ALFRED PROLIFERATION RESISTANCE FEATURES

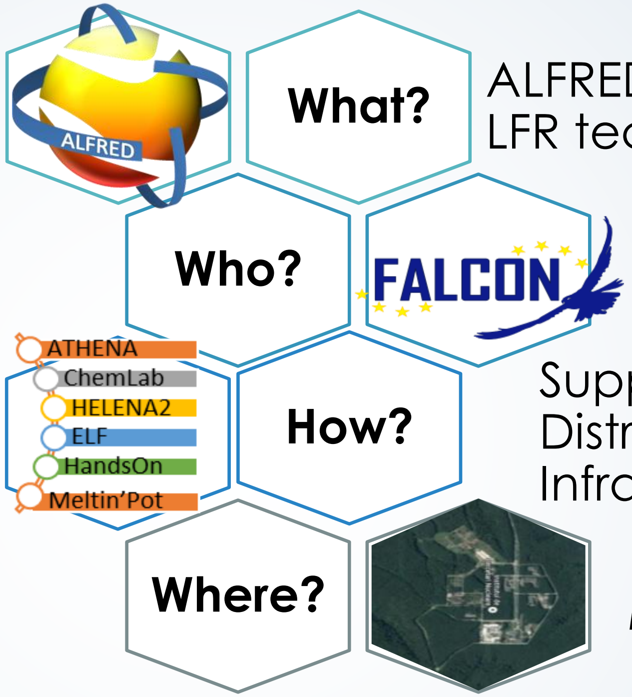
Dr. Mirela NITOI (RATEN ICN)

LFR in Romania

Deployment of demonstrator reactors - important step toward the commercial stage for GenIV systems

Deployment of ALFRED

- prove the advantages of LFR as a technology fulfilling the expectations for Gen-IV nuclear energy systems
- support in the long-term the safe and sustainable operation of future LFR plants



ALFRED is the ETDR for the LFR technology

Supported through a Distributed Research Infrastructure

Mioveni, Romania

Advanced Lead Fast Reactor European Demonstrator

- a design with increased safety and sustainability;
- a key facility for testing and qualifying in a relevant environment new structural materials and nuclear fuels, as well as innovative components and systems;
- an opportunity to improve the knowledge, competences and skills in a comprehensive and well-structured framework, on all operational aspects of LFR technology.

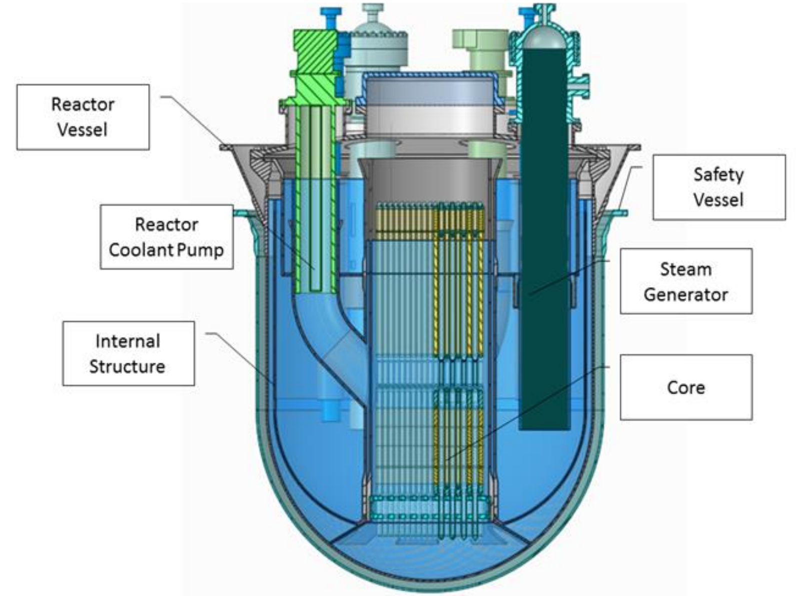
Design

- leveraging on advantages of using lead as coolant
- pool configuration, MOX fuel, 300MWt
- very compact design,
- SGs directly installed inside the RV with a great reduction of the complexity of the primary system,
- no primary pipes to be considered in a LOCA
- High retention of FPs in the lead in case of core degradation, thus reducing the source term
- High boiling T of Pb and low vapor pressure – great safety margins

