuel assemblies (fresh and spent) or the active parts of the fuel assemblies (fresh and spent). No dismantling activities of the active part of the fuel assemblies are foreseen on site. The upper part of the fuel assemblies extends above the level of the coolant and can be continuously monitored by cameras, a relevant feature for implementation of safeguards.

ALFRED design [4] incorporates several features to address non-proliferation [7] concerns, starting with ensuring that plutonium-239 is produced within the core with a higher proportion of other plutonium isotopes (no plutonium production in a blanket assembly).

In the efforts to investigate the reactor proliferation resistance and physical protection (PR&PP) [6], an analysis of the possible proliferation barriers has been conducted by RATEN ICN experts. Following the analysis, it was determined that the non-proliferation key features of ALFRED are related to the following:

- **Fuel Cycle and Material Choice**
  - The reactor uses MOX fuel -no need for an enrichment phase, which eliminates a proliferation-sensitive fuel cycle technology.
  - *Closed fuel cycle*: The closed fuel cycle option foresees a reprocessing phase with homogeneous recycling of all actinides (i.e., no separation between U, Pu and MAs). The closed cycle minimizes the amount of spent fuel that needs to be stored, reducing the potential for diversion of fissile material. Is possible to co-locate reprocessing facilities with the reactor to further reduce the need for off-site material movement. Still, even if the reduced transport of nuclear material is an advantage, more nuclear material targets on site may be a disadvantage.
- **Fuel Fabrication**

  MOX fuel will be imported from a suitable foreign factory. Improvements in operation protocols for nuclear material handling and transportation may be implemented. The activity regarding the import and transport of fuel will have to be authorized by the Romanian Regulatory Body.
- **Fuel Handling**

  Fuel assemblies are large & difficult to dismantle. No assembly disassembling is foreseen onsite. The fuel is typically removed as individual assemblies. FAs handling between the outside and inside of the RCS will be carried out by adopting a specifically designed container that guarantees the transfer of both fresh and irradiated fuel while immersed in an inventory of lead and the preheating of fresh fuel assemblies before dipping as well as the passive cooling of the spent FAs through natural convection of lead inside the container and containment atmosphere. Spent FAs are transferred in a special sealed container, to cope with the possibility of damaged fuel. A dedicated experimental facility will be implemented at RATEN ICN to test the fuel handling feasibility.
- **Reactor Design and Operation**
  - *Passive safety features*: natural circulation in DHR and ALFRED's inherent safety simplifies the reactor design and reduces the need for operator interventions, maintaining safety operations even in adverse conditions.
  - *Limited access to fissile materials*: The reactor's design and operational protocols contribute to prevent unauthorized access or extraction of fissile materials.

    The compact reactor design eliminates possibility of removing the core because it is covered by many components. During operation the FAs are continuously monitored thanks to their extension above the lead-free level. The large size of the fuel assemblies can be handled only with the availability of dedicated specialized plant equipment and requires a high level of operator skill and training. All operations are performed remotely because of the high radiation level around the fuel elements that create a substantial barrier for access by wrong persons.

Off-line refueling would be required at about 5 years. The diversion of fresh/spent fuel assemblies from the reactor core would only be possible during refueling activities, and since there is no direct exit from the reactor core area, the possible diversion path will go through the spent fuel storage facility. Still since registration and recording of unloaded and loaded FAs during refuelling will be performed, the nuclear safeguards system would most likely be able to detect any abnormal movement of fuel assemblies.

— **Use of Lead**

Because of its opacity, lead prevents verification of core fuel by direct visual inspection, but other techniques could be used.

— **Safeguards**

- *Design integrated safeguards*: The reactor incorporates features that facilitate safeguards, such as sealed fuel assemblies. The system provides for the installation of measurement instruments and surveillance equipment likely to be needed for verification.
- *National safeguards framework:* Besides the general norms for the control of safeguards in the nuclear field, and the detailed list of materials, devices, equipment and information relevant to the proliferation, there were issued norms on authorization procedures for activities involving materials, devices, equipment and related information, relevant to the proliferation of nuclear weapons and other nuclear explosive devices.
- *International safeguards*: ALFRED is developed to comply with IAEA safeguards, enabling effective verification and transparency of compliance with non-proliferation treaties.

3. CONCLUSIONS

Implementing a new innovative technology requires sustained efforts, on many levels. The new innovative reactor designs should comply with GIF objectives, and dedicated efforts should be directed for achieving the proliferation resistance. The investigation of non-proliferation inherent features of the ALFRED reactor is at the beginning, the future efforts aiming at performing an initial evaluation of the reactor proliferation resistance.

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