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Verification of interlid pressure monitoring using lead pipe for a spent fuel transport & storage cask

KAZUHIKO KATAYAMA
The Kansai Electric Power Co.,Inc.

ATSUSHI OTSUKA
The Kansai Electric Power Co.,Inc.

MITSUYUKI NOMURA
Nuclear Engineering, Ltd.

HIROYUKI YAMAMOTO
Nuclear Engineering, Ltd.

Abstract

In Japan, a dry metal cask is used for interim storage of spent fuels.

For the containment of radioactive material in dry metal cask, the inside of a cask is filled with helium gas having negative pressure and the interlid space is pressurized by helium gas. The metal cask is required to be designed so as to enable operators to monitor the containment function. Therefore pressure monitoring sensors are employed to continuously monitor interlid pressure.

Usually, in the interim storage facility, for the increase in efficiency of storage capacity, dry metal casks are kept standing. Therefore the interlid pressure monitoring sensors will be put on top of the cask. We call these the "direct system"

The pressure monitoring sensors are required to be correct periodically. For the maintenance of pressure monitoring sensors, it is necessary to work not only at high place but also under the environment of high temperature and radiation.

To work safely, we considered using a lead pipe (stainless steel tube, 6 mm in diameter and 6 m in length) so that the work might be possible done on the floor. We made the mock-up device to conduct various kinds of experiments in order to verify whether this system, we call the "lead pipe system", could be able to monitor gas pressure accurately under various conditions.

The contents of experiments are as follows.

- Verification that there is no meaningful difference between interlid pressure indicated values in the direct system and the lead pipe system in spite of environmental temperature differences.
- Verification of there is no meaningful detection delay with the lead pipe system at

the time of the small leak from a cask top-side.

- Verification of an alarm value being set up above the pressure change by environmental temperature, and being able to secure management time.

Finally we confirmed the “lead pipe system” is useful and contributes to worker's dose reduction and work environment improvement.

1. Introduction

The common dry metal cask is shown in Figure 1, which has double lids. The hollow space between the double lids, we call it the “interlid”, is filled with pressurized helium gas. For securing the containment function, the helium gas pressure is monitored by a sensor located on the port, which has to be inspected regularly for preventing drift phenomena.

In Japan, we are planning to storage casks vertically for storage increase in efficiency. And this requires us to work on the top of the cask, which is at approximate 6m high from the floor, and under hot and high radioactive environment.

Therefore, to work safely, we considered using the “lead pipe system” so that the work might be possible done on the floor.

