ELEMENTS FOR ALFRED PRE-OPERATIONAL MONITORING PROGRAM OF ENVIRONMENTAL RADIOACTIVITY

ELEMENTE PENTRU PROGRAMUL DE MONITORIZARE PRE-OPERAȚIONALĂ A RADIOACTIVITĂȚII MEDIULUI PENTRU REACTORUL ALFRED

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Abstract: *Designed to demonstrate the viability of the lead-cooled fast reactor technology (LFR), ALFRED (Advanced Lead-cooled Fast Reactor European Demonstrator) represents a key milestone for the achievement of the industrial maturity of the LFR concept.*

When applying for a license for the construction and operation of a nuclear installation, the applicant must meet the regulatory requirements taking into account the novelty, complexity and potential damage that the proposed activity represents.

The paper illustrates the elements necessary for planning and initiating a pre-operational monitoring program of environmental radioactivity, given the particularities of the ALFRED, and Mioveni platform as a reference location.

Keywords: Monitoring program, environmental radioactivity, ALFRED

Rezumat: *Conceput pentru a demonstra viabilitatea tehnologiei reactorului rapid răcit cu plumb (LFR), ALFRED (Demonstrator european avansat pentru reactor rapid răcit cu plumb) reprezintă o etapă cheie pentru atingerea maturității industriale a conceptului LFR.*

La solicitarea unei licențe pentru construcția și operarea unei instalații nucleare de ultimă generație, solicitantul trebuie să îndeplinească cerințele de reglementare avand in vedere noutatea, complexitatea și potențialul de daune pe care activitatea propusă îl reprezintă.

Lucrarea ilustreaza elementele necesare pentru planificarea și inițierea unui program de monitorizare pre-operațională a radioactivității mediului, având în vedere particularitățile constructive și funcționale ale demonstratorului ALFRED, precum și stabilirea ca amplasament de referință a platformei Mioveni.

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Cuvinte cheie: program monitorizare, radioactivitate mediu, reactor ALFRED

1. Introduction

As a demonstration reactor, ALFRED implementation will provide for industry, research organizations, safety authorities and universities across Europe interested in innovative nuclear systems the opportunity to improve their knowledge on all operational aspects of future LFRs.

When applying for a license for the construction and operation of a nuclear installation, the applicant must meet the regulatory requirements taking into account the novelty, complexity and potential damage that the proposed activity represents.

From the design and siting phase of a nuclear power plant, it is necessary to carry out complex analyzes on nuclear safety of the future nuclear objective, taking into account the various aspects that may influence the level of environmental and population exposure, as a consequence of plant operation. [1]

Monitoring of the radioactivity of the environment in the pre-operational period, for a nuclear installation, such as ALFRED demonstration reactor, aims to perform a preliminary radiological characterization of the site and to establish the reference levels for radioactivity parameters, which need to be monitored later, in the operational period.

Based on the expertise of RATEN ICN as national nuclear research organization and operator of TRIGA Research Reactors, on the advantages of an existing nuclear site, Mioveni Nuclear Platform was chosen as reference site for ALFRED demonstrator (on the same location being located the Nuclear Research Institute, RATEN ICN).

The site benefits of the: electrical supply, including 110 kV electrical station; water supply; demineralized water; wastewater treatment plant; radioactive waste facilities; fire brigade; heating plant; natural gas supply; physical protection; access road to transport large equipment; already investigated field (i.e. earthquake characterization). The site may benefit for the existing infrastructure, proximity of the ICN departments, availability of the experienced personnel for different activities. The choice will avoid some expenses with services and construction of buildings for these services.

In support of its licensing process and in order to provide the needed research, testing and qualification support, new research infrastructures are envisaged to be built on RATEN ICN site. The reference location of the demonstrator has the advantage of the existence of nuclear installations, with a fairly long operating history, for which environmental radioactivity monitoring programs have been established, in accordance with the existing regulatory requirements. Also, the fact that RATEN ICN Pitești operates a research reactor with an authorized thermal power of 14 MW makes the scope of the environmental monitoring program in-place large enough, so that the location of a demonstration plant with a thermal power of 300 MW does not require, at least in the pre-operational phase, an extension of the monitored area (up to 15 km around the site).

