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安全研究と日本の原型炉概念への展望
Prospect of Safety Research and DEMO Reactor Conceptual Study

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1. Introduction

As a result of the increasing public interest for stable energy supply by means of safe sources after the Fukushima nuclear accident, there is a need to reassess and reconfirm the safety advantages of fusion energy. Various safety studies in the past have identified the advantages in safety and environmental aspects of fusion power plants. However, to increase the level of confidence of the predictions, there is a need to revisit and expand on work done in the past and use more relevant source terms, system configuration, materials selection and plant parameters which have not necessarily been considered in some of the previous work. Given this situation, safety research has been started in the DEMO Design Activities of the Broader Approach.

2. Scope of safety research

The goal of the safety research is to analyze accidental sequences potentially anticipated in DEMO as radiological risks, to develop possible projections of the results to safety design for preventing and mitigating serious accidents, and eventually to compile the safety design guidelines.

In general, the process of licensing a nuclear plant requires a comprehensive safety assessment covering the safety analysis of the plant in depth in different operational phases and incidental/accidental situations as well as the doses to public and to workers in normal and abnormal conditions. The overall assessment comes to be implementable when the detailed design of the plant has been completed and the annual meteorological data in the planned construction site are given.

In contrast to this, the safety research starts as early as in the pre-conceptual design phase when neither key design parameters nor plant configuration is determined. It is a rather unusual situation compared with most of previous safety assessments, but, looking at this from a different angle, such a situation can provide a definite advantage of applying effective countermeasures to DEMO conceptual design toward improved safety.

3. Main research issues

3.1 Analysis of reference event sequences

By paying attention to radioactive source terms and energies showing a difference between DEMO and ITER, we can identify potentially important reference events for DEMO among a number of accidental sequences considered in the ITER safety assessment. In the same way, a comparison of the source terms with other power plants will help us to narrow down reference events for safety analysis, as well.

The reference event sequences will be analyzed using reliable and dedicated computer codes. The analysis will cover the transient analysis of the temperature of in-vessel components during a loss of coolant accident (LOCA), the temporal evolution of pressure in the confinement chambers during an over-pressure event caused by an in-vessel LOCA, and the effects of prevention or mitigation systems against these accidents. In the case of the Japanese DEMO concept based on water-cooling solid breeders, hydrogen explosion caused by the steam-beryllide reaction could be a safety concern. In addition, the possibility of explosion resulting from other reactions such as dust explosion and steam-metal reactions needs to be carefully examined.

3.2 Projection to DEMO design

What is required today is exploring every possible design option for ensuring passive safety to enhance the value of fusion energy. For the purpose, the analysis results should be fed back to the reference DEMO design so that the impacts of introducing various prevention and mitigation systems against abnormal events would be confirmed. In particular, in the wake of the

Fukushima accident, secure safety systems for residual heat removal in a loss of coolant accident (LOCA) and a loss of flow accident (LOFA) need to be investigated. Admittedly, the heat removal capability largely depends on the assembly architecture of the in-vessel components and the arrangement of cooling systems. This means that the LOCA and LOFA analysis can provide notable implications for narrowing down the in-vessel component architecture and the cooling systems.

In order to reduce the burden for future generations, the impact of the design on radioactive waste needs to be identified. The evaluation of radioactive waste would be performed to outline the management and disposal strategy of the waste to a relatively limited extent.

3.3 Beyond design basis events (BDBEs)

In addition to the analysis of reference event sequences based on design basis events, the analysis of the sequences following low-probability events is sometimes required. The events are called "beyond design basis events" (BDBEs). Despite with extremely low probability, it is required to assure that no consequences resulting from the BDBEs lead to a cliff-edge, i.e., a cataclysmic change of event causing a catastrophe. The Fukushima accident revealed a fact that a boundary between "design basis" and " beyond design basis" events in safety assessment is uncertain.

In the safety research, after the examples of previous safety assessments, the following events would be considered as BDBEs and the envelope of their consequences would be analyzed.

- Total loss of on-site power for a long period
- Total loss of coolant from all loops in the plant for a long period
- Multiple failures sequentially or simultaneously

The analysis results will be projected to the DEMO safety design as possible, albeit BDBEs.

3.4 Safety design guidelines

The final target of the DDA Safety Research is to compile the safety design guidelines, which will be fundamental principles for the successive DEMO conceptual design, together with other design guidelines on physics, engineering, etc.

The safety design guidelines are rationales to satisfy the "generic safety requirements" which will be set in the early time of the DDA Safety Research as a target to assure inherent safety of DEMO. For instance, the guidelines will include rationales on confinement barriers for radioactive materials, the secure power control of burning plasma, the integrity of the confinement barriers, the residual heat removal system, countermeasures against loss of coolant and power accidents, and the prevention and mitigation systems against abnormal events. The guidelines will include the management and disposal strategy of radioactive waste.