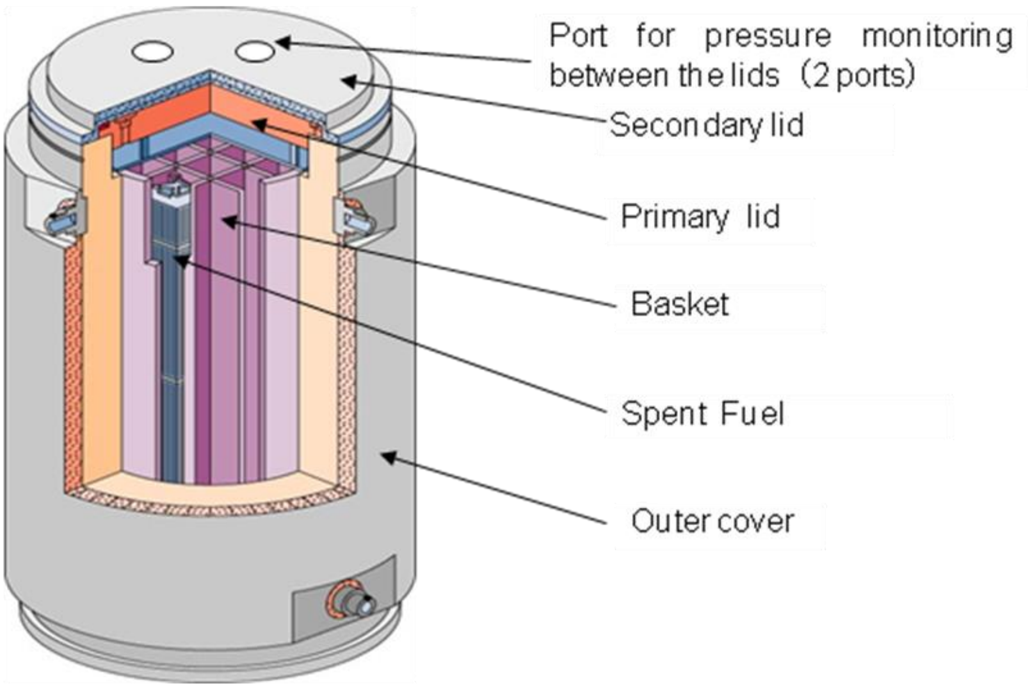


Figure 1. A dry metal cask (Transportation and storage combination)

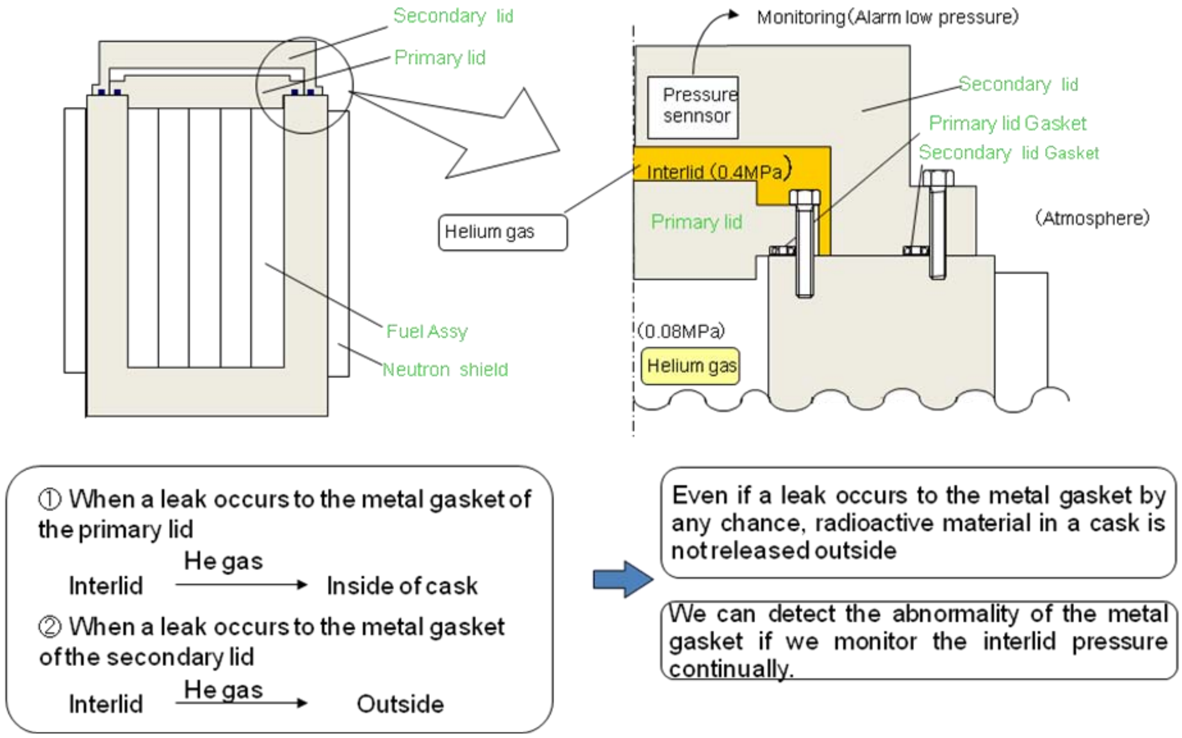


Figure 2. Seal monitoring mechanism

2. Verification points and methods

We have set three verification points as follows. We have carried out experiments with a mock-up equipment to verify the first and second points and also carried out analyses to verify the third one.

(1) Verification that there is no meaningful indicated pressure difference between the "direct system" and the "lead pipe system" even though given environmental temperature differences.

(2) Verification that there is no meaningful detection delay with the "lead pipe system" at the time of the small leak from a cask top-side.

