Optimization of Standby Gas Treatment System Capacity for US-ABWR

Yasuhiko Suzuki, Hirokazu Yoshino, Mika Tahara
Toshiba Corporation
Power Systems Company
Yokohama, Japan

1.ABSTRACT

Standby Gas Treatment System (SGTS) drawdown analysis is required in the US NRC's NUREG-0800 Standard Review Plan (SRP) 6.2.3 to check the appropriateness of the SGTS capacity.

The airtightness of reactor building secondary containment has been improved as a result of recent progress in construction technology, this paper explains the purpose of proposing the optimum SGTS capacity required for US- Advanced Boiling Water Reactor (ABWR).

From comparison with actual startup test data of Japanese ABWR plant, we found that it is appropriate to take the heat absorption effect into the SGTS drawdown analysis.

By considering heat absorption, the SGTS capacity is enough in the capacity that corresponds to the secondary containment leak rate design condition. A compact SGTS system can be achieved with better operability and maintainability, and lower cost.

2.BACKGROUND

The SGTS is one of the Engineered Safety Features (ESF) installed in Boiling Water Reactor (BWR) and ABWR plants to maintain negative pressure of the secondary containment and to limit the discharge of radioactivity into the environment during a reactor accident. Figure 2-1 shows a schematic diagram of the Standby Gas Treatment System.

Primary Containment Vessel (PCV) for ABWR is made from reinforced concrete, and secondary containment that includes PCV is also made using concrete structures. Figure 2-2 shows a sectional plan of the ABWR Reactor Building.

In SGTS drawdown analysis, NRC requires an SGTS capacity of lower than 0.25 inch w.g. (63 Pa) negative pressure within the drawdown time assumed in the analysis of radiological consequences of the design basis Loss Of Coolant Accident (LOCA).

ABWR SGTS design is conservative regarding the drawdown time, because it is to achieve 63 Pa negative pressure within 10 minutes. On the other hand, radiological consequences assume 20 minutes' drawdown time of the design basis LOCA.

The airtightness of reactor building secondary containment has been improved as a result of recent progress in construction technology such as improvement of the sealant of pipes and cables penetration. Figure 2-3 shows that secondary containment leak rates have attained 50 %/day or less in the plants that Toshiba has constructed in recent years. The SGTS capacity of plants in Japan (They are designed with the range of 2000 m^3/h ~ 3000 m^3/h) corresponds secondary containment leak rates. The SGTS capacity of ABWR Design Control Document (DCD) is 6800 m^3/h, even thought the secondary containment leak rate design condition is 50%/day. As a result, we think the following problems will arise.

- In an actual plant, secondary containment becomes overpressured.
- The fan operation in the flow rate is greatly reduced, and there is the problem of surging and excessive electric heater heat.
- As a result, machinery performance and operability will worsen.
- The machinery size becomes big, and this will have an impact on cost and general arrangement of reactor building.

As SGTS drawdown analysis should be included in Combined construction permit, and conditional Operating License (COL), we have studied the optimal SGTS capacity and drawdown analysis.

