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Use Experience of Sodium Valves in Sodium-cooled Thermal or Fast Reactors

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1. Introduction

The reactor maintains its original function through a series of processes such as energy transfer, heat exchange, and flow control. And the piping network responsible for these processes is usually referred to as the process piping system.

The main functions of valves in process piping systems are basically opening and closing of flow path, non-return of flow, throttling of flowrate, and overpressure protection.

The integrity and safety of process piping systems are further required if the energy density per unit volume of fluid is large or the temperatures of working fluid is high.

External leakage or loss of control ability of the transporting fluid becomes a risk factor that impairs the safety of the piping system.

If the transport fluid is toxic gases or contains liquids with flammable or radioactive materials, external leakage of the fluid may lead to a larger accident.

Almost all of paths for leakage of working fluid from inside the piping system to outside are stem seals of the valve, except in rare cases where it is normally leaked by fracture or damage to the processing piping system.

Therefore, the environment in which valves are installed and the function or purpose of installation of the valves must be considered together in selecting step of valves.

In addition, it should be considered whether the sealing parts of the valve stem that are finally in contact with the inside and outside of the processing piping system can be maintained integrity consistently.

A general case, external leakage of the working fluid through the valve stem part can be prevented by the gland packing installed on the top of the valve stem.

But, in the case of sodium cooled fast reactor, it is not easy to maintain integrity of the valve stem seal because the temperature difference between the working fluid and the valve drive part is greater than that of the conventional pressurized light water.

In addition, to maintain the integrity of the sealing parts of the sodium valve stem, it is necessary to prevent liquid sodium reaching the top of the valve bonnet because the gland packing may be damaged by the sodium oxides that is produced by reaction sodium and the residual oxygen inside the valve drive parts or valve body.

In the case of foreign countries with extensive experience in the operation of sodium experimental facilities or sodium cooled fast reactor, to implement the so-called "leak-free sodium valve" technology, the method of isolating the gland packing on top of the valve from the sodium in the valve body to prevent external leakage of working fluid or gases is preferred. And for this purpose, they have mainly used bellows seals or freeze stem seals with the forced or natural convection cooling system.

This study investigated the cases of valve application and operation error experiences including the stem sealing technology of the sodium valves which were used in sodium cooled thermal or fast reactors.

2. Use experience of sodium valves

Sodium cooled fast reactor have been under development for about 50 years and 29 sodium-cooled reactors using the sodium or sodium-potassium (NaK) as a coolant were constructed.

Among them, two (SRE, HNPF) was thermal neutron reactor and the other 27 reactors were fast neutrons reactors.

3 of the 27 SFRs (SNR-300, PEC, CRBRP) didn't have any operational experience because SNR-300 couldn't be loaded the core after construction and the PEC and CRBRP project were stopped during the construction.

24 SFRs have operational experience of about 400 reactor years while the operation period of two thermal reactors (SRE, HNPF) were less than 10 reactor years.

17 SFRs (EBR-I, EBR-II, BR-5/10, LAMPRE, DFR, FERMI-I, RAPSODIE, SEFOR, BN-350, PHENIX, PFR, KNK-I/II, FFTF, SUPER-PHENIX, MONJU) are closed or shut-down and 7 SFRs (BOR-60, JOYO, BN-600, BN-800, FBTR, PFBR, CEFR) are still in operation.

Investigation results confirm that most of the hot-legs and cold-legs of the primary heat transport systems (PHTS) didn't have a shutoff valves, except for 9 reactors constructed in the early stages of the SFR development.

In fact, for EBR-II and Fermi-I of the U.S., the throttle valve was installed to control flowrates distribution of the core blankets. However, it was reported that the shutoff valve was not installed in the cold-leg of the PHTS according to the IAEA report [1] since the valve operation was fixed after the distribution of flow was determined during the initial operation.

