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Evaluation of Passive Containment Cooling System design of SMART built in GBS for ocean environment under the Fukushima Accident Condition

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1. Introduction

In recent years, KAIST research team is developing a very advanced concept of ocean NPPs which can avoid natural disasters while potentially increasing economy and enhancing public acceptance. Authors chose Korean small reactor, SMART as a reference system to demonstrate the feasibility of the proposed ocean NPP. Ocean SMART is mounted on GBS (Gravity Based Structure). The ONPP can be towed to the installation site after the SMART is constructed within the GBS in a dry dock.

And, by incorporating IPSS (Integrated Passive Safety System), proposed by KAIST, in the ocean SMART the safety of the whole system will be significantly increased which can potentially eliminate any possibility of repeating Fukushima accident again.

2. Ocean SMART with GBS

Suggested general arrangement of ocean SMART is to use Gravity Based Structure (GBS). Gravity Based System is installed on the seabed, so no mooring system is needed.

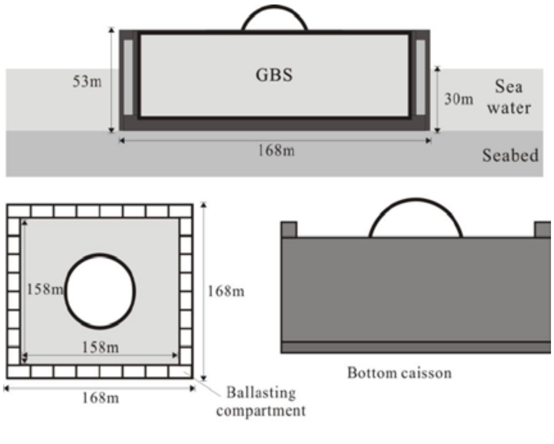


Fig. 1. Gravity Based Structure of Ocean SMART[1]

SMART reactor is below the sea level. This arrangement adds capability to the proposed system to inject sea water passively for the reactor cooling in case of severe accident. When an accident occurs, sea water can be used as cooling water source.

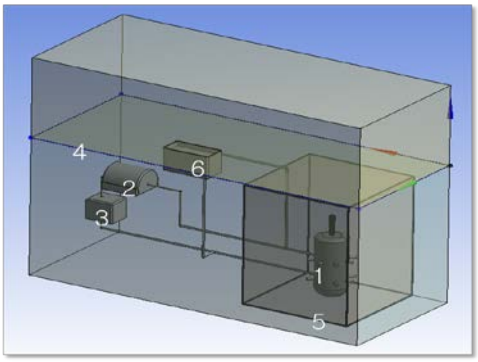


Fig. 2. GA of ocean SMART(1-Reactor, 2-Turbine, 3-Condenser, 4-Sea level, 5-Containment, 6-ECT)

3. IPSS in ocean SMART

3.1 Conceptual design of IPSS in ocean SMART

Authors adopted IPSS concept partially for ocean SMART. Fig.3 shows overview of IPSS on ocean SMART.

Authors adopted three passive safety systems from IPSS. They are: (1) passive residual heat removal system (this system already existed in the original version of SMART), (2) passive in-vessel retention, and (3) passive containment cooling system. Passive safety injection was removed from existing IPSS due to the need of rapid depressurization of the reactor before injecting the cooling water from IPST to the reactor core. But, to decrease the pressure of reactor vessel passively, additional system should be installed to the current licensed reactor system. However, as it can be recalled from SMART main features, the system is designed to remove the possibility of LBLOCA, but if we add the depressurization system, this newly added depressurization system can be the source of LBLOCA. Thus, this system will make a significant change to current SMART, so authors decided to remove passive safety injection from IPSS, and focus more on containment integrity and severe accident mitigation strategy.

There are two strong points of IPSS in ocean SMART. First, IPSS in ocean SMART can maintain long-term cooling indefinitely. Second, IPSS in ocean SMART can be installed to SMART with minimum design change.

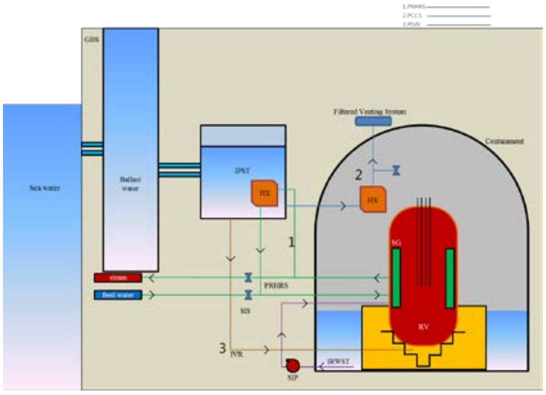


Fig. 3. IPSS on ocean SMART

3.2 Simple analysis of PCCS for ocean SMART

Authors calculated the temperature and pressure changes under the situation when SBLOCA and SBO occurred at the same time again but this time with passive containment cooling system (PCCS) operating. The assumptions of calculation are;

-Initial pressure of reactor vessel is 15.5MPa.