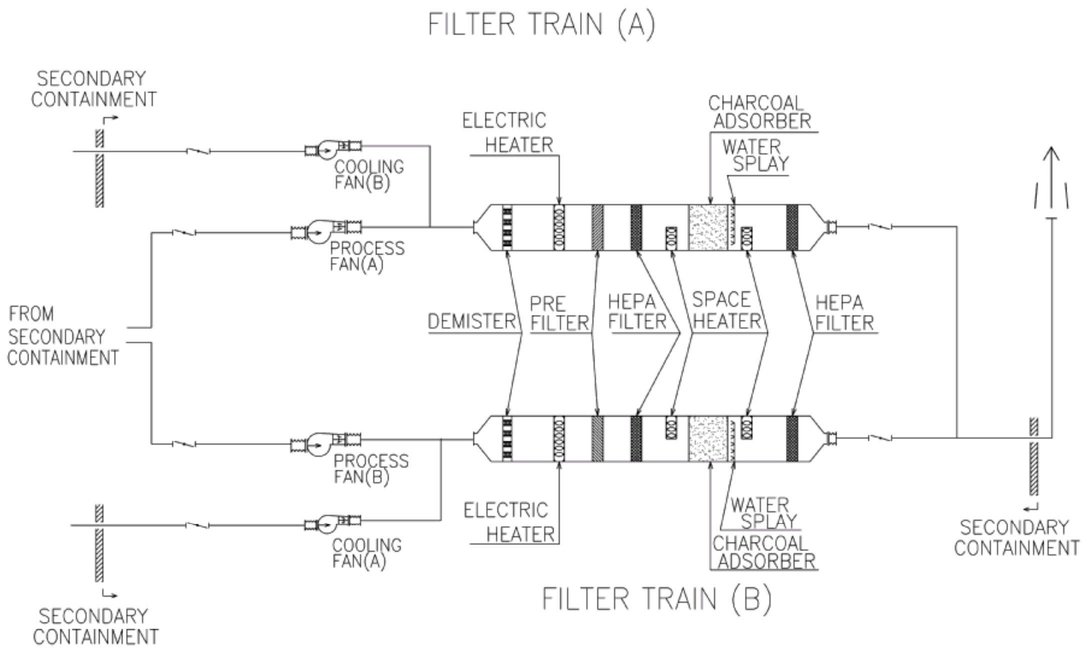


Figure 2-1 Schematic Diagram of Standby Gas Treatment System

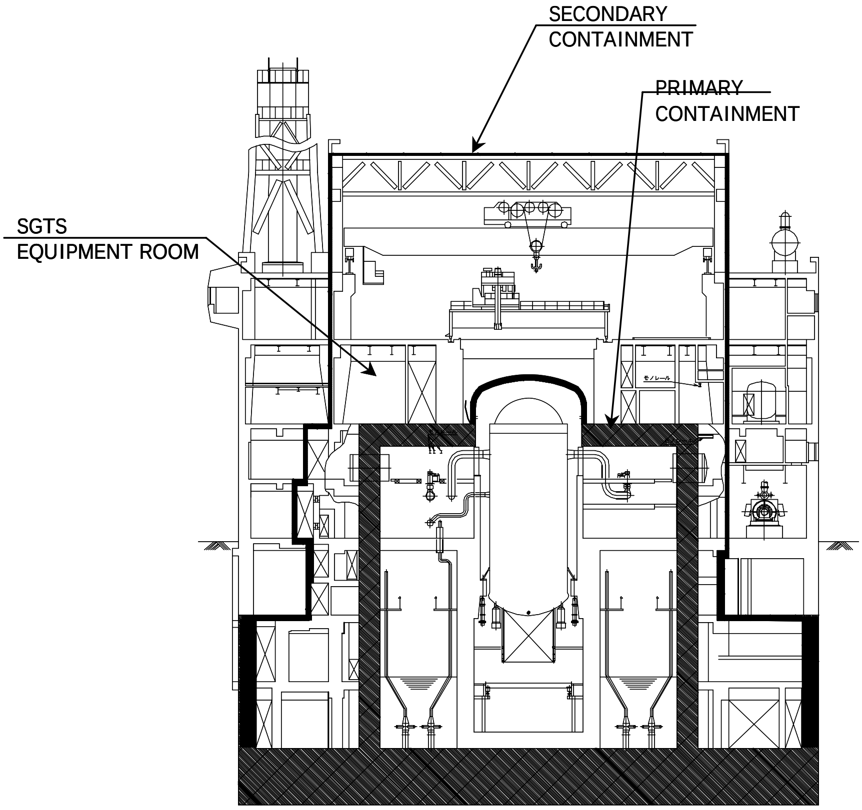


Figure 2-2 Sectional plan of ABWR reactor building

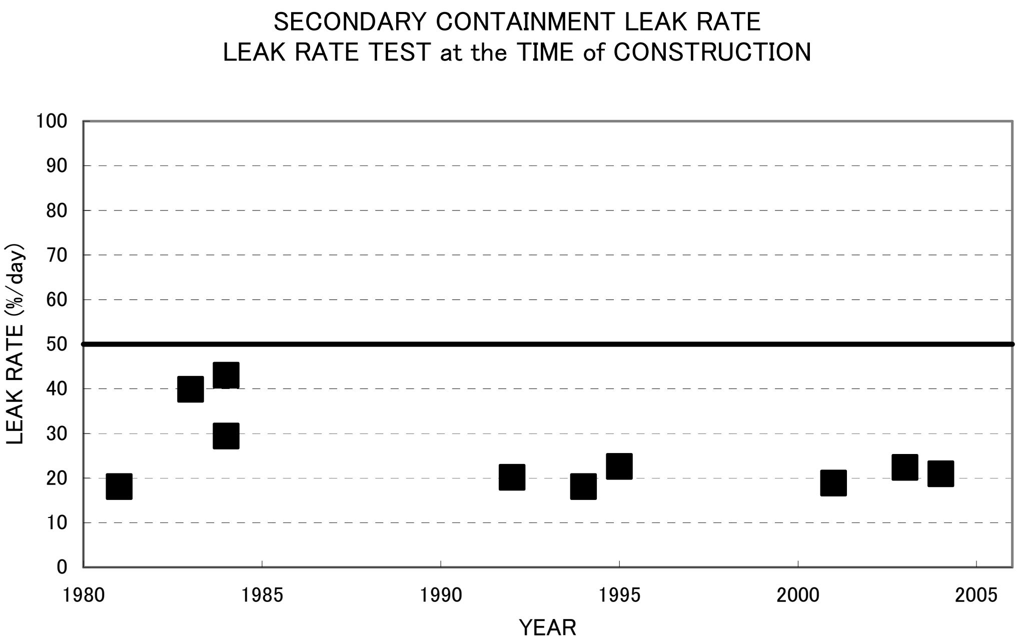


Figure 2-3 Secondary containment leak rates (converted into –63 Pa) results in recent Japanese plants

3. ARRANGEMENT OF ANALYSIS CONDITIONS

In this chapter, the items that should be taken into consideration in analysis are arranged based on the SRP 6.2.3 Ⅱ guideline.