(3) Verification of alarm values being set up appropriately given environmental temperature, and being able to secure management time.

3. Mock-up test equipment

We made a mock-up, which is 1/1 scale but has an upper and semicircle portion of the cask. It also has a needle valve to mimic small and large leakage from the "interlid". On the port, we made two conduits, one of which was for the direct system (left in Fig.3) and the other of which was for the "lead pipe system"(right in Fig.3). Both of them were soaked into a silicon oil bath together to control temperature.

The “lead pipe system” has a 6m length pipe, which is equivalent to the cask height and is soaked into a thermostatic chamber with antifreeze fluid to control temperature.
The pressure transducers which we used for a verification experiment are made in Kyowa Electronics Instruments co.,ltd.

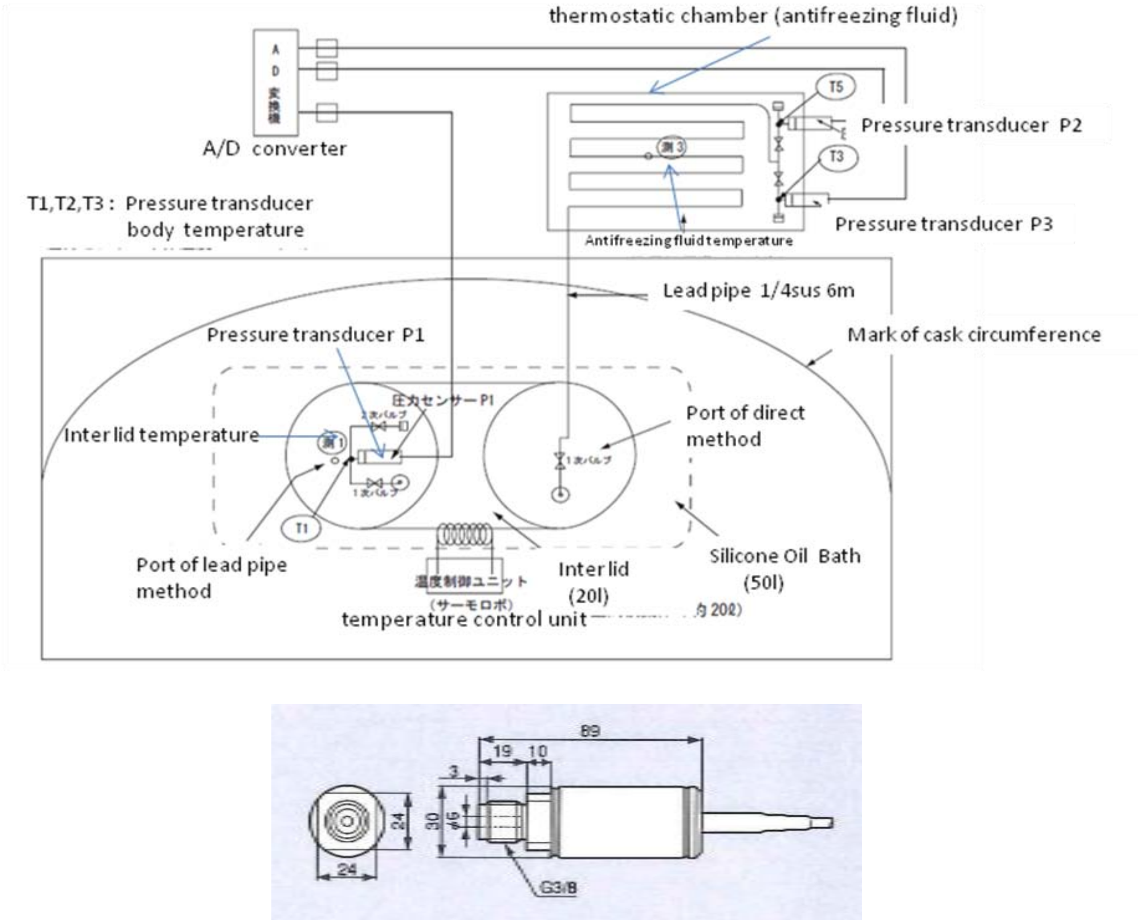


Figure 3. Mock-up test equipment

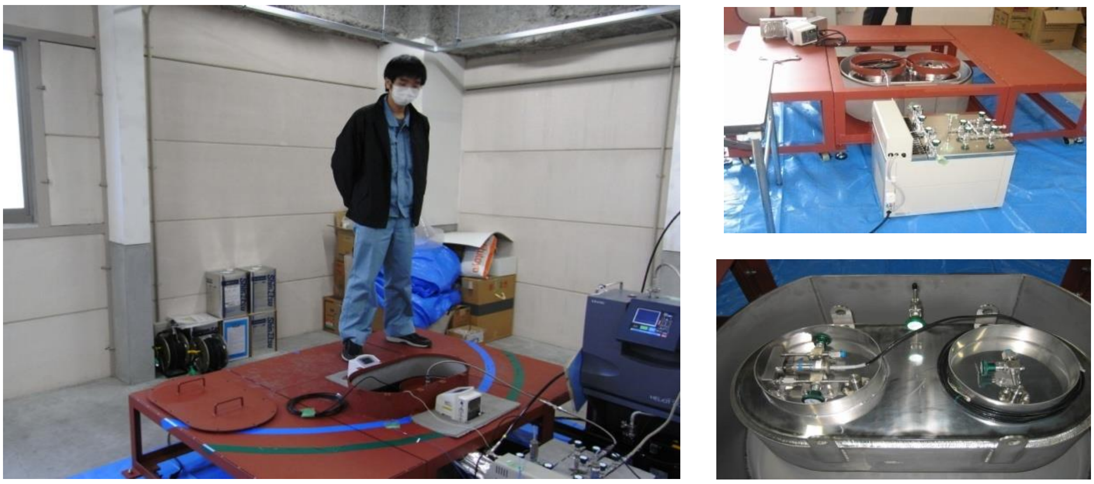


Figure 4. Photographs of the mock-up test equipment

4. Experiments' conditions

(1) The pressure indicated value of the lead pipe system in the time of normal storage

For the purpose of verifying no meaningful indicated pressure difference between the "direct system" and the "lead pipe system" even though given environmental temperature differences, the experiments were conducted with total 27 combinations of the following conditions.