-passive decay heat removal
-two independent and redundant shutdown systems (diverse actuation principles)

- control rods, bellow the core, passively inserted by buoyancy for SCRAM
- safety roads (only for SCRAM), above the core, inserted by pneumatic actuation, forced insertion by tungsten ballast

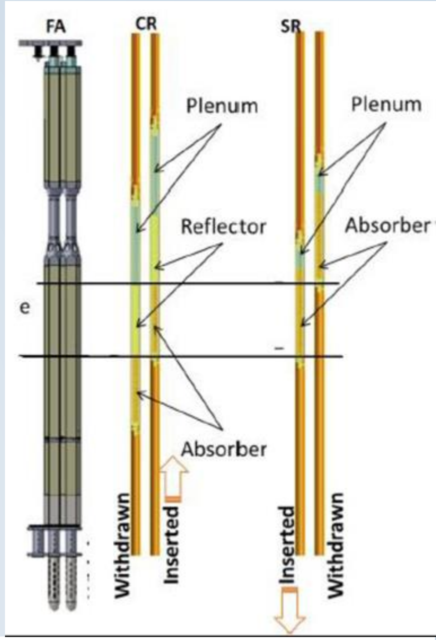
Parameter	Value
Reactor type	Lead cooled fast reactor
Primary system configuration	Pool type
Power conversion system	Rankine
Reactor vessel dimensions	
RV inner diameter	8.3 m
RV wall thickness	0.13 m
RV Height	10.0 m
SG dimensions	
SG total Height	10.41 m
SG Diameter (flange)	1.75 m
Fuel and core	
Fuel type	MOX
FA configuration	Hexagonal, closed
Fuel pin bundle	Hexagonal, grid-supported
Primary coolant	
Type	Lead
Pressure (cover gas)	0.1 MPa
Inventory	3640 tons
Secondary coolant	
Type	Water