Table 3-1 shows the SRP requirements for the items that should be taken into consideration in analysis, as well as the Toshiba analysis status and comparison with SRP.

The SRP requirements and our analysis conditions are in agreement. In addition, we would discuss the heat absorption effect that is not mentioned by SRP.

Table 3-1 Comparison of the consideration in analysis

ITEM	SRP	TOSHIBA ANALYSIS	COMPARISON with SRP
Heat Transfer From PCV	6.2.3 Section Ⅱ.1.a	Heat transfer of concrete by difference of temperature at the time that design base LOCA is considered.	AGREEMENT
Heat Loss to the Outside Air	6.2.3 Section Ⅱ.1.b	Adiabatic condition	AGREEMENT
Compressive Effect of PCV	6.2.3 Section Ⅱ.1.c	It is zero because of concrete.	AGREEMENT
Inleakage	6.2.3 Section Ⅱ.1.d	Inleakage rate (50 %/day @ 63 Pa) is considered.	AGREEMENT
Outleakage	6.2.3 Section Ⅱ.1.e	Outleakage do not consider at positive pressure.	AGREEMENT
Accident Condition	6.2.3 Section Ⅱ.1.f	The most severe single active failure for the SGTS drawdown analysis is loss of one divisional exhaust fan and it is considered that.	AGREEMENT
Heat Loads	6.2.3 Section Ⅱ.1.g	Equipment heat loads and lighting heat loads at the time of LOCA+LOP(Loss-Of-Power accident) accident condition are considered.	AGREEMENT
Fan Performance Characterristics	6.2.3 Section Ⅱ.1.h	A time lag up to rating of a fan is considered.	AGREEMENT
Heat Absorption	Reference is not made	Concrete heat absorption is considered. The concrete area in secondary containment is estimated with major floors, walls, and ceilings.	Not written in SRP*

* Conservative condition is necessary.

4.ANALYSIS MODEL

We have developed a SGTS drawdown analysis model by using CONTEMPT-LT in accordance with requirements of SRP. CONTEMPT-LT is a computer code developed to analyze the thermal hydraulic behavior of Light Water Reactor (LWR) containment in LOCA. The code is able to model four specific compartments such as the wetwell, drywell, annular and reactor primary system compartments. The characteristic of each compartment is shown in Table 4-1. The drywell compartment has valid functions for SGTS drawdown analysis. Therefore we have drawn on the drywell compartment of CONTEMPT-LT to construct the SGTS drawdown model. Figure 4-1 shows the scheme of the SGTS drawdown model. A description of the major functions included in the SGTS drawdown model is given below.

4.1 Secondary containment leakage model

The normal leakage model applies to the secondary containment leakage calculation. The equation used to calculate the leak rate for normal leakage is

$$W_{LN} = K_L \cdot \rho (p_i - p_e) \tag{4-1}$$

where

W_{LN}	: mass leakage rate [m^3/Pa·s]
K_L	: leakage coefficient [m^3/Pa·s]
ρ	: density of flowing vapor [kg/m^3]
p_i	: pressure in inlet compartment [Pa]
p_e	: pressure in exit compartment [Pa]

The leakage rate of the secondary containment is proportional to the square root of the pressure differential, as shown in Eq.(4-2). Hence, a table of leakage coefficient K_I depending on the pressure differential is applied to the CONTEMPT-LT code, in order to obtain the same leakage rate both with Eq.(4-1) and with Eq.(4-2) at any pressure difference.

$$W_{IN} = k \cdot \rho (p_i - p_e)^{0.5} \tag{4-2}$$

k : secondary containment leakage coefficient [m^3/Pa$^{0.5}$ s]

4.2 Mass and energy addition

The SGTS drawdown model utilizes the function of mass and energy addition for the simulation of the SGTS flow and the heat load in the secondary containment. CONTEMPT-LT prepares the following input tables in order to add the mass and energy to the drywell compartment.