The reactor type installed the shutoff valve at the PHTS was all loop type reactors except for the U.K. PFR and U.S. EBR-II.

Table 1. Sodium valve type used in sodium cooled thermal or fast reactors [2]

Facility	Type	Primary			Secondary (Steam Generator Isolation or flow rate control)	Auxiliary System
		Hot Leg Stop	Cold Leg Stop	Check Valve		
EBR-I	Loop	X	X	X	X	- Bellows seal gate
SRE	Loop	- Freeze stem seal globe	- Freeze stem seal globe	X	- Bellows seal globe - Freeze stem seal globe	- Swing check - Bellows seal globe - Freeze stem seal globe
BR-10 (BR-5)	Loop	- Bellows seal globe	- Bellows seal globe	- Swing	X	- Bellows seal globe
DFR	Loop	X	X	X	X	O
LAMPRE	Loop	X	X	- Swing	X	- Bellows seal valves
HNPF	Loop	- Freeze stem seal ball - Freeze stem seal gate	- Freeze stem seal gate	- Swing	- Freeze stem seal ball	- Freeze stem seal gate - Bellows seal globe
Fermi-I	Loop	X	- Double bellows seal angle globe	- Swing	X	- Bellows seal gate
EBR-II	Pool	X	- Bellows seal angle globe	X	X	- Bellows seal gate
Rapsodie	Loop	X	X	O	X	- Bellows seal valves - Freeze stem seal valves
BOR-60	Loop	- Bellows seal gate	- Bellows seal globe	O	- Bellows seal valves	- Bellows seal valves
SEFOR	Loop	O	O	X	X	- Bellows seal valves
KNK-II (KNK-I)	Loop	- Freeze stem seal gate	- Freeze stem seal gate	O	- Freeze stem seal gate	- Bellows seal globe - Freeze stem seal globe
BN-350	Loop	- Freeze stem seal double gate	- Freeze stem seal double gate	O	- Freeze stem seal slide	O
Phenix	Pool	X	X	- Swing	- Freeze stem seal butterfly - Freeze stem seal plug	- Bellows seal valves

PFR	Pool	- Sleeve	- Gland seal Poppet	X	- Gland seal Butterfly	- Bellows seal Globe
FFTF	Loop	- Freeze stem seal gate	- Freeze stem seal gate	- Tilting disk	X	- Bellows seal globe
BN-600	Pool	X	X	O	- Slide	- Bellows seal valves
JOYO	Loop	X	X	O	X	- Bellows seal globe
FBTR	Loop	X	X	O	O	- Bellows seal globe
Super-Phenix	Pool	X	X	X	X	- Bellows seal globe - Freeze stem seal globe
MONJU	Loop	X	X	- Swing	- Freeze stem seal gate - Freeze stem seal butterfly	- Bellows seal globe
CEFR	Pool	X	X	X	- Freeze stem seal gate	O
BN-800	Pool	X	X	O	O	O
PFBR	Pool	X	X	X	- Freeze stem seal butterfly	- Bellows seal globe
SNR-300	Loop	X	X	- Freeze stem seal butterfly	X	- Bellows seal globe
PEC	Loop (Semi-Pool)	X	X	O	X	- Same kinds used in Super-Phenix
CRBRP	Loop	X	X	- Tilting disk	O	O

All the hot-leg and cold-leg were installed the gate valve with the freeze stem seal except for BOR-60 (hot-leg: bellows seal gate valve, cold-leg: bellows seal globe valve).

It is confirmed that check valves for preventing reverse flow of the coolant when the circulation pump of the PHTS was shut down were installed except for 9 reactors. Then, the swing or tilting disk check valves were frequently used.

The shut-off valves for isolation of the secondary system or the steam generator were used various types, such as gate valves, glove valves, butterfly valves, and slide valves. But the valve stem seals was commonly used freeze stem seal.

Bellows seal glove valve and the freeze stem seal gate valve were used for other sodium systems including auxiliary sodium systems.

