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Enclosure 2

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Aircraft Impact Assessment for 4S (~~Proprietary~~)

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Aircraft Impact Assessment for 4S

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TOSHIBA CORPORATION

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LIST OF ACRONYMS AND ABBREVIATIONS

4S	Super-Safe, Small and Simple
AIA	Aircraft Impact Accident or Aircraft Impact Assessment
CFR	Code of Federal Regulations
COL	Combined Operating License
DBT	Design Basis Threat
EMP	Electromagnetic Pump
EPRI	Electric Power Research Institute
GE	General Electric Corp.
HVAC	Heating, Ventilation, and Air Conditioning
IAEA	International Atomic Energy Agency
IHTS	Intermediate Heat Transport System
IHX	Intermediate Heat Exchanger
IRACS	Intermediate Reactor Auxiliary Cooling System
NEI	Nuclear Energy Institute
NRC	U.S. Nuclear Regulatory Commission
RHR	Residual Heat Removal
RVACS	Reactor Vessel Auxiliary Cooling System
SG	Steam Generator
UN	United Nations

1 INTRODUCTION

The terrorist attacks on the United States on September 11, 2001 have focused public attention on the potential for a crash of a large commercial aircraft into structures that are part of important infrastructure, including nuclear power plants. In response to the terrorist attack, the United Nations (UN) Security Council passed Resolution 1373 (2001) with an attachment that defines the physical security objectives and fundamental principles proposed by the International Atomic Energy Agency (IAEA). For the aircraft impact accident (AIA) design basis threat (DBT) that is the subject of this report, the following objectives were approved:

- Protect against sabotage of nuclear facilities and sabotage of nuclear material in use and storage and during transport; and
- Mitigate or minimize the radiological consequences of sabotage.

The fundamental principles contained in the Resolution define the responsibility of the state, in particular, Principle G, which states: "*The state's physical protection should be based on the State's current evaluation of the threat.*" Principles H and I require a graded approach and defense-in-depth principles to be used for developing appropriate physical security measures against identified threats. The graded approach is a risk-based approach that requires allocating more resources where the risk is high and fewer resources for lower risks.

The IAEA has developed a solid foundation for dealing with security issues through its hierarchical approach starting from basic security and safety principles and branching to recommendations, guides, and technical guidance. It also developed state-of-the-art approaches for analyzing the aircraft impact accident DBT. However, there are significant uncertainties resulting from the many participants providing input, and variations with time, site, and the security status in different regions of the world. As a conclusion of a study conducted by IAEA on advanced nuclear reactors, small and passive reactors were seen to have potential advantages against attractiveness as a terrorist target and insider threats. However, a detailed analysis was recommended on a case-by-case basis to uncover any potential weaknesses at the early design stage.

The IAEA issued a document that covers recommendations on all elements of a physical security regime, including assignment of responsibilities to the state "competent authority" that plays the role of a regulator and the reactor license holder, as well as management of the physical protection program, risk management, defense in depth, etc. The document includes this requirement for new reactor facilities [1]:

"*Item 3.28: For a new reactor facility, the site selection and design should take physical protection into account as early as possible and also address the interface between physical protection, safety and nuclear material accountancy and control to avoid any conflicts and to ensure that all three elements support each other.*"

Subsequent to the events of 2001, the U.S. Nuclear Regulatory Commission (NRC) revised 10 CFR Part 50 and 10 CFR Part 52 to require a more rigorous aircraft impact assessment. The aircraft impact assessment rule requires new reactor design applicants to perform a design-specific assessment of the effects on the facility of the impact of large commercial aircraft using realistic analyses [2]. For use in satisfying the requirements of 10 CFR 50, the NRC issued Regulatory Guide 1.217 to deal with an aircraft impact resulting from a beyond-design-basis malicious act [3].

The industry has been studying numerous cases to assess and enhance the capability of current nuclear power plants to withstand an aircraft impact. The Nuclear Energy Institute (NEI) has developed a methodology and published guidelines to assist vendors and Combined Operating License (COL) applicants in assessing the physical, shock, and fire effects of the impact of a large commercial aircraft on nuclear reactor structures and other structures [4]. This guideline (hereafter, "the NEI guideline") is endorsed by the NRC [3].