-Water velocity from the reactor pressure vessel to containment is limited by Moody critical flow model. Eq.1 shows Moody critical flow model.

$$G^2 = \rho_g^2 \frac{2(h_0-(xh_g+(1-x)h_f)}{(x+(1-x)(\frac{\rho_g}{\rho_l})^{2/3})^3} \quad (1)$$

-Leaked water reaches equilibrium with containment atmosphere immediately

-Since the information of released energy absorption to containment structure is not available, we instead assumed 0%, 20% and 40% of released energy absorption to containment structure to observe the sensitivity of our result to the uncertainty. In other words, sensitivity study was performed to observe energy absorption effect on containment integrity threatening time.

- Heat exchanging performance is calculated by Eq.2.

Q = hA(Tout- Tin), hA=400kW/K (2)

Control volume of the calculation is described in Fig. 4.

The result of calculation is showed in Fig. 5 and Fig. 6. Both figures show that if the passive containment cooling system operates, the pressure and temperature of containment do not exceed the design limit even when there is no heat absorption to the structure is assumed. Fig. 7 shows the difference of accumulated mass released by Moody and homogeneous equilibrium critical flow model.

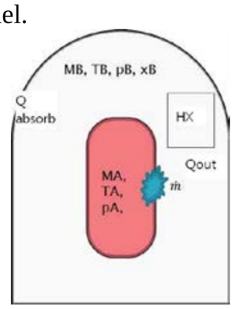


Fig. 4. Control Volume of Calculation

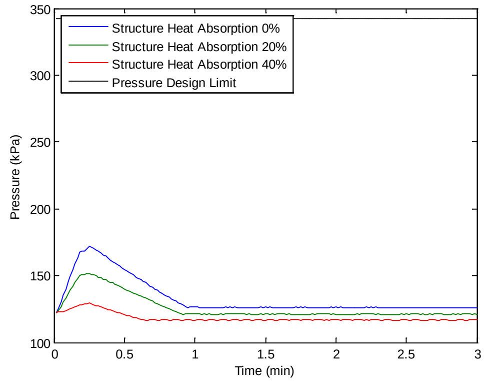


Fig. 5. Pressure change of containment

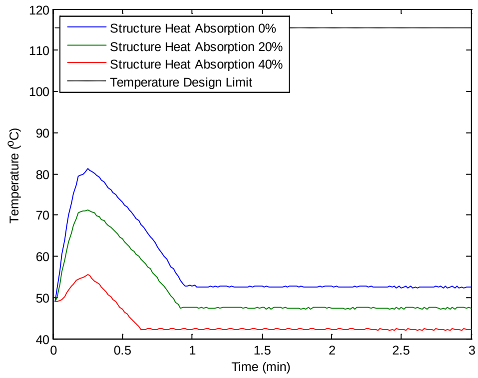
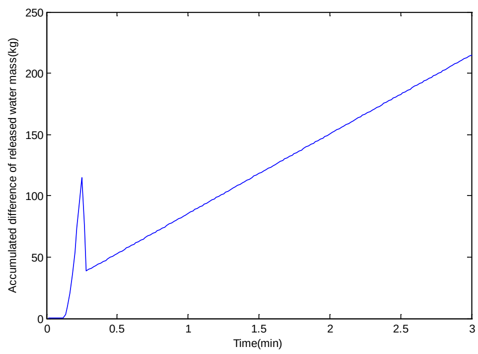


Fig. 6. Temperature change of containment



3. Summaries and Conclusions

Concept of SMART built in GBS to be installed in ocean environment is suggested in this paper. Also IPSS is adjusted for ocean SMART, to minimize the change of design of existing SMART. PCCS performance analysis was done. Despite the calculation condition is set to be beyond DBA, the integrity of reactor containment is maintained by having passive containment cooling system in ocean SMART. Further works will be necessary to improve the design and more detail analysis will be followed in the future.

REFERENCES

[1] Lee K., Lee, K.H., Lee, J.I., Jeong, Y.H., Lee, P.S., A new design for offshore nuclear power plants with enhanced safety features, Nuclear Engineering and Design, 254, 129-141 (2013)