1.1 Regulatory requirements for environmental radioactivity monitoring programs

The need to establish a pre-operational program for environmental monitoring is established by CNCAN specific regulations, as Norm on nuclear safety requirements regarding the siting of nuclear power plants [1] and in the Norm on environmental radioactivity monitoring in the vicinity of a nuclear or radiological installation [2].

The requirements for environmental radioactivity monitoring programs are established by NSR-22, having the following aspects included:

- The environmental radioactivity monitoring program will refer at least to the main routes of radiation exposure, respectively the external exposure routes and the internal exposure routes.
- In the pre-operational stage, the applicant / authorization holder must design the environmental radioactivity monitoring program, based on the pre-operational studies.

The pre-operational program may also be used for staff training and testing of equipment, methods and measurement procedures provided for in the operational program for monitoring the environmental radioactivity.

- The authorization holder must initiate the pre-operational program early enough before the start of operation of the installation, so that the reference values of the radioactive concentrations in the environment can be detected, as well as their variability.
- The environmental radioactivity monitoring program will be supplemented, as appropriate, with programs and / or supporting studies, intended for other types of measurements and / or activities to collect general environmental data and data on population characteristics.
- The applicant / authorization holder must ensure the monitoring of the climatic conditions, both in the pre-operational stage and during the operation of the installation.

Also, both in the pre-operational stage and during the operation of the installation, the hydrological characteristics of the rivers in which the liquid effluents are discharged or the hydrodynamic characteristics of the aquatic environment must be monitored, in case of discharges into lakes or seas.

In the pre-operational stage, the soils and the local hydrogeology must be monitored, as well as the topo-geographical features that can influence the gaseous effluents.

2. Reactor Specifics

The lead-cooled fast reactors concepts have taken into account the corrosive nature of lead oxide and its tendency to form deposits in the form of slag accumulations, which have been minimized by coolant chemistry control systems. Also, the adoption of pool-type configurations for the reactor eliminated the need to use pipes in the primary circuit, leading to the reduction of the associated risk of ruptures / breakages, with consequences on the safety of the installation [3].

The extremely corrosive character of molten lead on structural materials is controlled by managing the oxygen level in the primary circuit. The formation of lead oxide deposits is inhibited by reducing the oxide with the help of hydrogen.

It was observed from the operating experience of nuclear-reactor powered ships, which used the lead-bismuth eutectic as a coolant, the significant amounts of lead oxide slag (formed by the interaction of the coolant with moist air and their accumulation on metal surfaces in reactor core), led to significant degradation of heat transfer properties between the fuel elements and the coolant. In addition, the additional extraction of the control rods to compensate for the apparent loss of power of the reactor led to the appearance of clad defects, followed by massive contamination of the coolant. Such experiments led to the establishment of the design requirement to maintain a coating gas layer in the reactor vessel, above the coolant, consisting of an inert gas, with the addition of hydrogen, for the chemical reduction of lead oxide.

ALFRED primary system is pool-type configured, eliminating all problems related to out-of-vessel circulation of the primary coolant [3]. The Reactor Vessel is cylindrical, anchored to the reactor cavity from the top, by means of a vessel support. A steel layer covering the reactor pit, constitutes the Safety Vessel, the dimensions of gap between the safety vessel and the reactor vessel allowing the In-service Inspection activities. This design solution mitigates the consequences of through-wall cracks with leakage of lead: any reactor vessel leakage is discharged into the safety vessel.

The fuel is MOX type with hollow pellets and a low active height in order to improve the natural circulation. ALFRED is equipped with two diverse, redundant and separate shutdown systems (Control Rod and Safety Rod systems)

The Decay Heat Removal system (DHR) consists of two passive, redundant and independent systems [3], DHR1 and DHR 2, both composed of Isolation Condenser systems (ICs) connected to Steam Generators (SGs) secondary side (i.e. one IC for each SG).

Due to the properties of the lead (it does not react with water or air, it has a high boiling point, it has a higher density than the oxide fuel, it is compatible with existing cladding materials such as 15-15/Ti and T91) some intrinsic safety features are present.