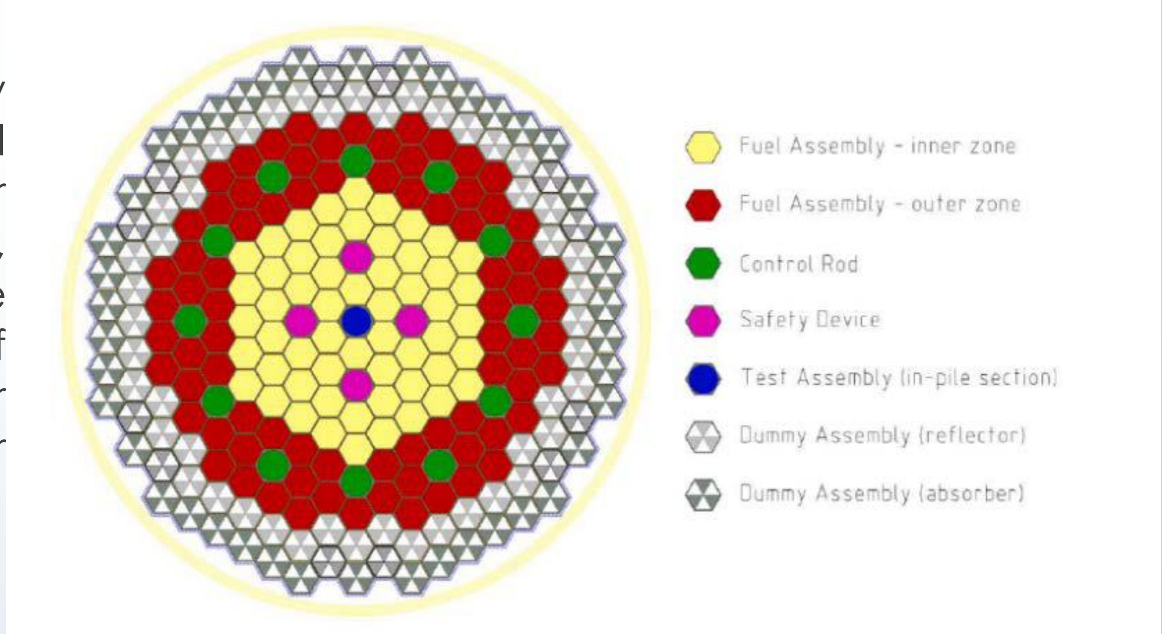


Core Configuration

- *fuel assemblies* (FA) -134 composed of rod bundles containing MOX fuel with different concentrations by weight of Pu (20.5 wt% in the inner region -56 FAs, and 26.2 wt% in the outer region with 78 FAs);
- *dummy assemblies* (102 dummy assemblies disposed into two external layers); The former works as a reflector in order to maximize neutron flux. The latter works as a shield in order to minimize radiation damage of structural materials and to limit it below 2 dpa for their design lifetime.
- *control assemblies* and *shutdown devices* for reactivity control in normal and accident conditions. The control assemblies (12 control rods) are placed in the outer active region and inserted from the bottom of the core, controlled by an electromagnetic switch for passive action, exploiting buoyancy force -based on bundles of absorber rods that can operate either actively or passively by buoyancy. The 4 safety roads in the inner zone can operate both actively and passively.

Core - wrapped sub-assemblies placed in a hexagonal lattice
The central position of the core is not occupied by fuel - has the function of material qualification by test under neutronic irradiation.





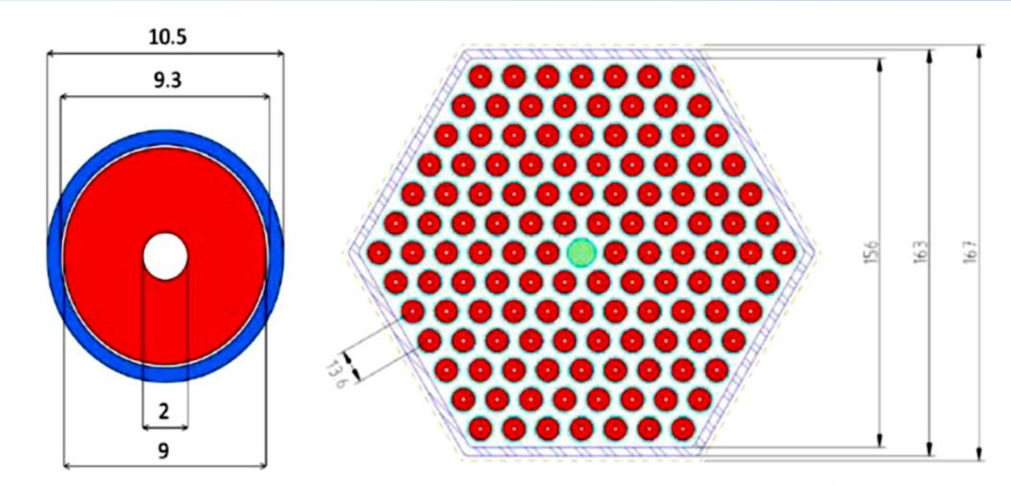
Fuel Assembly

MOX fuel pellets are hollowed to decrease the thermal gradient and mitigate the maximum fuel temperature while accommodating the fuel swelling. A helium gap separates the pellets from the AIM1 cladding. 126 fuel pins are arranged in a hexagonal wrapper, around a central position hosting a dummy pin for additional in-core instrumentation. The FAs are extended above the lead-free surface to simplify fuel handling during loading/unloading.

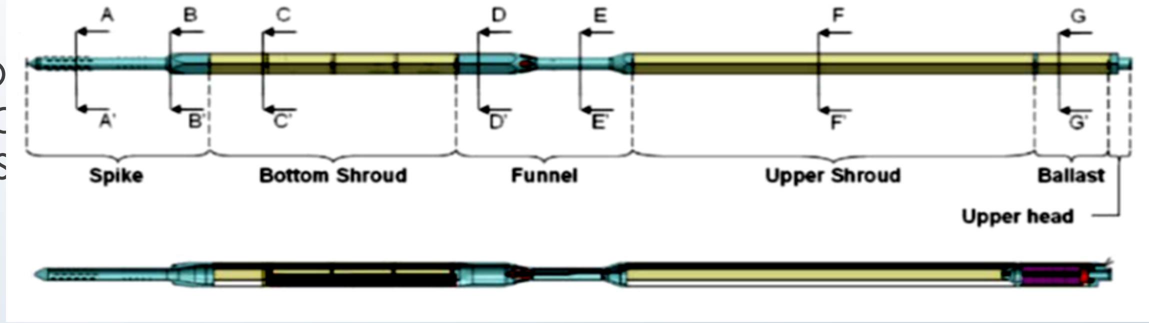
FAs are characterized by:

