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核融合炉の安全性と安心感
Safety and Reassurance Aspects of a Fusion Reactor

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1. Introduction

The accident of nuclear power plant at Fukushima Daiichi has brought terrible damages, and a lot of public people have been evacuated. Since a fusion reactor is a plant to harness fusion energy, we should carefully pay attention to safety issues related to nuclear energy, as well. It is worthwhile to reconsider the safety issues related to a fusion reactor. In addition, since the accident of nuclear power plant has drawn attention to energy policy in Japan, we should explain the role of fusion energy to the public.

From these viewpoints the JSPF has organized the task force committee, in which these issues (i.e., safety problem in the fusion reactor and the role of the fusion energy) have been discussed so as to summarize an assessment to the development of fusion energy. A content of the report[1] is as follows;

1. Role of fusion energy in 21st Century
    1.1 Energy problem and energy policy
    1.2 Characteristics of fusion energy and introduction scenario
2. Evaluation on safety issues for fusion plant
    2.1 Safety issue on ITER
    2.2 Safety issue on fusion plant
3. Radioactivity on a fusion reactor
    3.1 Decay heat problem of a fusion reactor
    3.2 Radioactive waste
4. Safety analysis for a fusion reactor
    4.1 Safety analysis codes and V&V experiments
    4.2 Safety issues for solid breeder blankets
    4.3 Safety issues for liquid breeder blankets
5. Safety aspect on tritium
    5.1 Environmental behavior of tritium
    5.2 Biological effect of tritium
    5.3 Measurement of environmental tritium
    5.4 Safety analysis of tritium
6. Summary

In fission reactors, three functions (i.e., (i) stop a chain reaction, (ii) cool down a fissile fuel and (iii) confine radioisotopes) are essential for safety securement. In the accident of Fukushima Daiichi, since the cooling of fuel rod due to decay heat was insufficient, radioisotopes such as ^{131}I, ^{137}Cs and so on were released in the environment. Therefore, we have reviewed safety analysis in a fusion reactor, paying much attention to the decay heat, and re-considered safety aspect on tritium in this report.

2. Safety analysis of a fusion reactor

2.1 Decay heat

The decay heat has been analyzed for the fusion reactor Slim-CS with P_F=3GW. In Fig. 1 the temporal evolutions of the decay heat are shown for Out-Board (OB) blanket, In-Board (IB) blanket, Divertor and Radiation shield.

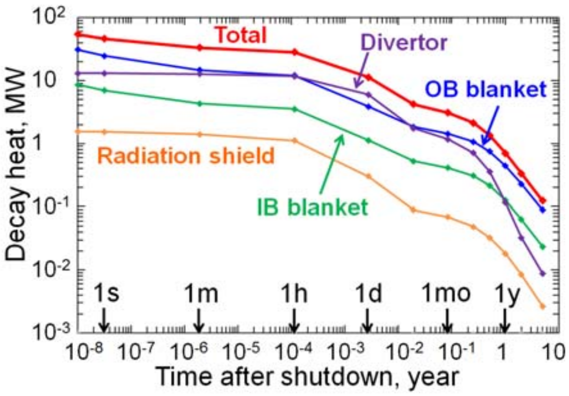


Fig. 1 Temporal evolution of the decay heat

Just after the shutdown of the reactor the total decay heat is roughly 54 MW, which is about 1.8% of the fusion power in operation. The decay heat at the OB blanket is quite large, and the dominant radioisotope is ^{56}Mn($T_{1/2}$=2.58 hours), which is originating from a ferritic steel F82H. At one day after the shutdown, the decay heat of the divertor becomes larger than other components. This is because the contribution from the tungsten decay heat becomes dominant. The main radioisotope is ^{187}W ($T_{1/2}$=1 day). The tungsten is a first candidate for the first wall and divertor at the DEMO, since the tungsten has many advantages such as high melting temperature, low sputtering yield and no long-life radwaste. However, from the viewpoint of the decay heat just after the shutdown we have to pay careful attention to the tungsten. At one month after the shutdown the decay heat becomes around 0.1% of the fusion power in operation.

2.2 Safety analysis of a fusion reactor

In 1990's intensive study (so-called SEAFP and SEAL activities) has been conducted in Europe. Figure 2 is a typical result of the time evolutions for each component in the case of LOCA at the PPCS reactor, where the decay heat at the blanket transfers to the outside of the cryostat through conduction, radiation and convection. The maximum temperature was limited around 1200 C. Here we should notice that in Fig. 2 a neutron wall loading was relatively low (i.e., $2MW/m^2$). The maximum temperature strongly depends on the neutron flux. This is because the decay heat just after the shutdown is proportional to the neutron flux, not to the neutron fluence. Since the short life time radioisotope such as a few days half-life contributes to the decay heat, the amount of these short life time radioisotopes saturate during a long period operation.

