TRANSFER CASK FOR EXTRACTING THE FUEL ASSEMBLIES FROM THE ALFRED REACTOR

MUGUREL PETRIŞOR UNGUREANU, IONUȚ DOBRIN, MARIA CRISTINA RĂDULESCU
Institute for Nuclear Research (RATEN ICN) Piteşti, Romania
e-mail: mugurel.ungureanu@nuclear.ro

Abstract

In order to assure the world sustainable development and to support increasing energy consumption due to population growth, it is necessary to increase the electricity production share of clean, safe, reliable and economical energy sources. The nuclear energy could have a major role in the production of sustainable energy with low greenhouse gases emissions. In this context, worldwide cooperation efforts were intensified for the development of future nuclear energy systems. Among the Gen IV nuclear systems concepts, Lead-cooled Fast Reactor (LFR) represents one of the most promising solutions by providing several advantages, the most representative being the simplicity in design, security and reliability in operation. ALFRED demonstrator is a prototype for a competitive commercial SMR based on LFR technology and will serve as an intermediate step to address licensing challenges and lack of nuclear operational experience. The research infrastructure to be developed as support for ALFRED includes six auxiliary installations that will cover all the aspects competing with the LFR technology. Hands-ON, is one of these experimental installations; it will include a part of the active zone simulated at real scale, containing fuel and reflector assemblies, and will demonstrate the fuel handling capability. A special interest presents fuel assembly extraction from the active zone and its introduction into a transfer cask. In the paper, a concept of transfer cask is presented, the technical performances and advantages of its use being exposed.

Keywords: *ALFRED, Hands-ON installation, LFR, fuel assembly, transfer cask*

Introduction

Romania enrolled from the early stages (2006) in European Consortium working to develop the European Lead Fast Reactor, GenIV project.

In 2011, a Memorandum of Understanding was signed by Romanian Government defining national availability to host ALFRED, LFR demonstrator. The support activities for ALFRED demonstrator construction in Romania are developed by the FALCON Consortium (Fostering ALfred CONstruction) including ANSALDO Nucleare (Italy), ENEA Bologna (Italy) and RATEN ICN Pite□ti (Romania) as partners. ALFRED construction follows to demonstrate the technical viability and economics of LFR; performing a key step towards LFR SMR is also envisioned.

The experimental research infrastructure to be built as licensing and RDI support for ALFRED demonstrator is characterized by a high complexity, intended for technological development, the results being directly applicable in the LFR technology based on a fast spectrum of neutrons and cooling with pure molten lead. The results obtained will have an essential impact for technological transfer through direct implementation in LFR technology.

ALFRED experimental infrastructure includes six large installations, as follows:

- ATHENA, large pool to test the main components in different thermal hydraulics regimes;
- ChemLab, lab coupled with ATHENA, lead and cover gas chemistry;
- HELENA2, loop type facility to test components and equipment in relevant thermal-hydraulic conditions, in particular, the ALFRED hottest fuel assembly;
- ELF, large scale pool-type facility, to test the endurance and reliability under both forced circulation and natural circulation regimes;
- Hands-ON, pool type experimental facility, to demonstrate the fuel handling of fuel assemblies;
- Meltin'Pot, set of facilities to investigate the fuel-coolant interaction, fuel dispersion and relocation in the coolant resulting from a severe accidental scenario, retention of fission products in lead and/or migration in cover gas, retention in lead of Po isotopes and influence of a gas/steam trapping on its migration.

Hands-On is a pool-type installation, which uses pure lead and can host fuel assemblies similar to those used in the ALFRED reactor. As part of routine maintenance procedures, core and system components are replaced. In these phases, activated materials are moved back and forth from the reactor to designated shielded regions, necessitating the use of suitable equipment and methods that must be tested before being applied to any reactor that is currently in operation, the facility being equipped with all the necessary devices for fuel assembly transfer operations.

By including the Hands-ON installation in the ALFRED demonstrator research infrastructure, several objectives were targeted, namely:
▪ 1:1 scale testing of the nuclear fuel assemblies handling, the initial tests taking place in the air, later moving to the tests performed in molten lead;
▪ demonstration of the ability to control the loading, unloading and repositioning of the fuel assemblies, including their transfer in the transfer cask and further, outside the active area, in the support of the transfer cask;
▪ based on the data obtained regarding the maneuverability and repeatability of fuel assemblies loading-unloading operations, nuclear fuel handling procedures will be drawn up for ALFRED demonstrator and LFR technology, for all maneuverability situations.