- interlid pressure：0.25MPa，0.35MPa，0.45MPa
- port temperature：25℃，50℃，80℃
- lead pipe temperature (Thermostatic chamber temperature) ：0℃，25℃，45℃

The pressure indicated value was measured after confirming that pressure and temperature conditions had become stability.

(2) The pressure detection delay of lead pipe system at the small and big leakage

For the purpose of verifying no meaningful detection delay with the "lead pipe system" at the time of the leak, we carried out experiments under following conditions.

- interlid pressure：0.25MPa, 0.35MPa, 0.45MPa
- interlid temperature (port temperature)：50℃
- lead pipe temperature (thermostatic chamber temperature)：0℃, 25℃, 45℃
- leakage rate (initial pressure: 0.45MPa)：
  - 0.0004 MPa/hour (small leakage)
  - 8.0 MPa/hour (large leakage)
  - 30 MPa/hour (extra-large leakage, fully open bent-valve, i.e. the needle valve)

- leakage rate (the biggest leakage)：fully open bent-valve to confirm delay time
- interval of measurement：one second

5. Results of experiments

(1)-1 At first, we set the criterion of the meaningful indicated pressure difference.

A general combined instrument error was found by the square root of sum of square each precision based on the instrument constitution of the figure.

$\pm((\text{precision of PT})^2+(\text{precision of AMP})^2+(\text{precision of A/D-CVN})^2)^{1/2}=\pm 0.0029\text{MPa}$

So, we set this value as the criterion.