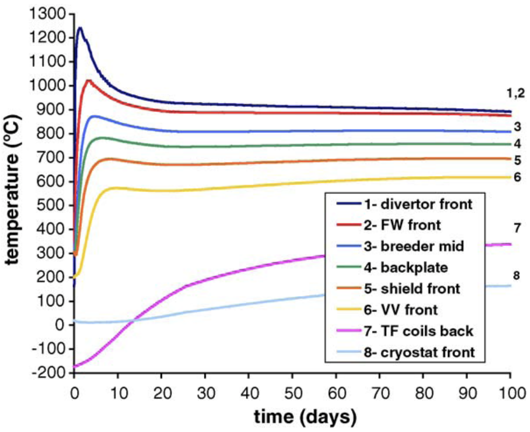


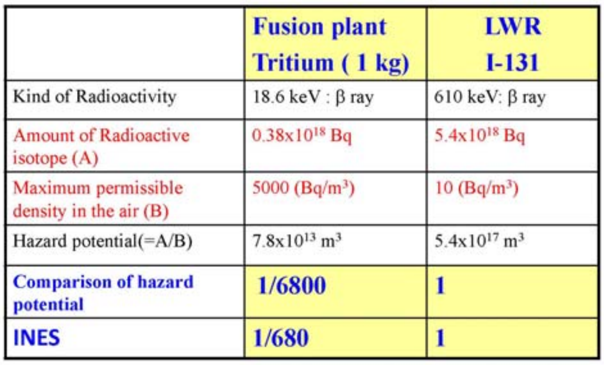
Fig. 2 Temperature behavior in the case of LOCA.

3. Safety aspect on tritium

When we discuss reassurance of nuclear plant, comparison of the hazard potential related to total amount of vulnerable radioisotopes might be useful. Here we have compared hazard potential of tritium in fusion plant with that of ^{131}I in Light Water Reactor (LWR). Since a total amount of tritium depends on the plant design in a fusion reactor, we assumed a tritium of 1 kg. Comparison result is summarized in Table 1. Roughly speaking, the total amount of radioactive isotope (A) was one order smaller in fusion reactor than that in fission reactor. While, the maximum permissible density in the air (B) is quite different between tritium and ^{131}I; i.e., about 500 times in tritium as large as in ^{131}I because of difference of beta-ray energy. Based on these values, let us define the hazard potential as a total amount of radioisotope (A) divided by the maximum permissible density in the air (B); i.e., A/B value. I believe this hazard potential might become a kind of reassurance index. If so, we could say that the hazard potential of 1 kg tritium in fusion reactor is smaller by a factor of 6800 than that of ^{131}I in fission reactor.

By the way, IAEA and OECD/NEA defines the international nuclear and radiological event scale, from Level 1 to Level 7. In this INES report, ^{131}I equivalent values are defined for various radioisotopes, and the ^{131}I equivalent value of tritium is evaluated to be 1/50. If we use this value, the hazard potential of fusion plant is around 1/680 as small as that of LWR.

Table 1. Comparison of hazard potential between fusion plant and LWR.



	Fusion plant **Tritium (1 kg)**	**LWR** **I-131**
Kind of Radioactivity	18.6 keV : β ray	610 keV: β ray
Amount of Radioactive isotope (A)	$0.38x10^{18}$ Bq	$5.4x10^{18}$ Bq
Maximum permissible density in the air (B)	5000 (Bq/m^3)	10 (Bq/m^3)
Hazard potential(=A/B)	$7.8x10^{13}$ m^3	$5.4x10^{17}$ m^3
Comparison of hazard potential	**1/6800**	**1**
INES	**1/680**	**1**

International Nuclear and Radiological Event Scale : IAEA and OECD/NEA

4. Future issues

Recently safety research was activated in the framework of BA activity in Japan, by paying attention to following aspects;

(a) difference between ITER and DEMO,
(b) passive and active safety functions/tools,
(c) code development and V&V experiments,
(d) iteration between safety and design.

In addition to these engineering researches, activities related to social understanding and public acceptance might be strongly expected for the fusion energy development.

Reference

[1] Report on Characteristics of Fusion Energy and Safety/Security Issues for Fusion Reactor, NIFS-MEMO-63 (2013).