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Safety assessment of the lithium target of the international fusion materials irradiation facility

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Abstract

This article presents the international fusion materials irradiation facility lithium target safety and thermal transient analysis, to evaluate the most important risk factors related to the system operation and to verify the fulfillment of the safety criteria. Main conclusions are that target safety is accomplished: hazards associated with lithium operation are confined within the IFMIF security boundaries and environmental impact is negligible, and the plant well answers to the simulated transients, being able to reach steady conditions in a condition of safety.

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1. Introduction

Li target safety assessment has been performed, in the framework of the development of the international fusion materials irradiation facility (IFMIF) [1], as an accelerator-based D–Li (deuteron–lithium) neutron source for testing candidate materials and components for fusion, by a high current deuteron linear accelerator and a high speed Li flow target. The activity concerned at first the lithium target risk analysis, by means of failure mode and effect analysis (FMEA) and fault tree approaches. This was followed by the thermal hydraulic transient analysis of the target lithium loop, in operational and accident conditions through numerical simulation by thermal hydraulic code.

2. Facility description

The target facilities [1], which provide a cooled stream of liquid lithium to the target zone, consist of:

– the target assembly itself, which must present a stable lithium jet to the beam, where the kinetic energy of the deuteron beam is deposited and neutrons are produced;
– the lithium loop, which circulates the lithium to and from the target assembly and removes the heat deposited by the deuteron beam. This heat is then transferred through heat exchangers to a secondary organic liquid cooling loop and a tertiary water cooling loop, and finally to a cooling tower acting as a heat sink. The lithium loop also contains systems for maintaining the high purity of the lithium required for radiological safety and for minimize corrosion of the loop structure by the hot flowing lithium.

3. Safety analysis

FMEA [2] identified, as major target system-related hazards, the radioactive material generation in the lithium loop (tritium and Be-7), as main products of nuclear interaction between deuterons and the liquid lithium, and the risk related to the liquid lithium loop operation. These results are reflected in the design and system operation. In fact, the majority of tritium and other relevant radioactive mate-

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rials and impurities are removed by trapping and are kept under control by the relative impurity monitoring loop. Vacuum condition of test cell and the confinement from the outside combined with the controlled argon gas atmosphere of the lithium cell, assure that the countermeasures against lithium fire risk due to lithium–air reaction are managed. In addition the study has pointed out any safety concerns at the interface with test facilities and accelerator facilities. In fact some of the events result in excessive evaporation of the lithium that would diffuse to the beam line vacuum, thereby causing an effect of poor vacuum and contamination of the beam. To cope with this issue, beam duct is evacuated by the differential pumping system and the beam vacuum system and the exhaust duct are provided with mist traps to trap the lithium moist. The vacuum environment in the test cell atmosphere eliminates the possibility of lithium–air reaction and also reduces the ingress of lithium into the beam line, in case of an hypothesized event of backwall rupture. Other barriers to withstand lithium propagation into the accelerator, should such an event or a loss of vacuum accident occur, are provided by sets of:

– fast acting valves, which are required to immediately isolate the target from the accelerator after an emergency beam shut-down,
– gate valves placed outside of the test cell shield wall, which constitute the physical interface between the accelerator and target.

Lastly the analysis has provided a set of postulated initiating events (PIEs), that is off-normal events that could result in hazardous consequences for the plant, helpful in the further accident sequence quantification phase, [3].

The PIEs shown in Table 1 are categorized according to their likelihood of occurrence as in Table 2 into two broad classes: the events related to the loss of function – including e.g. loss of flow in the target Li loop, loss of heat sink – which imply the faults of components designed to assure the required function and the events related to coolant leak/spill – as Li LOCA,– which involve the rupture of the primary boundary of the coolant carrying components.

Table 1
List of postulated initiating events

PIE code	PIE description	Category
LF	Loss of flow in the target Li loop	II
LFCT	Loss of flow in the cold trap cooling loop	II
LH	Loss of heat sink	II
Li-LOCA	Lithium LOCA	II
LP	Loss of Li purification	II
LS1	Lithium spill in the test cell	III
LTR1	Li-or cooler tube rupture	III
LV-B	Loss of vacuum in the beam line	II
Or-LOCA	Organic LOCA	III
W-LOCA	Water LOCA	III
Ar-LOCA	Argon LOCA	III
N/S	Not safety relevant initiator	II

Table 2
Event sequences categorization

Event category	Event description	Event frequency
I	Operational events	More than one per year
II	Likely events	1×10^{-2}/y
III	Unlikely events	10^{-2}–10^{-4}/y
IV	Extremely unlikely events	10^{-4}–10^{-6}/y
V	Hypothetical sequences	Less than 10^{-6}/y

4. Unavailability assessment

The unavailability of the whole target facility, has been attained through the evaluation of each single system whose failure in the requested mission contributes singularly to the loss of the target, as listed below [2,4],

Loss of primary (lithium) cooling system
Loss of secondary (oil) cooling system
Loss of water cooling system
Loss of cold trap cooling system
Loss of lithium purification system
Loss of lithium target vacuum system
Loss of electrical power distribution system

The final result of the plant fault tree analysis in terms of IFMIF target system probability of failure over a one week mission time is: $Q_{\mathrm{TOT}} = 1.29\mathrm{E}{-}01$, [2,4].

5. Thermal-hydraulic transient analysis

The thermal hydraulic code Relap5 Mod3.2 has been utilised for the simulation of the three main circuit loops of the facility, the primary circuit (lithium cooled), the secondary circuit (organic oil cooled) and the tertiary circuit (water cooled), in order to analyse the global thermal hydraulic behaviour of the plant [2],

in steady state conditions at full power
in the operational transients of start-up and shut-down
in accident conditions.

Transient thermal hydraulic analysis of the plant through RELAP5/Mod3.2 [2] simulation shows that

– plant response to the operational start-up and shut-down transients is quite good,
– the plant responds well to the simulated accident transients and it is able to reach new steady state safety conditions in a short time or has the potential to recover from the accident within the safety margins.

6. Conclusions

Risk analysis has revealed that the hazards associated with the lithium operation are confined within the IFMIF security boundaries and the environmental impact is negligible. In fact the analysis has shown that target facilities and engineered safeguards are designed both to reduce the accident probability and, at the same time, to eliminate any subsequent release to the environment.

This process pointed out also the initiators of accident sequences to be further evaluated within the PSA (probabilistic safety assessment) studies, involving the IFMIF plant as a whole, and devoted to the event tree development and assessment. In addition a target system unavailability figure lying around 1.0E−1, as a result of a detailed fault tree model, is considered a quite acceptable value for the envisioned performance of the machine.

Transient thermal hydraulic analysis of the plant through RELAP5/Mod3.2 simulation has demonstrated that the system is able to fulfil the safety requirements, during the postulated accident transients.

Additional safety analysis will be required as soon as a more detailed design is available, in order to reach a final assessment for licensing and construction purposes.

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