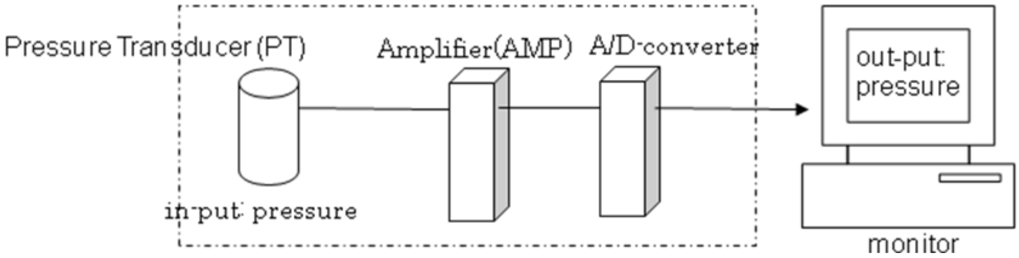


Figure 5. The instrument constitution

(1)-2 The results of pressure indicated value in the time of normal storage

Figure 6 shows the relation of the difference of the both pressure indicating level on difference of temperature level.

The maximum difference of the both pressure indicating level was 0.0015MPa and was less than 0.0029MPa which we set as the criterion.

So we can say that the difference between the "direct system" and the "lead-pipe system" was in the tolerance level.

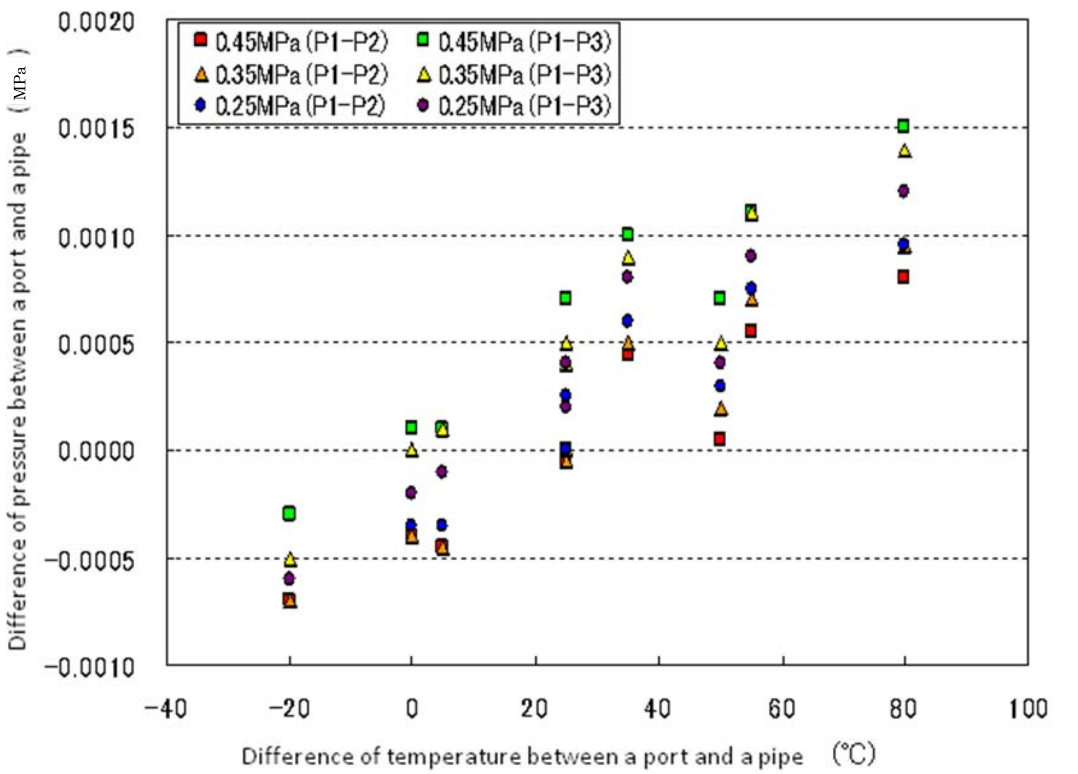


Figure 6. Relation of the difference of the both pressure indicating level on difference of temperature level

Generally, since a pressure transducer has temperature characteristics, the relation between the main part temperature of a transducer and pressure indicated value was investigated in detail. As a result, this sensor has 0.00003 MPa/℃ characteristic.