The use of passive systems for decay hat removal systems [3] is very important and gives large grace times available for the operator intervention, if needed. There is no need for core catcher due to the fact that the scenario of core melt is practically eliminated by design. Also, there is no risk of re-criticality in case of core damage due to the floating of the fuel elements in the lead coolant. There are large margins in terms of core voiding by a very improbable vaporization of the lead. On the other hand, lead is a low moderating medium and has low absorption cross-section leading to a hard neutron fast spectrum.

To avoid contamination of the lead with oxygen from the air, the free space above the coolant is filled with inert gas [3].

In addition to noble gases, lead is considered to have a high capacity to retain fission products. It has been observed that iodine and cesium tend to form stable compounds with lead up to a temperature of 600 ° C. Thus, following an event that would lead to a massive failure of the fuel clad, the noble gases would be released into the cover gas, while the fuel and other fission products would be retained in the coolant, either by solubilization or forming lead compounds. Volatile fission products could be released also into the cover gas. Because due to the low-pressure pool configuration of the reactor vessel, coolant loss events are highly unlikely and self-limiting (due to solidification of lead as its temperature decreases), radioactivity release accident scenarios are almost exclusively related to cover gas leaks. Thus, for establishing a source term, the volatilization fractions of fission products are the basis. Moreover, the paths of release and migration into the environment, which must be considered, are based exclusively on the physical and chemical behavior of volatile fission products and noble gases.

Regarding the activation products, and their release into the environment, under normal operating conditions, in the case of LFR, of particular interest is Polonium-210. Po-210 is a radionuclide formed from Pb-208, present in a proportion of 52.35% in the coolant, by the mechanism described by the equation (1):

$$^{208}Pb(n,\gamma)\rightarrow {}^{209}Pb\xrightarrow{\beta(0.14z)}{}^{209}Bi(n,\gamma)^{210}Bi\xrightarrow{\beta(5.0z)}{}^{210}Po\xrightarrow{\alpha(138.4z)}{}^{206}Pb(stab.) \qquad (1)$$

In ALFRED lead was chosen as the coolant in order to minimize the formation of Po-210.

The simulation results have shown that Po-210 can reach a concentration of up to 18 MBq/kg in the primary coolant, after a reactor operation for 5 years. This value is almost four orders of magnitude lower than the concentration of Po-210 achieved in the coolant of a lead-bismuth cooled fast reactor (~ 0.4 TBq / kg) [4].

The polonium, which is volatile at the reactor operating temperature, migrates into the cover gas where it forms aerosols. Leakage of cover gas or coolant can create contamination problems [4]. Under certain conditions of operation or maintenance, purges of the inert gas space are provided, and in these situations, releases of gaseous effluents contaminated with Po-210 may occur. In LBE reactor, in the case of a leakage of the cover gas of 0.01% of the total volume per day, the concentration of Po-210 in the reactor hall might exceed 200 times the maximum allowed concentration, in the absence of a system. polonium retention.

During routine operations and especially during maintenance operations, the inherent Po-210 contamination of the reactor building facilities can lead to the generation of a stream of liquid waste resulting from decontamination. In case of a failure of the steam generator tubes, followed by the depressurization of the secondary circuit, the primary agent can enter the water in the secondary circuit, which can lead to its contamination with activation products including Po-210.

2.1 Emission and migration paths of radionuclides in the environment

The main path of releasing radionuclides produced in LFR type reactors is through the cover gas. Thus, any purges, or technological losses of the cover gas, can lead, under normal operating conditions, to releases into the environment of activation products and possibly limited quantities of noble gases or volatile fission products. Once released into the environment, these radionuclides will disperse, depending on their physico-chemical properties, leading to contamination of environmental factors. A second emission path, of much less importance, compared to conventional reactors, is that of contamination of water in the secondary circuit, as a result of possible leaks in the primary circuit. In the LFR case, this type of event has a self-limiting character, due to the tendency of molten lead to react with water, forming deposits of lead oxide, which will eventually seal any leaks.

3. The existing environmental radioactivity monitoring program

The reference location of the ALFRED demonstration reactor has the advantage of having in the same location a research reactor with a long operating experience. As a result, there is already a comprehensive environmental radioactivity monitoring program for this site, which can also serve as a pre-operational monitoring program for ALFRED. [5] The radionuclides considered in the planning of the existing monitoring program are similar to those specific to a nuclear power plant, the only necessary extension being the addition to their list of LFR specific radionuclides, namely those resulting from the activation of the primary coolant.