Hands-ON experimental installation

The Hands-ON facility is designed to simulate a part of the major system using dummy parts in order to evaluate and assess the dependability of handling equipment and practices. Using pure lead, Hands-ON is an experimental facility resembling a pool (see Fig. 1). The facility's goal is to imitate how sub-assemblies from the core of a pool-type LFR handle fuel. The installation has the capacity to house mock-ups of fuel assemblies, absorber assemblies, and dummy assemblies that are the same size as target LFRs, most notably ALFRED. All the equipment required for processing them is present in the facility.

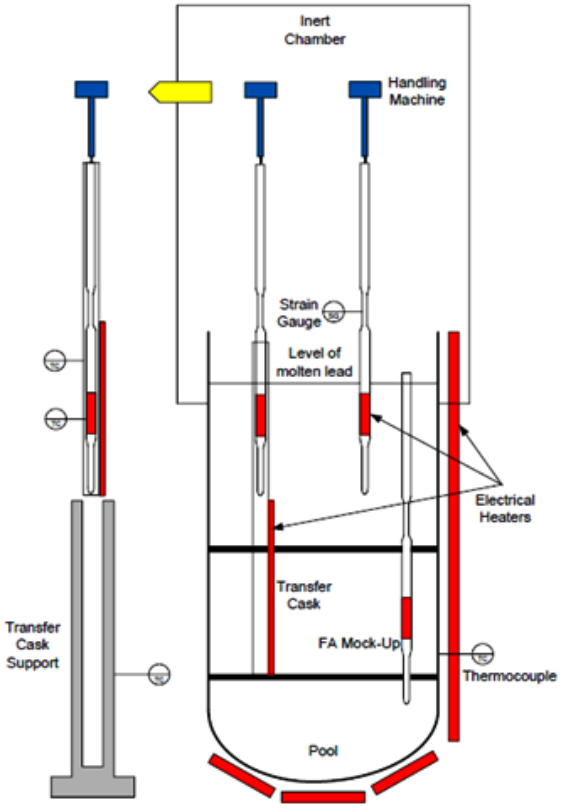


Fig. 1. Main components of the Hands-ON facility

The facility will consist of two parts:
▪ a lead vessel kept in shutdown mode that will house, in its initial layout, a full-scale simulator of a sector of the ALFRED core including fuel, control, and shield assemblies as well as all surrounding support and restraint structures to represent the handling target, and
▪ a mock-up of the handling machine that includes all the related transfer elements needed to replicate the exact conditions.

In accordance with the requirement to ensure protection for the workers, people, and environment in all phases of the ALFRED life-cycle, the ability to assess the design and associated operating procedures as well as off-normal operations for the fuel handling system will permit to address and overcome all current uncertainties related to the handling of irradiated fuel.

Fuel assemblies transfer cask

The loading/unloading machine has the role of extracting a given fuel assembly from the current location and moving it to a free location or vice versa, from the supply area to the destination location, as well as transferring the spent fuel to the intermediate storage facility. The assemblies, depending on their destination, can be fuel assemblies, reflector assemblies, assemblies containing control bars or security bars. Due to the identical geometric structure, all these types of cassettes are handled in a similar way by the fuel handling machine.

The fresh fuel assembly must be brought from the fuel storage and inserted into the active area without being accompanied by lead oxidation. Also, extracting a spent fuel assembly and transferring it to the spent fuel storage pool must avoid the formation of lead oxides in the reactor pool. Due to this strict requirement, in the real situation, fuel handling will be done by inserting the fuel assembly into a sealed container.

The transfer cask should have the necessary dimensions to accommodate inside it a fuel assembly at the actual dimensions corresponding to ALFRED demonstration reactor core and will be equipped with electric heaters capable of maintaining the lead in a liquid state during handling operations. The cask will be closed and sealed before being extracted from the pool and placed in the inert room, in order to avoid the lead oxidation, as well as the release of lead vapors into the room’s atmosphere. After it will be extracted outside the inert chamber, the cask will be placed in a special support in a vertical position.

Hands-ON will include a sector of the active zone simulated at real scale, containing fuel assemblies and simulated control-command systems. In the Hands-ON experimental facility, the structure of the active zone will contain 6 fuel assemblies identical to those used for ALFRED reactor, a cassette of absorbent material placed centrally, surrounded by 2 rows of reflector assemblies. The cassettes will be extracted vertically and repositioned in the active area. Above the active area there will be a space for the extracted box of 8-10 m, to which is added a maneuvering space for the loading/unloading machine. The structure will contain all the fasteners of the assemblies. The pool will have 1.4 m internal diameter and a depth of about 10 m, to simulate on a 1:1 scale the situation in ALFRED, with a view to a real simulation of the cassette’s extraction from the reactor.