(2) The results of pressure detection delay at the small and big leakage.
Verification for the detection delay of the lead-pipe system, we performed the experiment which simulated extra large leak such as 30MPa/h from the cask top-side. The results of the experiment are shown in Figure 7. The most delayed time is only one second which appears in the extra-large leakage.
So we estimate that there was no meaningful detection delay with the "lead pipe system" at the time of the small leak from a cask top-side.

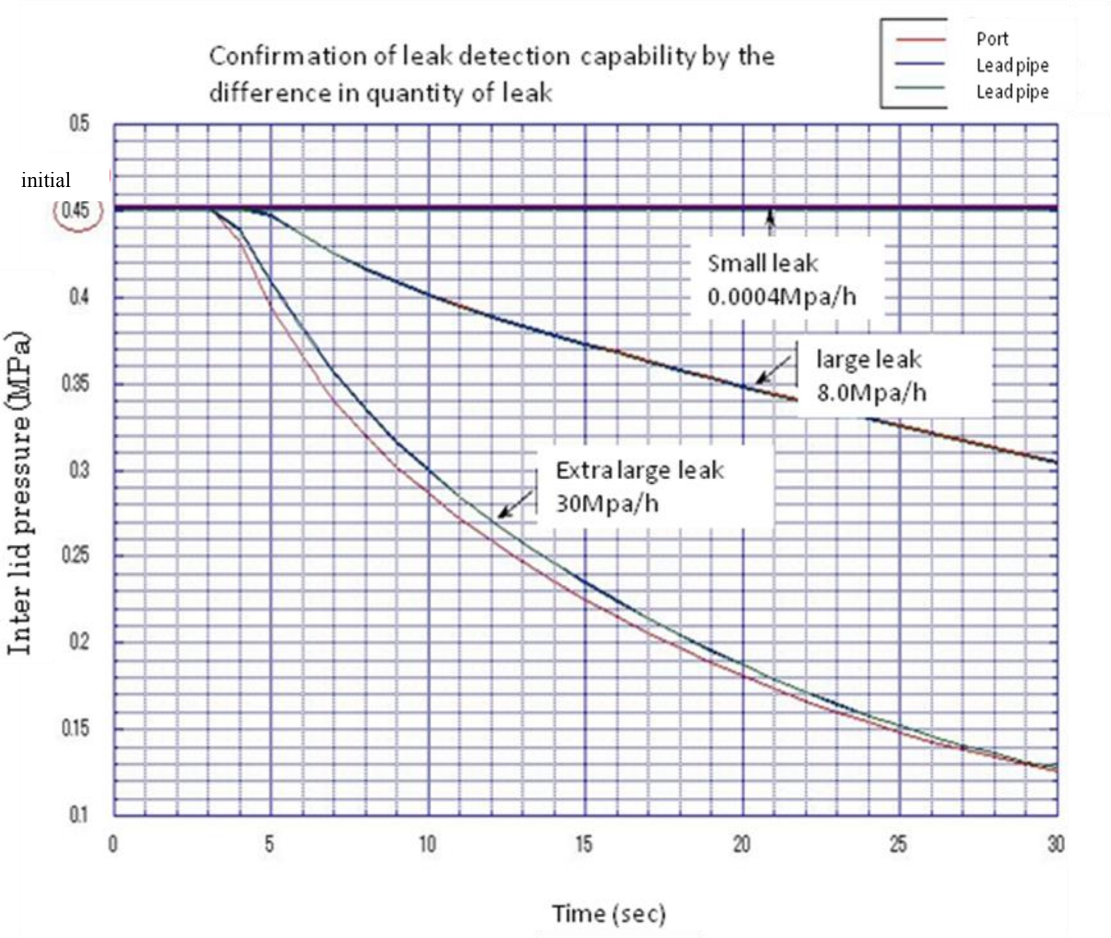


Figure 7. Verification for the detection delay of the lead-pipe system

6. Alarm for confirming containment function

We set three alarm values in order to prevent from losing of the containment function, which are "Caution of pressure decreasing rate", "Pressure low-low", and "Pressure low".
"Caution of pressure decreasing rate" is to notify leakage and defined in consideration of time to investigate the leak point and to manage.
"Pressure low-low" is defined in consideration of time to completely attach the 3rd lid

before the pressure reaches a design lower limit.