(1) Drywell vapor region direct heat and water addition table

(2) Drywell air addition table

(3) Drywell decay power and metal-water reaction multipliers and water addition table

4.3 Heat transfer through heat-conducting structures

CONTEMPT-LT provides heat-conducting structures that are able to transfer heat between any combinations of compartments or between any compartment and the outside air. The one-dimensional multi-region heat conduction equation used in CONTEMPT-LI is

$$g(x)\ \frac{\partial u(x,t)}{\partial t} = \nabla k(x)\cdot\nabla u(x,t) + S(x,t) \qquad (4\text{-}3)$$

where u : temperature [K]
x : space variable [m]
t : time variable [s]
g : volumetric heat capacity [J/m³・s]
k : thermal conductivity [W/m・K]
S : source term per unit volume [W/m³]

The boundary condition is

$$-k\ \frac{\partial u}{\partial \bar{n}} = H(u,t)\ [u - u_B(t)] \qquad (4\text{-}4)$$

where u : surface temperature [K]
$u_B(t)$: bulk temperature [K]
$\bar{n}$: vector in the direction out of the heat-conducting structure
H(u,t) : heat transfer coefficient [J/s m² K]

The heat transfer coefficient is based on the natural convection heat transfer that occurs on the concrete structure surface in the secondary containment. The bulk temperature is the secondary containment vapor region temperature. The rate of heat transfer between the surface of a heat-conducting structure and an adjacent medium is calculated by the following equation.

$$R_{HT} = A \cdot h^b \cdot H\,(u - u_B) \quad (4\text{-}5)$$

R_{HT} : heat transfer rate [W]

H : heat transfer coefficient [J/s m^2 K]

A : effective heat transfer surface area multiplier [-]

h^b : geometry surface area adjustment factor [m^2]

u : surface temperature of the structure [K]

u_B : temperature of the medium adjacent to the boundary [K]

Table 4- 1 Applicable Compartment in CONTEMPT-LT

Number	1	2	3	4
Object	Primary containment system	Wetwell	Drywell	Annular
Region	Liquid only	Vapor and Liquid	Vapor and Liquid	Vapor and Liquid
Available function				
Leakage	×	○	○	○
ECCS and spray	○	○	○	×
Fan cooler	×	×	○	×
Mass and energy addition	○	×	○	×
Heat-conducting structure	△	○	○	○

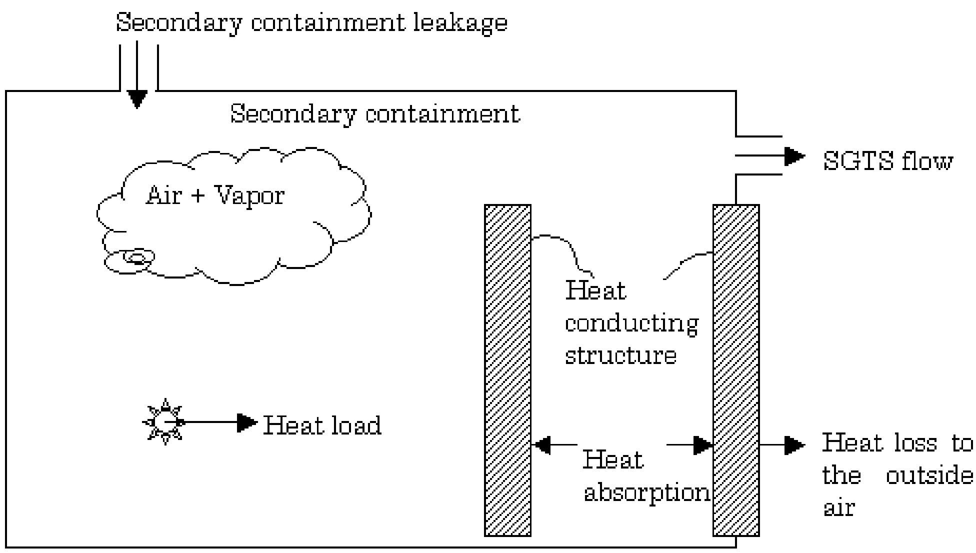


Figure 4- 1 Scheme of the SGTS drawdown model by CONTEMPT-LT

5.ANALYSIS

5.1 Startup test of actual plants

In this section, the heat absorption effect not mentioned by SRP is considered. This section makes a comparison with the actual data for an ABWR plant in Japan where a startup test has been performed recently, to check whether the heat absorption effect is estimated correctly. Figure 5.1-1 shows a comparison of the analysis results for three cases in which heat absorption and heat loss to the outside air are substituted with actual data. CASE1 and CASE2 compare the heat absorption effect. CASE3 and measurement data compare the estimate of heat absorption extent is adequate. Table 5.1-1 shows the differences with regard to the heat absorption and heat loss to the outside air for each case. Table 5.1-2 shows the input data used for each analysis case.