The transfer cask will be designed so that, when extracting a fuel assembly, it is necessary to remove 6 assemblies located around the one to be extracted. To extract a fuel assembly, a sequence of steps takes place, as follows:
- identify the fuel assembly that must be extracted from the active area (Fig. 2a);
- lateral movement of the 6 dummy assemblies in an external support, to ensure a free area necessary for handling the transfer cask (Fig. 2b);
- insertion of the transfer cask over the fuel assembly through the upper part, being handled by the fuel handling machine. The container is provided with 3 spikes at the bottom to ensure stability when it reaches the lower grid (Fig. 2c);
- extraction of the container-fuel assembly with the help of the fuel handling machine and its transfer to the inert chamber (Fig. 2d);
- relocation of the 6 dummy assemblies in their initial places (Fig. 2e);
- introduction of a new fuel assembly in the vacant place (Fig. 2f).

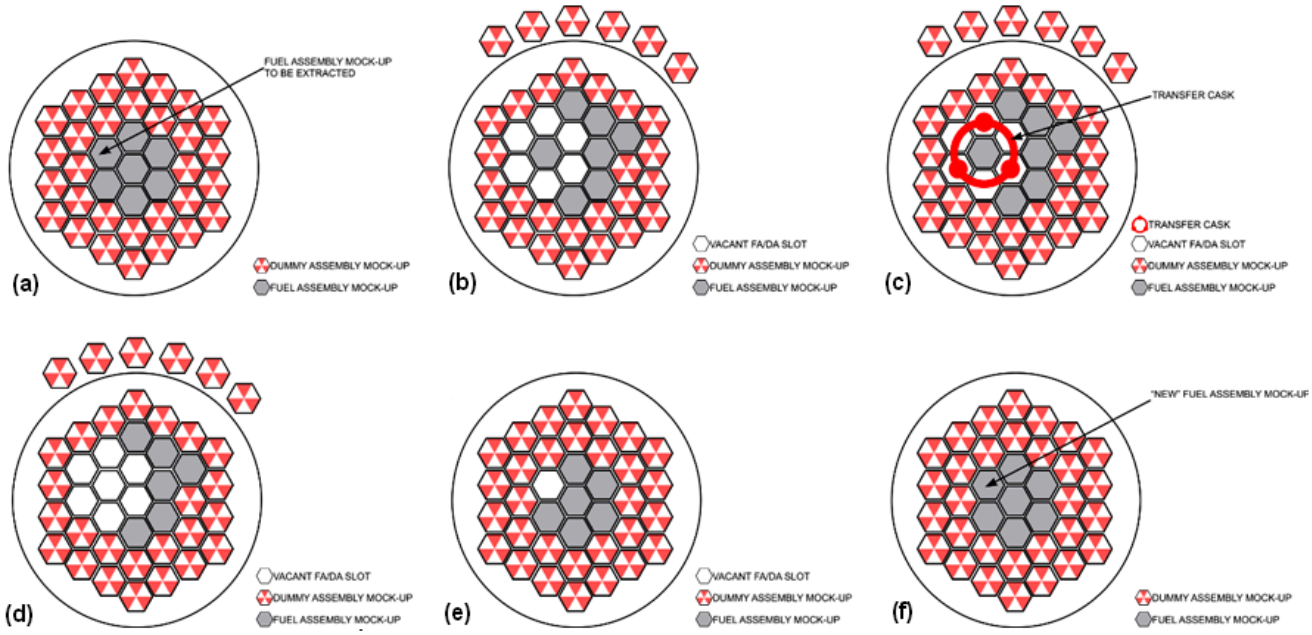


Fig. 2. Stages of replacing the fuel assembly

Description of the transfer cask

The main components of the transfer cask (Fig. 3.) are:
- the inlet valve, positioned in the lower part of the cask, with the role of allowing the introduction of the fuel assembly, as well as with the role of sealing;

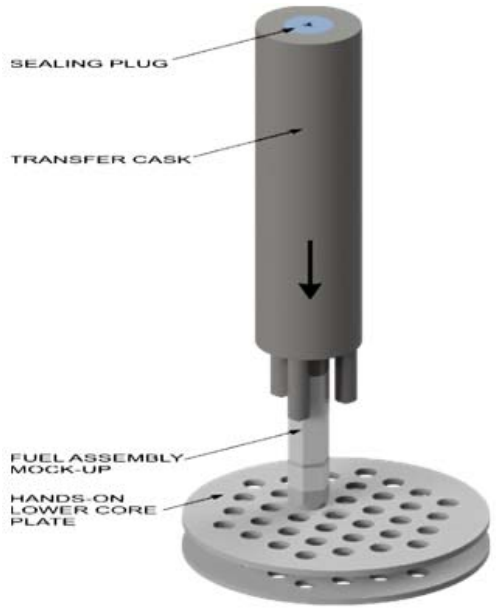


Fig. 3. Transfer cask

- sealing plug located in the upper section of the cask, provided with a gripping mechanism with claws, similar to the channel closing plug mechanism used in CANDU nuclear power plants;
- the body of the cask, made of stainless steel, provided at the bottom with 3 spikes identical to those of a fuel assembly, to ensure stability when the transfer cask is inserted into the lower base plate.