“Pressure low” is set to prevent the “Pressure low-low” alarm from ringing abruptly, when the pressure decreasing rate is smaller than ’’caution of pressure decreasing rate’’

(1)-1“Caution of pressure decreasing rate”

“Caution of pressure decreasing rate” is defined in consideration of the “permission leakage rate”, the “decreased pressure tendency by environmental temperature change” and the “minimum detection capability of pressure monitoring system”

a. Permission leakage rate

The “permission leakage rate” is set on 2.97×10^{-6}MPa/h based on the AEST (“Standard for safety design and inspection of metal cask for spent fuel interim storage facility 2010” P121-130)*1

Detail setting manners are written as follows

・Pressure of cask cavity increasing in a year

$$(0.088\ \text{MPa} - 0.08\ \text{MPa})/60\text{y} = 1.3\times10^{-4}\text{MPa/y}$$

・The annual decrease assumption of Interlid pressure (Permission leakage rate)

$$1.3\times10^{-4}\text{MPa/y}\times4\ \text{m}^3/0.02\text{m}^3 = 2.6\times10^{-2}\text{MPa/y}$$

$$2.6\times10^{-2}\text{MPa/y} = 2.97\times10^{-6}\text{MPa/h}$$

Table.1 Examples of defining standard leakage rate

Evaluation conditions	Initial cask cavity pressure	0.08 MPa
	Initial interlid pressure	0.4MPa
	Atmospheric pressure	0.097 MPa
	cavity of cask volume	4 m^3
	Interlid volume	0.02m^3
	Storage term	60 years
Calculation results	Standard leakage rate	1.6×10^{-6} MPa
	Design cask maximum pressure after 60 years storage	0.088 MPa

b. Decreased pressure tendency by environmental temperature change

Because of the double lid structure, the temperature change of the interlid space is smaller than the environment temperature change. But we conservatively set the value at 0.0015MPa/h supposed that the interlid space temperature changes at 9 ℃ in 8 hours as same the maximum historical record of the environmental temperature change.

$$0.4\times(1-(273+16)/(273+25))/8 = 0.0015\text{MPa/h}$$

c. The minimum detection value of pressure monitoring system

The minimum detection capability of pressure monitoring system is 0.0001MPa.

Generally speaking, for the purpose of detecting the change correctly, the "Caution of pressure decreasing rate" is defined by one order magnitude larger than the minimum detection capability of pressure monitoring system. Therefore the value of decreased pressure by environmental temperature change'' is set as the value of "Caution of pressure decreasing rate" .(0.0015MPa/h)

(1)-2"Pressure low-low"

"Pressure low-low" is set for securing the period to attach the 3rd lid until the interlid pressure may not become below a value of designing lower limit（0.24MPa for PWR） *2

Then the defining of alarm value was set in consideration of both the "Assumption leakage rate'' and the "working time of 3rd lid attached''

a. "Assumption leakage rate''

Even if a leakage occurs from the primary lid, the big amount of leakage will be unlikely considered because the gas inside cask is Helium and cask has double lid structure.

So, we conservatively presume the "assumption leakage rate at 0.003MPa/h by assuming twice of the value of "Caution of pressure decreasing rate".

b. The working time of the 3rd lid attached

We estimated the time to attach the 3rd lid. It was conservatively 9.5 hours.

c. The process of setting the alarm "Pressure low-low"

"Pressure low-low" is defined in consideration of the decreasing pressure will not reach the designing lower limit (0.24MPa) and the permission leakage volume from the interlid space to the cask cavity (0.008MPa/60y).

The pressure decreasing while the working of attaching the 3rd lid is as follows:.

$$9.5h \times 0.003MPa/h = 0.029MPa$$

So the "Pressure low-low" is set as follows

$$0.24MPa + 0.008MPa + 0.029MPa = 0.277MPa \fallingdotseq 0.3MPa$$

(1)-3“Pressure low”

“Pressure low” is defined in consideration of being able to investigate a leak point and determine how to manage before the “Pressure low-low” is dispatched.