Table 5.1-1 Comparison of heat absorption
and heat loss to outside air in the analysis of the 3 cases

CASE	HEAT ABSORPTION	HEAT LOSS of the OUTSIDE AIR
CASE 1	No consideration	Adiabatic
CASE 2	Consideration	Adiabatic
CASE 3	Consideration	Consideration

Table 5.1-2 Input data for actual plant analysis

CONTENTS	Startup Test
Rated Electric Output (Before SGTS Start)	1380MW (100%)
Test Condition	Simultaneouse Full Closure of all MSIVs Test
SGTS Capacity	Measurement Data
Ambient Temperature	18.8℃
Ambient Humidity	39%RH
Secondary Containment Initial Temperature	28.5℃
Secondary Containment Initial Humidity	20%RH
Secondary Containment Inleakage Rate	22.4%/day
Secondary Containment Initial Negative Pressure	212Pa
Sensible Heatload	386.6kW

Figure 5.1-1 indicates the following.

a) CASE1 (without heat absorption, without heat loss to outside air)

It is significantly different from the actual data.

b) CASE2 (with heat absorption, without heat loss to outside air)

Although the actual data is approximated, it is still conservative.

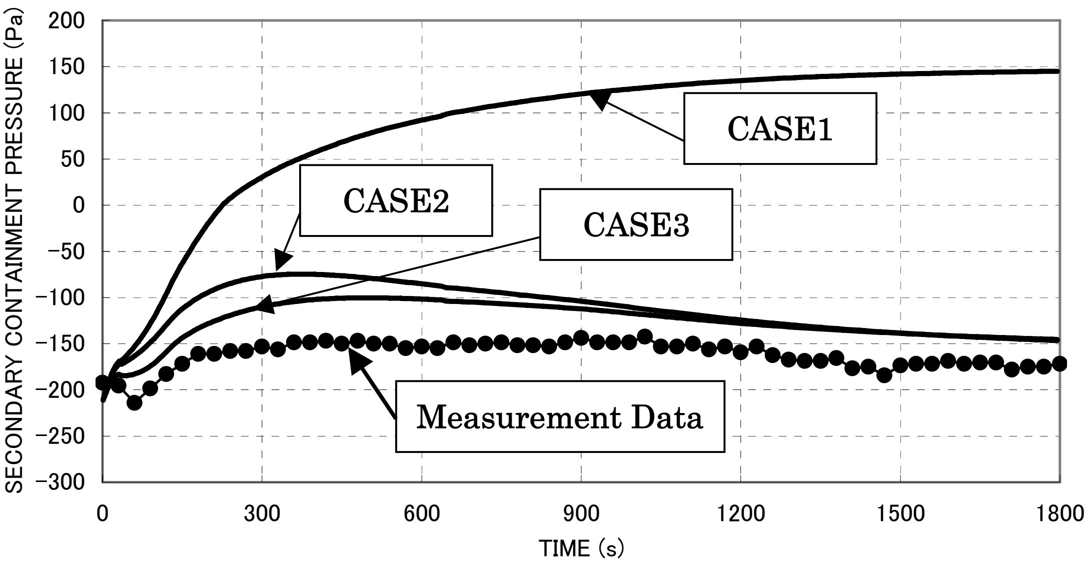
c) CASE3 (with heat absorption, with heat loss to outside air)

Although the actual data is closely approximated, it is still conservative.

We also have actual plant data from Japan where a startup test has been conducted recently. It has been checked that the analysis results and measurement data both showed the same trends.

On reflection of these findings, it became clear that (1) it is appropriate to take the heat absorption effect into consideration for analysis, and that (2) the estimate of heat absorption is sufficiently conservative.

Consequently, using the conditions of Table 5.1-3, we have confirmed that the analysis results correspond to a measurement data of actual plants.



CASE1: without heat absorption and heat loss to the outside air

CASE2: with heat absorption, without heat loss to the outside air

CASE3: with heat absorption and heat loss to the outside air

Figure 5.1-1 Measurement data vs. analysis result

Table 5.1-3 Consideration in analysis

ITEM	TOSHIBA ANALYSIS
Heat Transfer From PCV	Heat transfer of concrete by difference of temperature at the time of design base LOCA is considered.
Heat Loss to the Outside Air	Adiabatic condition
Compressive Effect of PCV	It is Zero because of concrete.
Inleakage	Inleakage rate (50 %/day @ 63 Pa) is considered.
Outleakage	Outleakage do not consider at positive pressure.
Accident Condition	The most severe single active failure for the SGTS drawdown analysis is loss of one divisional exhaust fan and it is considers that.
Heat Loads	Equipment heat loads and lighting heat loads at the time of LOCA+LOP(Loss–Of–Power accident) accident condition are considered.
Fan Performance Characterristics	A time lag up to rating of a fan is considered.
Heat Absorption	Concrete heat absorption is considered. The concrete area in secondary containment is estimated with major floors, walls, and ceilings.