The nuclear power industry in the United States is confident that nuclear plant structures that contain nuclear fuel can withstand aircraft impacts. This confidence is based on the fact that nuclear plant structures have thick concrete walls with heavy reinforcing steel and are designed to withstand large earthquakes, extreme overpressures, and hurricane force winds. This confidence was validated by analytical study, taking large commercial aircraft impact into account [5].

The Toshiba 4S (Super-Safe, Small and Simple) is designed to withstand beyond-design-basis events such as a large aircraft crash. The purpose of this report is to validate this capability by considering 4S's design-specific conditions. The analysis described herein basically conforms to the NEI Guideline, which does not consider safeguards information. This analysis will be further updated as appropriate after Toshiba obtains access to the relevant safeguards information as the pre-application review process continues.

Section 2 describes the purpose and scope of this report. Section 3 presents the process and definition of the 4S preliminary aircraft impact assessment. In Section 4, the evaluation performed for the containment structures is described. The impact and provision against aircraft attack is described in Section 5. The evaluation performed for the residual heat removal system is described in Section 6. Section 7 summarizes the main conclusions of the report.

2 PURPOSE AND SCOPE

2.1 Purpose

The purpose of this report is twofold:

1. To document the process and data regarding the aircraft impact assessment for the 4S.

2. To obtain feedback from the NRC staff on the presented material either in writing or in a meeting at the staff's convenience. Such feedback will be utilized by the 4S project in confirming and/or completing the plant design.

2.2 Scope

This report describes the process for identifying the accident scenario due to aircraft impact and performing an aircraft impact evaluation to show that 4S's plant structures and safety features can withstand the appropriate aircraft impact. In this report, the overview of safety features primarily covers the residual heat removal system, as the capability of the Reactor Vessel Auxiliary Cooling System (RVACS) is the focus of the heat removal evaluation in case of aircraft impact. These results are based on evaluation of the 10MWe-4S design.

3 ASSESSMENT REQUIREMENTS

The NRC has issued 10 CFR 50.150, "Aircraft Impact Assessment," and requires applicants to identify and incorporate into the design those design features and functional capabilities to show that, with reduced use of operator actions:

- The reactor core remains cooled, or the containment remains intact; and
- Spent fuel cooling or spent fuel pool integrity is maintained.

The NEI Guideline provides a common methodology for performing the assessments to ensure a technically sound and consistent approach is used for reactor design [4]. This methodology provides two evaluation methods to meet the assessment requirement mandated by 10 CFR 50.150 [2]:

- Containment and Spent Fuel Pool Evaluation

  — Two distinct types of structural failure modes are evaluated for containment structures and spent fuel pools. Local (scabbing and perforation) failure caused by impact of the aircraft engines and global (plastic collapse) failure caused by impact of the complete aircraft. As described in the NEI Guideline, local failure is largely independent of the global force/deflection characteristics of the structure.

- Heat Removal Evaluation

  — Physical, shock, and fire effects of an aircraft impact can cause damage to systems needed to maintain cooling of fuel in the vessel as well as the spent fuel pool. Assessing the physical, shock, and fire effects of aircraft impacts on the ability to maintain fuel cooling are more complex than analyzing impacts on containment structures and spent fuel pools.

As for the spent fuel pool, the 4S has no spent fuel pool due to its long-term (30 years for the 10 MWe version) operation without refueling. Therefore, this report focuses only on the soundness of the 4S containment structure and heat removal system.

4 CONTAINMENT STRUCTURES

The 4S reactor is housed in a below-grade structure as shown in Figure 4-1. This layout contributes to the mitigation of an aircraft impact. The thick walls of reactor building contain the steam generator (SG) room and control room and is designed to withstand not only the direct aircraft impact to the structure, but also the external fire and explosion caused by the impact. Therefore, an aircraft crash-induced fire inside the reactor buildings would be avoided by preventing perforation of these below-grade buildings. The above-grade turbine building is not protected from aircraft impact.

An aircraft crash could also cause a malfunction of instrumentation in the reactor. This influence will be examined in a subsequent evaluation.