- The spike, which allows the correct positioning of the FAs and flow distribution
- The funnel allowing the exit of lead and accommodating the necessary instrumentation such as thermocouples and neutron detectors
- The ballast to prevent FAs from floating in liquid lead
- The upper shroud allowing the FA to be manipulated outside lead.

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 o loading errors by design. An upper core plate, providec of a stiff radial restraint, is brought to engage the heads of the S/As to tighten the lattice.



Fuel rod array	127 fuel pins in triangular lattice	-
Fuel rod pitch	13.6	mm
No. fuel rods/assembly	127	
Fuel pellet OD	10.5	mm
Fuel central hole D	2	mm
Cladding tube	AIM1 stainless steel (version of 15-15Ti class steels optimized for swelling resistance)	-
Cladding OD	10.5	mm
Cladding ID	9.3	mm
Cladding thickness	0.6	mm
Fill gas	He	-



Proliferation resistance

- Proliferation barriers:
  - *Intrinsic* -features inherent to a particular fuel cycle system /nuclear energy system (i.e., technology and design features);
  - *extrinsic*, involving administratively-added measures (physical protection and international safeguards).
- Dynamic relation between extrinsic and intrinsic barriers. The proliferation resistance is achieved by a combination of them.
- To satisfy international standards for adequacy of protection against the diversion of nuclear material, external barriers can be added to compensate for weaknesses in intrinsic barriers.
- Nonproliferation assessment:
  - identifies the barriers to proliferation;
  - evaluates their effectiveness.

Safeguards-legal framework

- **Agreement Between Romania and the Agency for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, April 1973 -**Romania has become the first Member State with unilateral agreement with the Agency ensuring that material supplied from another country will not be used to any military purpose.
- **Revisions and Addendums –Additional Protocol - INFCIRC/180/Add.1, signed in Vienna on 11 June 1999, entered into force on 7 July 2000**
- **NGN-01** - Norms for the control of safeguards in the nuclear field (Official Gazette of Romania no. 766, November 30, 2001)
- **NGN-02** -Detailed list of materials, devices, equipment and information relevant to the proliferation of nuclear weapons and other nuclear explosive devices (Official Gazette of Romania No. 687, 18 September 2002)
- **NGN-03** -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 (Official Gazette no. 957, 24 September 2024)

NGN-02

- Equipment and/or related components specially designed or manufactured for nuclear reactors:
- Handling equipment specially designed or prepared for fuel insertion or extraction
- Control rods, coolant pumps, steam generators, internal structures in the reactor vessel (maintaining fuel alignment, guiding the primary coolant, guiding the instrumentation in the core), neutron detection and measurement instruments for determining neutron flux levels

NGN-03

- The nuclear activities must be authorized -The authorization is the official document granting the holder the right to carry out the nuclear activity.
- CNCAN must be notified before the start of the activity and it establishes whether or not the notified activities are subject to the authorization regime.
- The authorization for production, possession, materials, devices and equipment relevant to proliferation is valid for 5 years maximum. The authorization for transfer, import, export is valid for 2 years maximum.
- The validity period can be extended (motivation of the request) but only once, and for no more than 3 months.

NGN-01

Procedures for:

- classification of nuclear materials and establishment of exemption from nuclear safeguards
- designation of the material balance area and selection of main measurement points for determining the flow and stocks of nuclear materials
- recording of nuclear materials and preparation, analysis and transmission of reports
- frequency and method of preparation of physical inventories
- notification of an incident or exceptional circumstances resulting in loss of nuclear materials
- system of measurement of quantities of nuclear material received, produced, shipped or moved from the inventory and of the quantities existing in the inventory
- program of control measurements

In the reports on inventory variations, separate records shall be made for the following nuclear quantities: depleted uranium, natural uranium, uranium enriched up to 20%, uranium enriched above 20%, plutonium and thorium.