The main elements of the environmental radioactivity monitoring program at ICN Pitești are the following: [5]

- Monitoring locations;
- Radionuclides and monitored environmental compartments;
- Sampling frequency;
- Measurement frequency;
- Evaluating the effectiveness of source control.

3.1 Monitoring locations

In accordance with the requirements of the Norms on the monitoring of environmental radioactivity in the vicinity of a nuclear or radiological installation [2], the monitoring locations were selected as close as possible to the end of the exposure route. All four types of monitoring locations were used: [5]

- Indicator locations
- Background locations
- Control locations
- Additional locations

As the nearest urban locality for RATEN ICN nuclear platform, is the Mioveni city, and the vast majority of households in the vicinity of the site have permanent housing, it was established as a critical group for gaseous effluent emissions, the population group consisting of people living in these houses. For the purposes of the new regulations, the reference person in the population for exposure to ionizing radiation as a result of the operation of nuclear installations at the RATEN ICN site may be considered to be a person living in one of the above-mentioned houses.

Indicator locations

Indicator locations are used to evaluate the dose to the public. These locations were established taking into account a number of factors, such as: the type of radioactive releases in the environment, the critical groups and the transfer pathways of radionuclides.

The indicator locations for deposits (gaseous emissions) were selected off-site, taking into account the distribution of wind frequency, directions and the distribution of the population in the area.

Background locations

The background locations are monitoring locations located outside the perimeter of the nuclear or radiological installation, used to determine the natural background radiation levels.

The background locations were established at a proper distance from the area of influence of the TRIGA reactor, in the opposite direction to the predominant wind direction, for gaseous emissions and upstream of the discharge point, for liquid emissions.

Control locations

The control locations are used, together with the indicator locations, to determine the average dilution factor as a function of the distance from the nuclear reactor over a given monitoring period, in order to independently evaluate the atmospheric dispersion calculations of the gaseous effluents. This type of location must be located in the sector with the highest wind frequency, at a higher distance than the indicator location. The distance from the reactor must be at most 20 km.

The environmental sampling / monitoring locations are shown in figure 1.

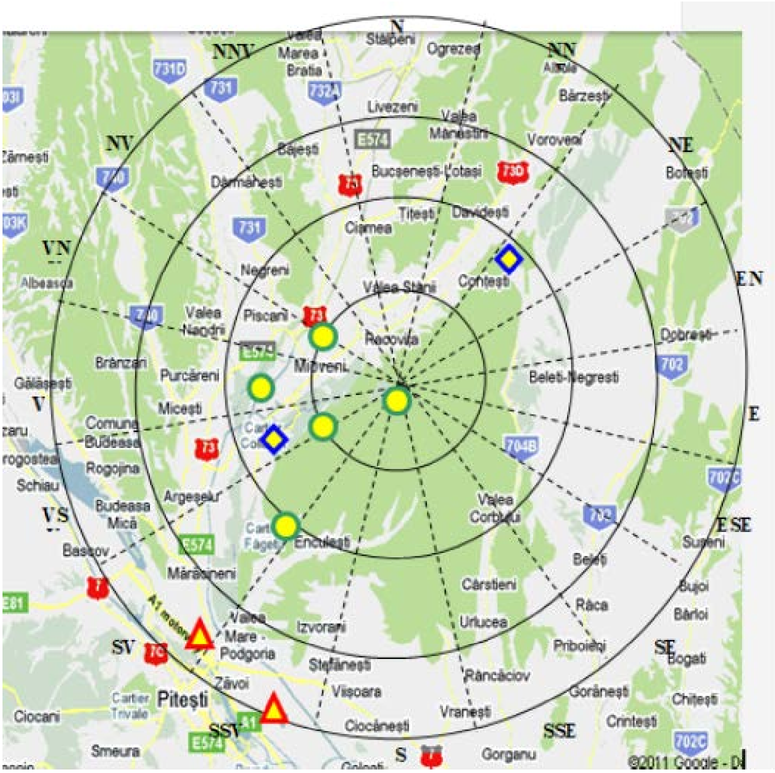

Figure 1 - Environmental sampling / monitoring locations in the ICN site vicinity.