Two types of above-grade stacks for discharge of residual heat from the reactor are located at the top of the reactor building as shown in Figure 4-1. The residual heat removal systems are described in the following section.

A complete assessment of the ability of the reactor building to withstand an aircraft impact would require access to the detailed safeguards information identifying the parameters for such an analysis. This evaluation will be further updated as appropriate after Toshiba obtains access to the relevant safeguards information as the pre-application review process continues.

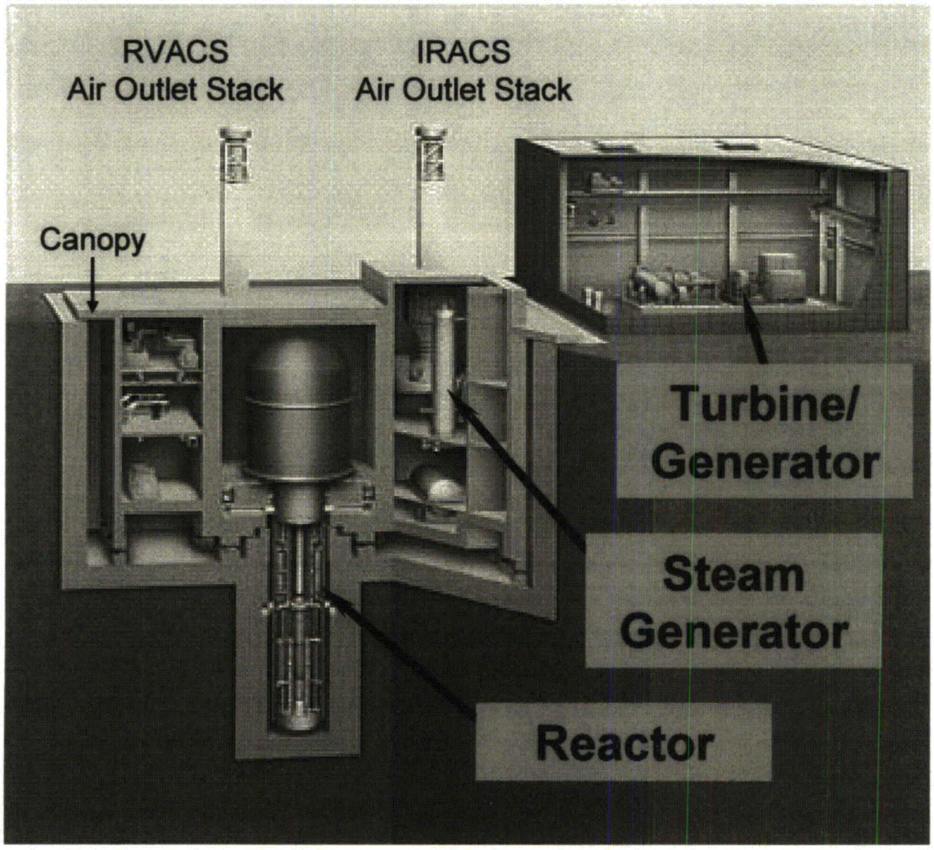

Figure 4-1 4S Plant Cut-View

5 IMPACT AND PROVISION AGAINST AIRCRAFT ATTACK

5.1 Physical Impact

Physical impact on 4S plant and current provision are described in Table 5-1.

Table 5-1 Physical Impact of Aircraft Impact and Provision

Initial Event	Effect factor	Provision
Impact to reactor building	Building breakage	(Prevention of breakage) • Reinforce the building to withstand aircraft impact.
	Loss of power	(Prevention of loss of power) • Disperse emergency power to avoid simultaneous malfunction. (Mitigation of loss of power influence) • RVACS as a final heat sink can remove the decay heat even in the station black out, thus loss of power dose not effect decay heat removal system immediately.
	Seismic isolator breakage	(Prevention of breakage) • Reinforce roof hatch to withstand aircraft impact from the top. • Direct side impact can be avoided in the under ground construction or install the wall around building. Further analysis would be an issue in the future.
	Degradation of control room habitability due to malfunction of HVAC system	(Mitigation of degradation) • Stock the emergency breathing equipment to ensure operator's safety.
	Breakage of safety graded instruments due to impact	(Protection of instruments) • Consider the installing rubber cushion to protect instruments.
	Loss of residual heat removal capability due to RVACS blockage by wreckage	(Mitigation of influence of RVACS blockage) • Install the RVACS air exhaust stack well away from each other to avoid simultaneous breakage • Add another ventilation path through emergency exhaust vent, which is protected by reinforced structure and would be activated by heavy machinery only in case of emergency situation. Regarding the 10MWe-4S, RVACS can keep required residual heat removal capability up to 75% blockage, whose analysis results are presented in Sec.6.4. Blockage rate can keep ~70% in case of