According to a comprehensive analysis of use experiences of the sodium valves in SFRs, the primary and secondary systems composed with relatively large diameter piping was preferred to use gate valves.

Also, because of the structural characteristics of the gate valve, the sealing technique of the valve stem was mainly used to a freeze-stem seal that is easy to apply for long travel.

Glove valves were also used primarily in auxiliary systems and other small sodium systems composed with relatively large diameter piping. Then, sealing technique of valve stem is mainly used to bellows seals that accommodates to apply for short travel.

In 1985, the Centralized Reliability Data Organization (CREDO) reported the analysis results of use experience of sodium valves about more than 700 sodium valves used in SFRs and sodium experimental facilities of U.S. and japan [3].

According to the analysis results, the rates of damage and the frequency of unscheduled maintenance of sodium valve (gate valves, glove valves) were much lower than that of the water valves used in light water reactor.

Of course, since the operating environments such as temperature or pressure of the SFR is different from light water reactor, it is difficult to determine that the sodium valves are better in durability or function than water valve.

However, it was assumed that the sodium valves were designed to be more conservative than the water valves for use in the sodium environment.

Summary of the accident history about sodium valves used in SFRs are as follows.

- Mechanical design errors and lack of mechanical and structural durability of valve components including gland packing (HNPF, EBR-II, Fermi-I, FFTF, Super-Phenix, BR-5/10)
- Damage to Bellows by impurities such as sodium oxide, foreign matter, non-ferrous metals (EBR-II, Fermi-I, BN-600) or large internal leakage (BR-5/10)
- Damage to bellows by fabrication, installation or operator error (Fermi-I, Phoenix, Super-Phenix) or damaged valve body (FBTR)
- Bellows failure due to the thermal expansion or solidification of residual sodium in bellows or inadequate design of the valve preheating system (SRE, Fermi-I)
- Damage to gland packing by sodium oxides accumulated in valve stem of freeze stem seal (HNPF)
- Damage to Bellows due to Flow Induced Vibration (HNPF)
- Valve discs and valve seats not operable by sticking (EBR-II)
- Other Bellows Damaged (EBR-II, Fermi-I, FFTF, PFR, Phoenix, BOR-60, BN-600, JOYO)

3. Conclusions

Sodium valves, prevention techniques for external leakage through the valve stem of the internal fluid, and use experiences in overseas sodium cooled fast reactor and in domestic sodium experimental facility are investigated in order to identify the issues to be aware of to develop the concept of a leak-free sodium valve.

As a result of analyzing the use experience of sodium valves used in the primary system, secondary system, and auxiliary systems of sodium cooled fast reactor, the freeze stem seal gate valve is preferred in the primary and the secondary system composed of a relatively large diameter pipes because freeze stem seals are suitable for gate valve with long stroke distance.

Also, the bellows seal globe valve is preferred in the auxiliary system composed of a relatively small diameter pipes because bellows seals are suitable for globe valve with short stroke distance.

Accident experiences of sodium valve used in sodium cooled fast reactor are investigated. In the early stage of the sodium cooled fast reactor development, there were many bellows failures due to the valve design error or the valve maker's mistake, and insufficient understanding of the operator etc.

But bellows failure cases had seldom been seen after the experiences and design skill of the bellows seal valve was accumulated.

Freeze stem seal valves were used as an alternative to the bellows seal in the early stage of the sodium cooled fast reactor development and it is more difficult to find accident experiences of freeze stem seal valves.

As a result of analyzing the use experience of sodium valves and valve stem seal techniques, it is considered that a bellows seal globe valve and a freeze stem seal gate valve should be selected as leak-free sodium valve to be developed.

This research is expected to help determining the direction of technology development for the leakage-free sodium valves in the future.

Also, the reliability of the processing piping system will be more enhanced if the multi-protection concept valve combined the bellows seals with the freeze stem seal is developed.

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