IAEA Study on Passive Shutdown Systems for Fast Reactors: Status Review

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Abstract. Inherent and passive safety features are becoming very important for fast reactors especially when active systems such as the SCRAM-systems for reactor shutdown are not functioning properly. Passive shutdown systems can operate either continuously (analogous to reactivity feedback mechanism or function as a backup actuation method for the conventional reactor SCRAM system. Numerous passive shutdown systems designs have been developed over the years in fast reactor research programs across the world. To summarize the state-of-the-art in this field, the members of the technical working group on fast reactors at the IAEA (TWG-FR) has been collecting the various approaches, design principles, engineering solutions and their impact on reactor safety and operation, in a joint collaborative project over the last year. A review of a total of a large number of different systems, divided in to different categories depending on the way they are actuated, will be presented in a Nuclear Energy Series report written jointly by members of the TWG-FR group. Some of these systems and the general findings of the TWG-FR study group will be presented in the poster session at the FR17 meeting.

Key Words: Passive safety, Inherent safety, Shutdown systems, ATWS

1. Introduction

Numerous passive shutdown systems designs have been developed over the years in fast reactor research programs across the world. To summarize the state-of-the-art in this field, the members of the technical working group on fast reactors at the IAEA (TWG-FR) has been collecting the various approaches, design principles, engineering solutions and their impact on reactor safety and operation, in a joint collaborative project over the last year. A review of a large number of different systems, divided in to different categories depending on the way they are actuated, will eventually be presented in a Nuclear Energy Series report currently being written jointly by members of the TWG-FR group.

Specific systems to improve reactor safety performance during accidental transients have been developed in nearly all fast reactor programmes, and a large number of proposed systems have reached various stages of maturity. The challenges facing the designer of passive shutdown systems include:

- Speed, reliability and predictability of actuation during accident scenarios
- Testability during operation
- Lifetime and performance degradation issues
- Impact on core operation
- Impact on neutron economy and core design
- Accurate modelling in safety analysis
- Needed qualification programs
- Costs

Based on previous reactor R&D activities on this topic within the US, general functional requirements for the development of passive shutdown system designs have been specified as follows:

1. The system should have sufficient worth, and should be sufficiently fast-acting such that an appropriate amount of negative reactivity is introduced within the time required to prevent damage to the core for postulated faulted conditions;
2. System should be fault tolerance to deformations caused DEC energetic events;
3. The system should be able to function under the loads imposed by design-basis seismic conditions including a margin;
4. Based on reactor instrumentation it should be possible to identify the location of the system relative to the core;
5. The system should be built of materials that can withstand fast reactor flux and coolant temperature environment for its design lifetime.

Some other characteristic are desirable but not mandatory.

1. The system should be testable in-situ;
2. The system should be resettable in situ;
3. The influence of the system on any mode of normal reactor operation; i.e., startup, shutdown, full power, and partial power with partial flow should be as low as reasonably achievable.

2. System classification

In the study, we have categorized systems based on their method of actuation. The most well-known approaches in shutdown system design can be categorized by their actuation principle as follows:

1. Flow.
2. Coolant temperature

3. Curie-point temperature actuated absorbers
4. Rupture discs

Categories 1 and 2 represent continuously operating and self-resetting systems, while categories 3-4 consist of alternative (passive) methods of reactor SCRAM. Category 1 responds only to changes in the primary coolant flow rate, while Categories 2-4 respond to temperature and thus actuate during any postulated accident that raises temperatures above set limits. The objective of all systems (or combination of systems) is to increase margins to failure and avoid coolant boiling during very severe unprotected transients when the standard SCRAM systems are not functioning as intended.

3. Systems included in the IAEA NES report and operational history

A large number of passive shutdown devices from across the globe were studied and will be presented in the upcoming NES report on the subject. These include the following approaches:

- Lithium Expansion Module
- Lithium Injection Module
- Curie Point Latches
- Thermostatic Switches
- Fusible Link Latches
- Thermal Volumetric Expansion Drives
- Flow Levitated Absorbers
- Cartesian Diver
- Levitated Absorber Particles
- Enhanced Thermal Elongation of Control Rod Drive Line
- Gas Expansion Module
- Periphery Channels for Coolant (Na/Pb) Voiding
- Autonomous Reactivity Control (ARC)
- TWR Thermostat
- Thermo-Siphon Based PSS
- Static Absorber Feedback Equipment (SAFE)

The study will also include some of the operational history of passive shutdown systems that have been in use in fast reactors. The design and operation of the systems that have been used operationally in the BN-350, BN-600 and most recently in the BN-800 reactors in Russia, as well as in the FFTF reactor in the United States, are included in the report.

4. Future systems currently under active development

A number of systems are currently in active development for use in existing and future fast reactor systems. The TWG-FR study includes detailed descriptions of the following systems, categorized by their method of actuation:

1. Flow actuated
    a. Flow-levitated absorbers
    b. Gas Expansion Modules
2. Temperature actuated
    a. Lithium expansion modules
    b. Enhanced control rod driveline expansion
    c. Autonomous Reactivity Control (ARC)
    d. Thermo-siphon

e. Absorber for Safety at Transient (FAST)

5. Conclusions

Following a meeting of the IAEA technical working group of fast reactors (IAEA TWG-FR), the participants expressed a clear need to have the information regarding the development of passive shutdown devices for fast reactors documented in a central and well-structured format, which also steered the initiation of a NES document. It was also recommended that the existing systems for which an operational experience already exists should also be addressed in the study, along with the innovative concepts under development. Moreover the study will encompass all Fast Neutron Systems and not be limited to Liquid Metal Cooled Fast Reactors. This paper has summarized the main contents of the upcoming document (which is now in its final drafting stage) and serves as a reference point for the posters presented on the topic of passive shutdown devices at the FR17 conference.