Initial Event	Effect factor	Provision
		all of air exhaust stack blockage by utilizing the third emergency ventilation path.
	Oil spillage from upper core equipments	• No influence on reactor safety.
Impact to reactor building	Sodium leakage, sodium – water reaction	(Prevention of sodium leakage and reaction) • Reinforce reactor building structure to protect facility and prevent large scale sodium leakage.
Impact to turbine building	Turbine breakage	• Reactor shutdown and residual heat removal are available and no radioactive material release in case of turbine breakage. Therefore, it has no influence on reactor safety.
Impact to service building	Building breakage	• Service building is independent on reactor building; therefore it has no influence on reactor safety.

5.2 Fire Impact

Not only the physical impact, aircraft fuel invasion and fire hazard inside reactor building are issues to be considered. Table 5-2 describes possible fuel invasion and fire and current provisions.

Table 5-2 Aircraft Fuel Invasion / Fire Impact and Provision

Reactor building:

Initial Event	Effect factor	Provision
Fuel leakage into RVACS stack by aircraft crash (Figure 5-2 (1))	Fire on airflow path or bottom of RVACS	(Prevention of fuel leakage into RVACS stack) • Reinforce the RVACS stack basement to withstand aircraft impact and to prevent large amount leakage into airflow path (Figure 5-1 (1))
Fuel leakage into seismic isolation gap by aircraft crash (Figure 4-1 (Canopy) and Figure 5-2 (2))	Fire at RVACS air inlet (Figure 5-2 (3))	• Preliminary analysis indicated effect of heat flow is limited and dose not affect reactor safety * Fire duration time is calculated to be 4.5 hr by reference to Table 18.1.1 in [6].
	Damage of seismic isolation by fire at seismic isolation pit (Figure 5-2 (4))	(Prevention of fire at seismic isolation pit) • Reinforce canopy structure to protect seismic isolation pit from fuel leakage. (Prevention of seismic isolation breakage) • Install enclosing bund to protect seismic isolation from fire heat. • Install fire-resistive covering to seismic isolation rubber to withstand fire heat and to avoid supporting malfunction [7].
Fire in SG room	Sodium treatment equipment damage	(Prevention of sodium treatment equipment damage) Reinforce reactor building structure to protect facility and prevent large fuel leakage into SG room.

(Continue)

Other Buildings:

Initial Event	Effect factor	Provision
Fire in turbine building	Turbine damage	• No radioactive material release in case of turbine breakage. Therefore, it has no influence on reactor safety.
Fire in service building	Building damage	• Service building is independent on reactor building; therefore it has no influence on reactor safety.