LEGEND:

Control: 

Background: 

Indicator: 

<u>Additional locations</u>

Additional locations are established for sampling that is not part of the specific identified routes of exposure. These locations are established within the site as follows:

-seven locations for sampling soil and spontaneous vegetation samples;

- nine deep water sampling locations (drilling);

- a rainwater sampling location.

The dose rate monitoring is performed using an FHZ 621 G-L2-10 probe, which continuously measures the dose rate. The probe is located on the SW direction from the reactor chimney, at a distance of approximately 300 m from it, at a height of 10 m from the ground. The location was chosen so that there are no buildings between the reactor chimney and the probe.

4. Analysis of the necessity to supplement the existing environmental radioactivity monitoring program

The environmental radioactivity monitoring program for RATEN ICN platform contains all the necessary elements to meet the objectives of a pre-operational characterization program of a nuclear power plant site, namely those of characterization of environmental factors that could influence the transfer of radionuclides in the environment during operation of nuclear installation and the establishment of the initial level of environmental radioactivity at the site of the future nuclear installation. Due to the presence of the RATEN ICN research reactor at the ALFRED demonstrator reference site, the existing monitoring program focuses on identifying the presence in the environment of a set of radionuclides specific to light water-cooled reactors, including a range of fission products along with corrosion and activation products, specific to structural materials of the reactor circuits.

The analysis of the radioactivity release pathways into the environment from the primary circuit of an LFR established that the main way of escaping for radioactive products from the reactor vessel involves the release of cover gas, which, in principle, may contain: noble gases, volatile fission products and polonium-210, as an activation product which at the temperature of molten lead has a marked tendency to vaporize (boiling point: 254 ° C).

Considering the particularities of ALFRED, it was identified the need to supplement the list of analyzes to determine the radioactivity of environmental factors, to include polonium-210 in the category of radionuclides of interest. In this regard, it is proposed that once the location of the demonstrator be finalized, at least two locations be established, located in the vicinity of the future installation from which soil and vegetation samples will be taken in order to determine the Po-210 content. Also, for the samples taken from the background location established within the environmental radioactivity monitoring program of RATEN ICN and from at least one drilling from the ICN site, determinations of the Po-210 content will be made.

It should be noted that Po-210 is an environmental radionuclide, it can be present in rock samples, in radioactive equilibrium with the U-238 series.

In soil samples, the above-mentioned balance is often disturbed due to physical processes leading to radon 222 migration, and in water and vegetation samples, this balance is never achieved due to chemical and physiological processes specific to each of the two environments. In conclusion, as an indicator of the maximum level at which a pollution with Po-210 can be detected in relation to its natural level, in environmental samples, can be considered, in parallel with the analysis of the concentration of Po 210, and the analysis of the natural Pb-210 radioisotope concentration, which precedes Po-210 in the natural series. As it does not occur in nuclear reactions generating Po-210 in the LFR, it is expected to be possible to attribute the excess concentration of Po-210 to pollution from this type of reactor.

In the event that it is considered an alternative location for the ALFRED demonstrator, which is not located in the area of an existing nuclear installation, the site characterization program will have to include a pre-operational environmental radioactivity monitoring program, which to allow the establishment of the reference level for the radioactivity of the environment and to prepare the monitoring methods that will be applied in the operational phase.

5. Conclusions

- Each advanced nuclear installation project presents a specific set of challenges in the authorization process. When applying for a license for the construction and operation of an innovative nuclear installation, the applicant must meet the regulatory requirements taking into account the novelty, complexity and potential damage that the proposed activity represents.
- The necessary elements for planning and initiating a pre-operational monitoring program for environmental radioactivity (considering the reference location and an alternative location) have been identified, indicating the requirements for extending the existing monitoring program or for initiating a self-standing monitoring program.
- The efforts will pay-off in the process of obtaining the license to construct and operate ALFRED demonstrator.

Acknowledgements

Part of the activities have been conducted under the PRO ALFRED Project - *Activities for the Preparation of the ALFRED Research Infrastructure*

Development in Romania, coordinated by RATEN, which has received funds from the Romanian Ministry of Education and Research trough the contract no. 5/18.09.2019.

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