So we set this value as follows:

“Pressure low”：0.4MPa- 0.055MPa=0.345MPa

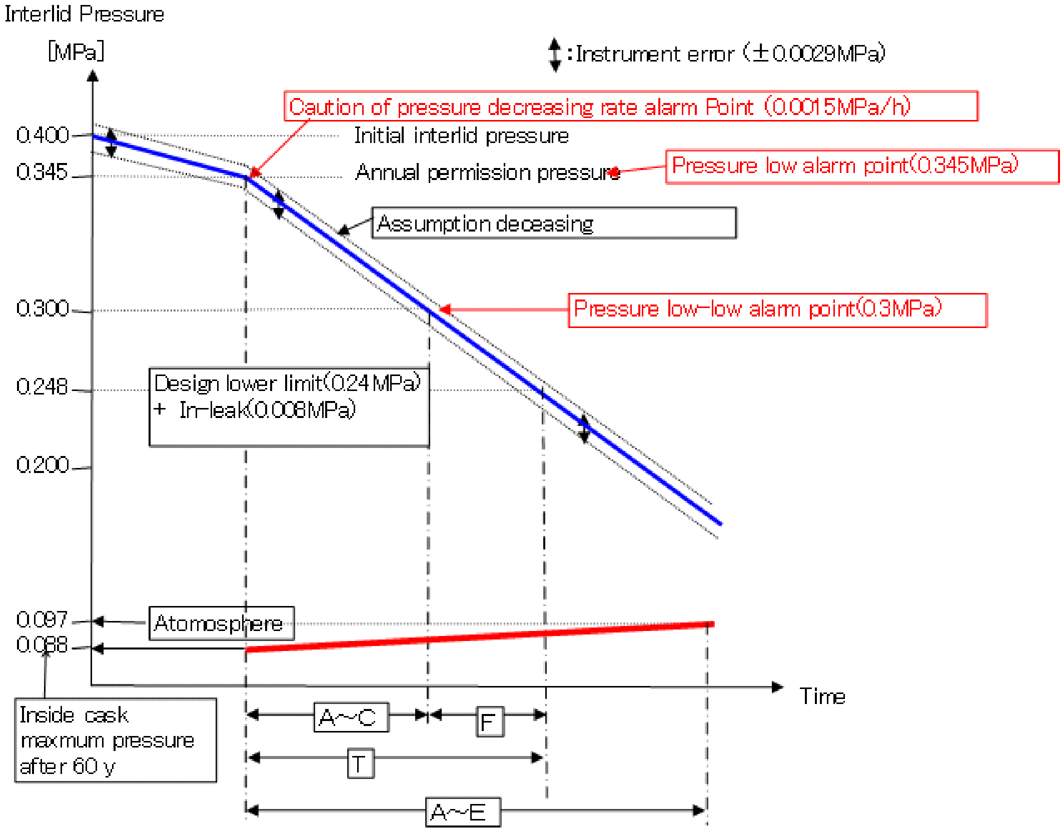
Initial interlid pressure：0.4MPa

Permission annual interlid pressure decreasing：0.055MPa

(2)Verification of defining the alarm in consideration of working time.

We verified that we secure the times to investigate a leak point and determine how to management until the interlid pressure reach the design limit after the “Pressure low” is dispatched.

This figure shows the results of verification.



T:Time from leak detection to reach design lower limit

A~C:Specification and recovery time of the disclosure part by secondary lid seal performance inspection

F:Time to move the cask to handling area and to attach the third lid

A~E:Time to maintain minus pressure in the cask

Figure 8. Alarm set points study

7. Conclusion

(1) Although the “lead pipe system” has a characteristic of pressure indication fluctuation along with the environmental temperature change, the range of this fluctuation is within a general combined instrument error, and it can fully be used as pressure monitoring.

(2) The difference between the direct system and the “lead pipe system” was not found about the detection performance in a minute leak state.

(3) When monitoring by the “lead pipe system”, it turned out that repair work time can be fully taken by an alarm dispatch .

REFERENCES

*1: Standard for safety design and inspection of metal cask for spent fuel interim storage facility. 2010, AESJ, P121-P130

*2: The security policy of spent fuel transportation after the interim storage. The separate sheet 5. 2010, Transport technical advisory committee,