Inspections

- inspections by international bodies – are carried out in accordance with international agreements to which Romania is party
- normal inspections -checks of compliance with the registration system; the quantity and composition of all nuclear materials subject to safeguards control; information on possible causes of differences in inventories, differences between sender/receiver
- ad-hoc inspections – verification of information on nuclear materials; verification of changes since the initial inspection – verification of the quantity and composition of materials upon transfer to Romania

Safeguards-summary

- *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.
- *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 and equipment, 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.

Preliminary reflections

Concealed diversion

- deterred and detected by international safeguards. Upper parts of the fuel assemblies are monitored, and there is a high level of automation in transfer facility surveillance.
- Fuel assemblies are large items easily accountable. Because the core is monitored and safeguarded and spent fuel storage will be verified against production records and placed under surveillance, concealed production of nuclear material is difficult.
- The substitution of few pins at the (offsite) fabrication facility and the diversion of the irradiated target pins at the (offsite) central reprocessing facility would very likely be detected by routine inspection verification activities.

Production in Clandestine Facilities

- The utilization of lead coolant requires a specialized infrastructure. The relatively complicated fuel handling and unique fuel requirements are hard to be concealed.
- The reactor is not directly suited for clandestine replication in a nuclear weapons programme. On the other hand, the operation of ALFRED will require a number of skills, competences, technological know-how and operations experience that might play a role in the development of a clandestine nuclear programme

Fuel Cycle and Material Choice

- *MOX fuel* -no need for an enrichment phase, which eliminates a proliferation-sensitive fuel cycle technology
- *Closed fuel cycle*: The closed fuel cycle option 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 information

Fuel Fabrication

- No fuel fabrication factory planned on the premises. MOX fuel will be imported from a 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 removed as individual assemblies. FAs handling between the outside and inside of the reactor will be carried out by adopting a specifically designed container. A dedicated experimental facility will be implemented at RATEN ICN to test the fuel handling feasibility.

Experimental infrastructure

ALFRED infrastructure

- **Carry out LFR technology-specific research (thermo-hydraulic regimes, chemical control of oxygen and impurities)**
- **Investigate the behavior of materials in corrosion and erosion regimes**
- **Study the transport of chemical elements and species in molten lead and cover gas**
- **Ensure the testing, demonstration and qualification of LFR components**
- **Support the validation and verification of computational codes/methodologies**

HandsON

Pool-type experimental facility, to demonstrate the feasibility of handling of fuel assemblies

-Validation of fuel handling procedure and equipment
-Reliability and robustness of the design solutions adopted for the fuel handling system (loading/unloading control)
-Functionality and reliability of the fuel transfer system with associated transfer container
-Large scale testing and technological assessment of the fuel assemblies' maneuverability, in air (stage 1) and in molten lead (stage 2)

Reactor Design and Operation

- Safety approach of ALFRED is consolidated by:
  - use of inherent safety characteristics;
  - use of passive safety systems;
  - minimization of the reliance on the operator interventions.
- *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 whole core. 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 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 refuelling* would be required at about 5 years. The diversion of fresh/spent fuel assemblies from the reactor core would only be possible during refuelling activities, and since there is no direct path from the reactor core area, the possible diversion path will go through the spent fuel storage facility. Still, taking into account that 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.

Take-away messages

- The new innovative reactor designs should comply with GIF objectives, and dedicated efforts should be directed to assess the proliferation resistance.
- New topic
  - preliminary elements were identified and discussed
  - future efforts will be dedicated to perform an initial evaluation of the reactor proliferation resistance.

Topics for discussion

- Proliferation risks of transportation of nuclear material
- Reactor accessibility: on one hand a system that is highly accessible makes safeguards inspections easier while on the other hand less accessible systems may have a proliferation resistance advantage
- Consideration of 3S concept – need for harmonization of methodologies
- Closed fuel cycle impact on non-proliferation - a closed nuclear fuel cycle offers potential benefits in terms of waste management and resource utilization, but it may also introduce new proliferation risks

Thank you for your attention!