5.2 Optimization analysis for US-ABWR

In order to study the optimal SGTS capacity for US-ABWR, the following four cases have been performed.

- CASE4 : SGTS capacity 6800 m^3/h without heat absorption.
- CASE5 : SGTS capacity 6800 m^3/h with heat absorption.
- CASE6 : SGTS capacity 3000 m^3/h without heat absorption.
- CASE7 : SGTS capacity 3000 m^3/h with heat absorption.

A requirement for the analysis result is to achieve less than -63Pa after an accident in 10 minutes. Table 5.2-1 shows the input data of each case for analysis.

Table 5.2-1 Input data of analysis for US-ABWR

CONTENTS \ CASE	CASE4	CASE5	CASE6	CASE7
SGTS Capacity	6800m^3/h	6800m^3/h	3000m^3/h	3000m^3/h
Ambient Temperature	46℃ (Design Condition)			
Ambient Humidity	90%RH (Design Condition)			
Secondary Containment Inleakage Rate	50%/day (Design Condition)			
Heatload	LOCA + LOP (Design Condition)			
Heat Absorption	No consideration	Consideration	No consideration	Consideration

Figure 5.2-1 shows the optimization study of the SGTS capacity. From the analysis results, the following conclusions can be drawn.

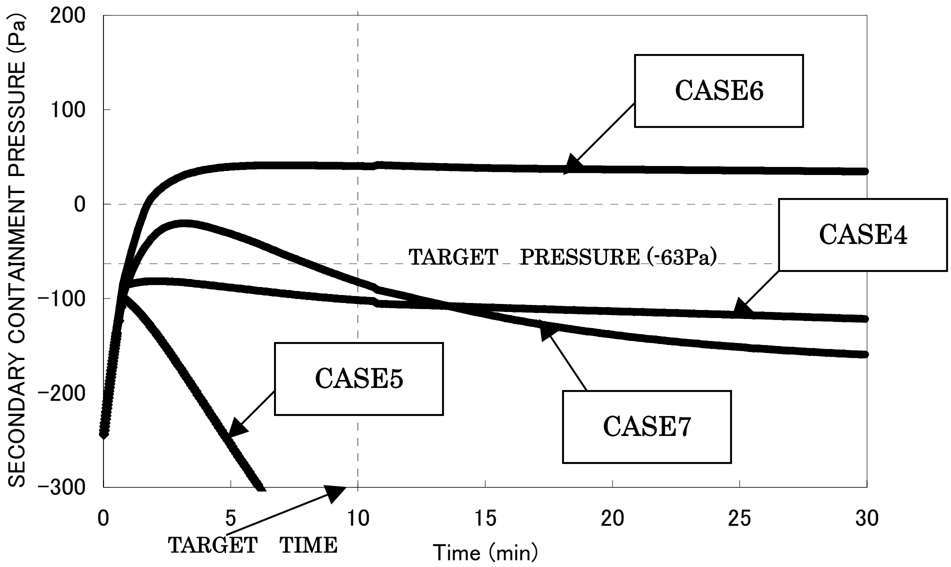
a) CASE4, 5

When heat absorption effect is not considered, an SGTS capacity of 6800 m^3/h is needed (CASE4). However, it is thought that an actual plant with heat absorption is close to CASE5. CASE5 shows that the negative pressure is too great, so that the SGTS fans operate at a reduced flow rate to protect the secondary containment pressure boundary. However, there are some problems such as surges of the SGTS fans, and overheating of the SGTS electric heaters.

b) CASE7

The SGTS capacity is set to 3000 m^3/h as a result of taking heat absorption into consideration (CASE7). We think that CASE7 is close to the trend of the actual plant. Consequently, 3000 m^3/h is the optimal SGTS capacity for US-ABWR. A SGTS capacity of 3000 m^3/h corresponds to equipment whose operability and compactness have been taken into consideration. The size of a SGTS train can be reduced by about 63 % (6800 m^3/h → 3000 m^3/h).

Closer consideration of the above has made it clear that a 3000 m^3/h SGTS capacity is sufficient to attain a pressure of –63 Pa within 10 minutes.



CASE4: 6800 m^3/h, without heat absorption	CASE5: 6800 m^3/h, with heat absorption
CASE6: 3000 m^3/h, without heat absorption	CASE7: 3000 m^3/h, with heat absorption

Figure 5.2-1 Optimization of SGTS flow rate

5.3 Comparison of CONTEMPT-LT and TRAC code

It was mentioned in Chapter 5.1 that we have constructed a SGTS drawdown analysis model by using CONTEMPT-LT and verified the model based on actual plant data. CONTEMPT-LT has sufficient scope to satisfy the SRP requirements of the SGTS drawdown analysis. However, CONTEMPT-LT is too simple to analyze the continuous behavior in PCV through the secondary containment. We have therefore used the heat load generated in the secondary containment due to LOCA as the input data.