The inlet valve and the sealing plug have the role of avoiding the oxidation of lead, as well as the release of lead vapors into the room atmosphere.

During the process of loading the fuel assembly into the transfer cask, a series of maneuvers must be performed:
- the transfer cask moves, actuated by the fuel handling machine, on top of the assemblies, up to the assembly to be extracted, without the sealing plug mounted. The upper part of the transfer cask is provided with a cutout similar to that of a fuel assembly and an additional cutout, to maintain equal pressure inside and outside the transfer cask. When it is placed exactly next to the fuel assembly to be extracted, the fuel handling machine starts the operation of lowering the transfer cask (Fig. 4).

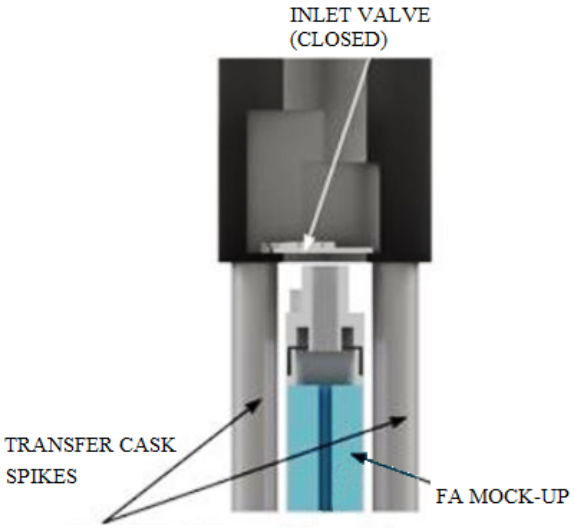


Fig. 4. Transfer cask above the fuel assembly

- when the lower part of the transfer cask touches the fuel assembly, the inlet valve starts to open under the action of the fuel assembly, thus allowing the introduction of the fuel assembly into the transfer cask (Fig. 5).



Fig. 5. Sealing valve open

- after the valve has opened, the fuel handling machine starts the slow lowering of the cask until it is fixed in the lower grid by means of the 3 cask fixing spikes (Fig. 6).



Fig. 6. Transfer cask fixed in the lower grid

- to insert completely the fuel assembly, after the transfer cask is fixed in the lower fixing grid, the fuel handling machine is disconnected from the transfer cask and connected to the fuel assembly by raising it until it exceeds the height of the intake valve.

After the inlet valve returns to the closed position, the fuel assembly is left down, so that it rests in the valve, locking it in the closed position, achieving in this way the sealing in the lower area (Fig. 7).



Fig. 7. The fuel assembly completely inserted into the cask

After the fuel assembly is completely inserted into the transfer cask, the fuel handling machine closes it in the upper part with the sealing plug, thus achieving complete sealing of the container.

To move the transfer cask from the Hands-ON pool to the inert chamber, the fuel handling machine connects to the sealing plug in this way.

Discussions on the results

Extracting a fuel assembly is an activity that involves a series of laborious, high-precision operations.

Through this constructive solution of transfer cask, it is required to move from the Hands-ON pool a minimum number of fuel assemblies around the one to be extracted, as it is necessary that only 6 fuel assemblies be moved outside the Hands-ON pool, substantially simplifying the complexity and number of operations performed in the extraction process.

The transfer cask design is relatively simple, reducing the possibility of unwanted events occurring during extraction.

This technical solution solves the problem of lead oxidation in the transfer cask, as long as it being sealed in the extremities before moving from the Hands-ON pool to the inert chamber, by means of the shut-off valve and the shut-off plug.

Conclusions

The chosen technical solution represents a theoretical study that can be improved as more details are known about the existing conditions in the active area and the final configuration of the fuel assemblies.

Throughout the transfer cask design process, it will be considered that during the operations of loading, unloading and repositioning the assemblies in the ALFRED's active area, reliability and safety in operation will be decisive in choosing the technical solution.

References

[1] Constantin, M. (2019) "PRO ALFRED-Report on the conceptual definition of the Hands-ON installation; WP1-L1.4", INR internal report, RI-12285, Institute for Nuclear Research Pitesti, Romania (in Romanian).

[2] Diaconu, D., Păunoiu, C., Toma, A., Turcu, I., Constantin, M., Nițoi, M., Gugiu, D. (2020) "PRO ALFRED-ALFRED White Book; WP7-L7.9", INR internal report, RI-12647, Institute for Nuclear Research Pitesti, Romania (in Romanian).