On the other hand, the TRAC code has been developed to analyze the thermal hydraulic behavior in the LWR, and this code is capable of analyzing a wide range of behavior with a generous amount of flexibility. Furthermore, TRAC has a wealth of control models that can simulate the detailed control behavior associated with equipment operation, fan flow rate and so on. We have thus also developed a SGTS drawdown model using the TRAC code.

Figure 5.3-1 shows the scheme of the SGTS drawdown model by TRAC. One compartment simulates the secondary containment like the CONTEMPT-LT model in order to compare the results between the TRAC analysis and CONTEMPT-LT analysis. In the TRAC model, the secondary containment leakage, SGTS flow, heat-conducting structures and Heating, Ventilating and Air-Conditioning (HVAC) operation are simulated. The SGTS drawdown analysis is conducted according to the following steps.

Step 1: Steady-state analysis with the heat load of normal operation and HVAC operation

Step 2: HVAC is turned off and the heat load is changed to the accident condition

Step 3: SGTS startup

Comparisons of the analysis results between TRAC and CONTEMPT-LT about the actual plant behavior and US-ABWR design analysis are shown in Figure 5.3-2 and Figure 5.3-3, respectively. The trends of the pressure differentials almost agree, although the result of CONTEMPT-LT is slightly more conservative than the result of TRAC. A time lag of the HVAC isolation affects the pressure differential of the TRAC results.

As stated above, we have two types of SGTS drawdown analysis model; one is modeled using CONTEMPT-LT and the other is modeled using TRAC. We will use these models appropriately according to the objectives and to progress to the design of reasonable plant systems.

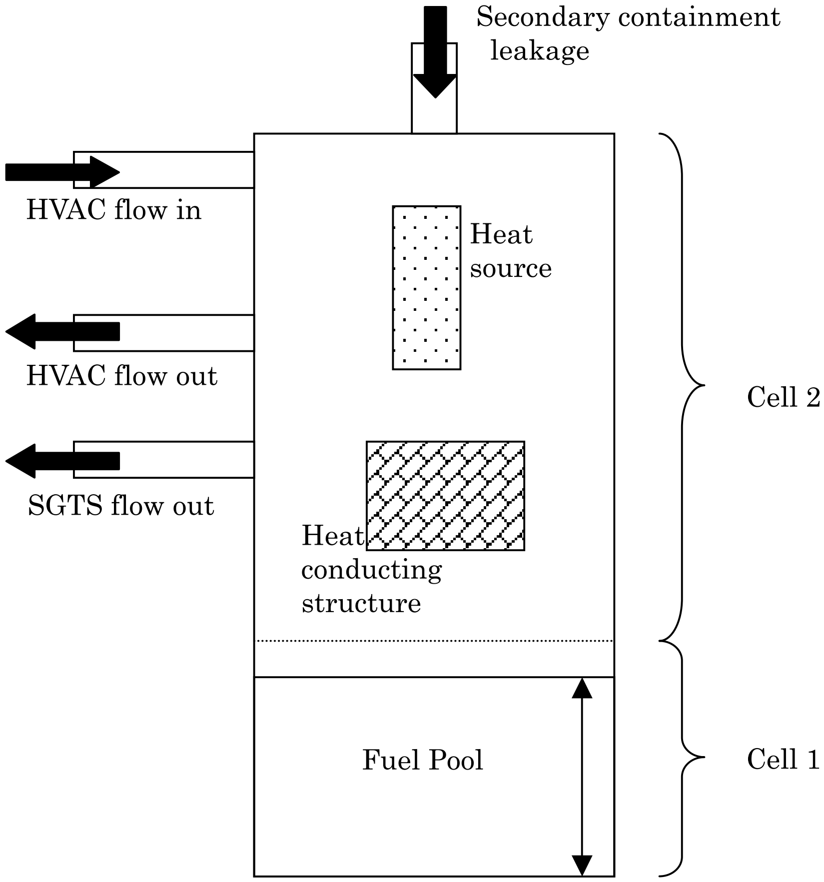


Figure 5.3-1 Scheme of the SGTS drawdown model by TRAC

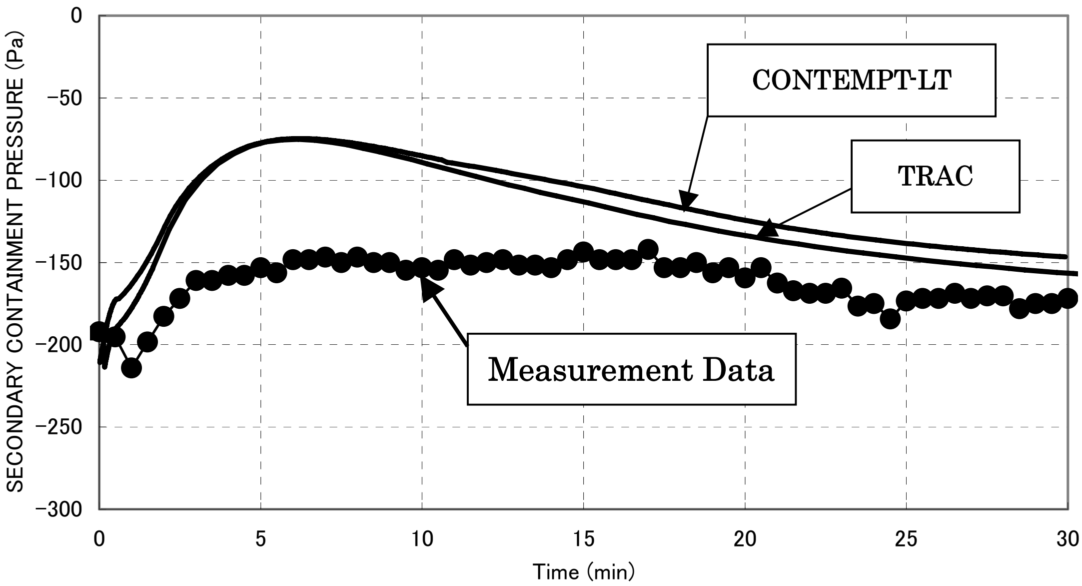


Figure 5.3-2 Comparison of the analysis results by TRAC and CONTEMPT-LT (Actual plant)

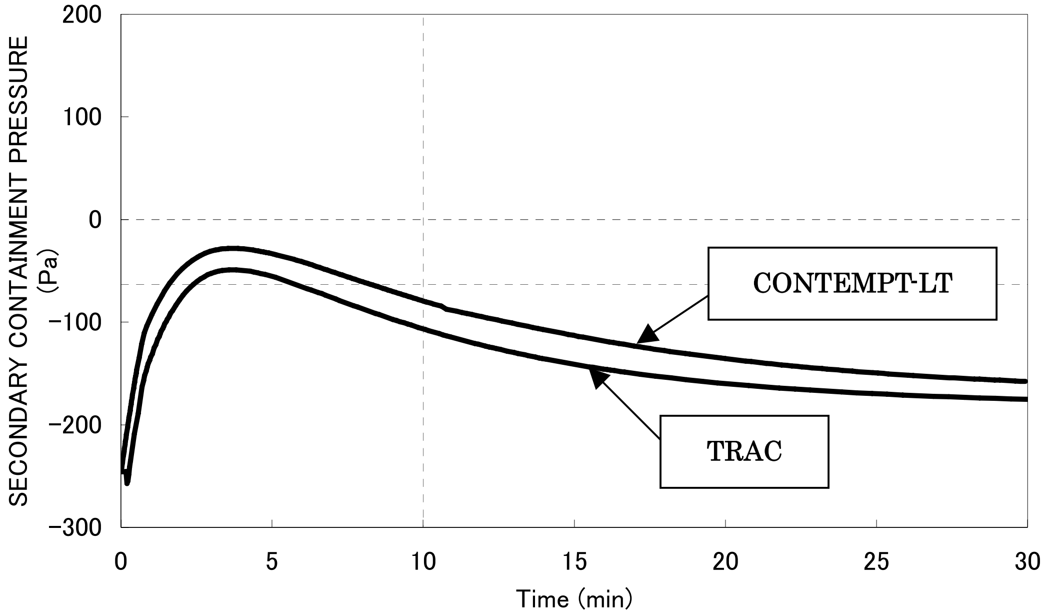


Figure 5.3-3 Comparison of the analysis results by TRAC and CONTEMPT-LT (US-ABWR design condition)

6.CONCLUSION

Toshiba has been constructed 22 BWR plants in Japan. Toshiba has been working on design, construction, testing, maintenance and modification activities. This paper shows optimization of the SGTS capacity for US-ABWR based on our engineering experience. In conclusion,

(1) From comparison with actual startup test data of Japanese ABWR plant, we found that it is appropriate to take the heat absorption effect into the SGTS drawdown analysis.

(2) By considering heat absorption, SGTS capacity can reduce from 6800 m^3/h to 3000 m^3/h which is correspond to the secondary containment leak rate design condition.

(3) A compact SGTS system can be achieved with better operability and maintainability, and lower cost.

(4) Two types of the SGTS drawdown analysis model are applicable; one is modeled using CONTEMPT-LT and the other is modeled using TRAC. These two analytical results show good agreement.

7.REFERENCES

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