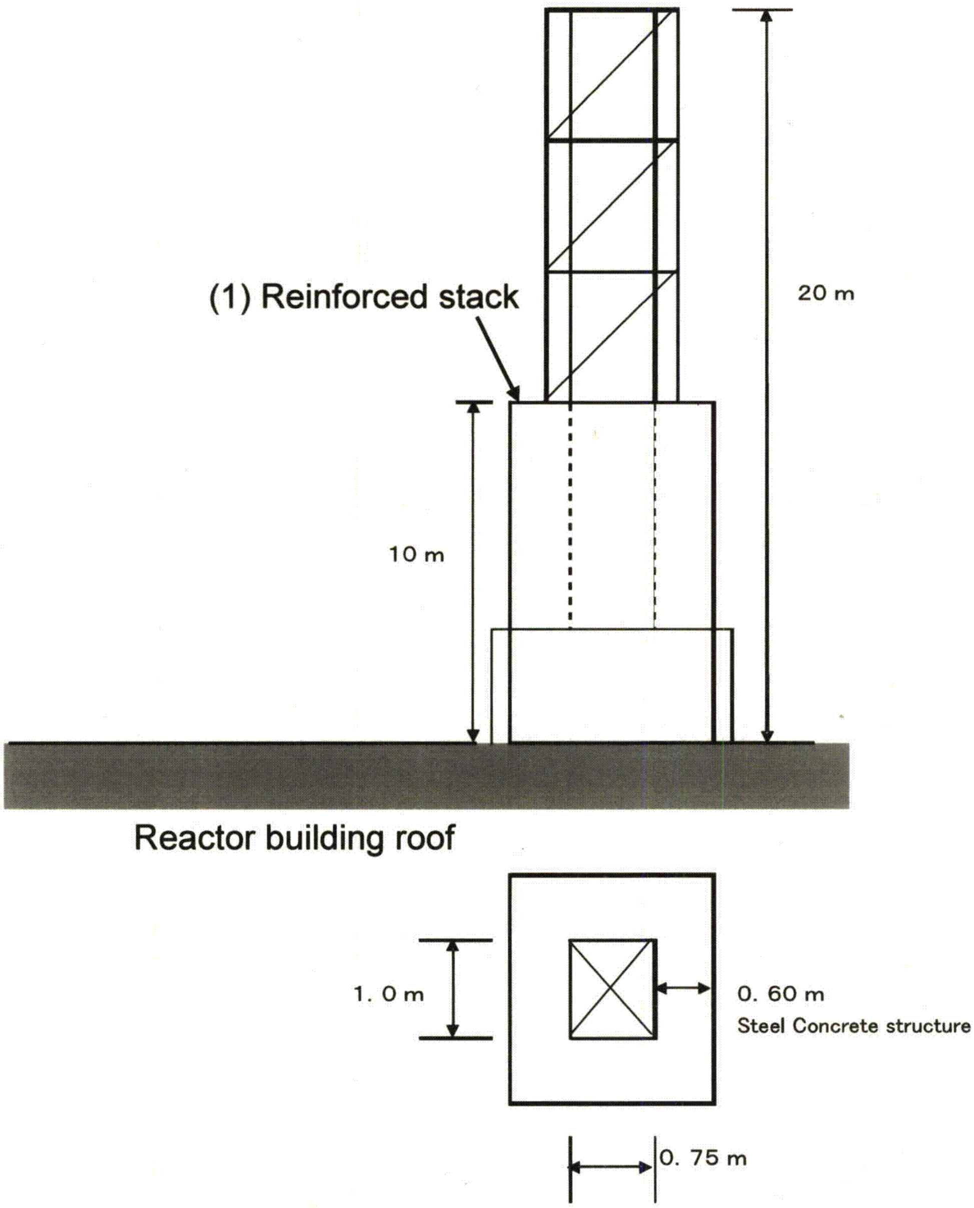

Figure 5-1 RVACS Air Exhaust Stack Concept

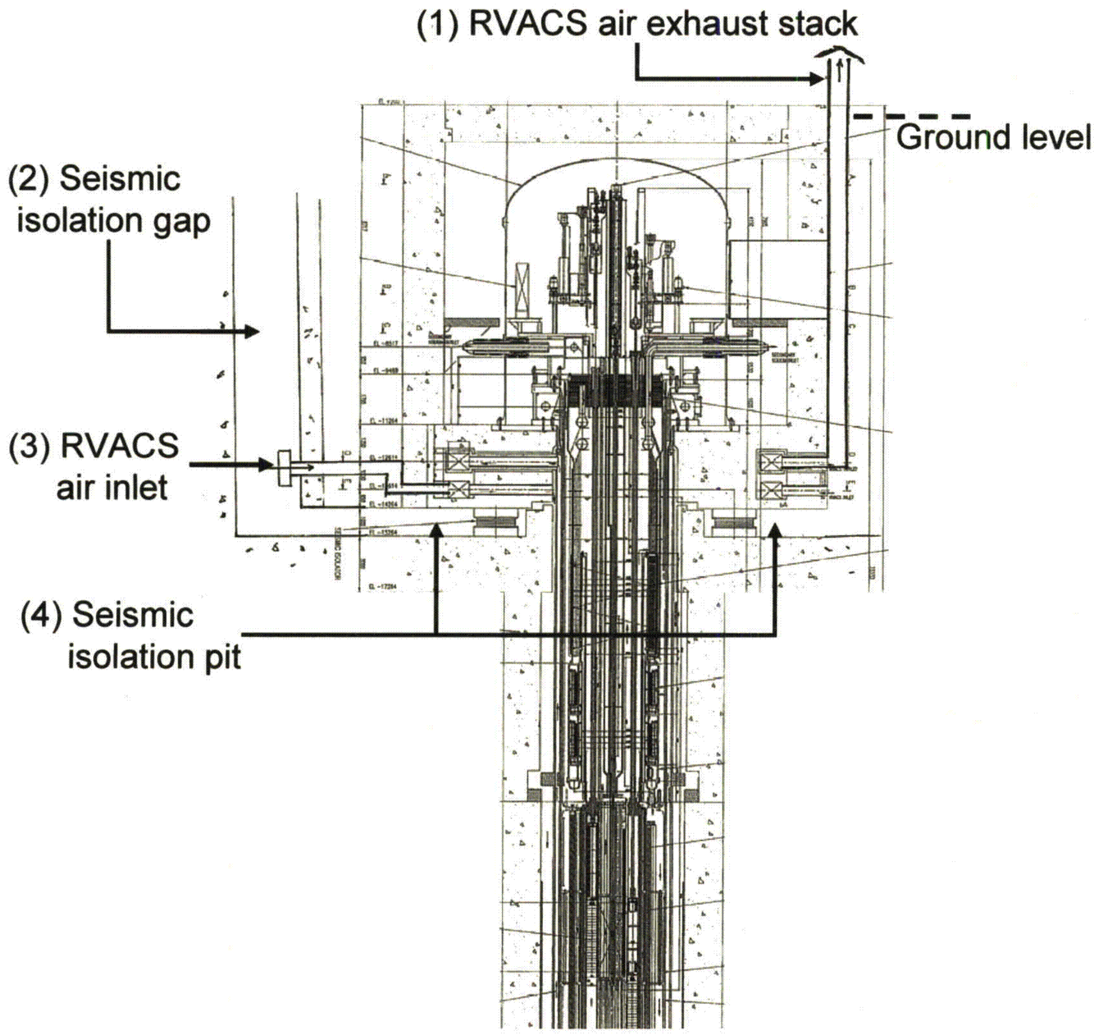

Figure 5-2 Aircraft Fuel Invasion Pathway

6 RESIDUAL HEAT REMOVAL SYSTEMS

6.1 System Descriptions

4S has two independent, redundant, and passive systems for mitigating accidents. One is the Intermediate Reactor Auxiliary Cooling System (IRACS), which removes residual heat by natural convection of sodium and air through the air cooler installed in the Intermediate Heat Transport System (IHTS). The other is the Reactor Vessel Auxiliary Cooling System (RVACS), which removes residual heat by natural convection of air around the outside of the reactor guard vessel. Figure 6-1 shows a schematic diagram of these residual heat removal systems. Neither of these residual heat removal systems requires electric power to function. In both cases, the atmosphere can be used to cool the reactor and no water cooling system is needed as a heat sink.

The RVACS serves as a heat collector between the cylindrical underground concrete wall around the guard vessel and the reactor vessel. Ambient cold air descends between the underground cylinder wall and the heat collector, turns up at the lower end of the heat collector cylinder, and rises between the heat collector and guard vessel. Radiation heat from the reactor vessel is removed with natural convection heat transfer in the gap between the guard vessel and the heat collector. This process takes place under all plant conditions and for all design events entirely by natural phenomena without the intervention of any active equipment.

The RVACS ducting includes two independent paths for both the intake and exhaust air ducts. To prevent a streaming path of neutron and gamma rays from the core via the RVACS structure, the duct routing is arranged to block any streaming. The exhaust duct is elevated approximately 13 m from the reactor core relative to the air intake. Since, under certain conditions, the RVACS exhaust air temperature may exceed the allowable concrete temperature, the structure is insulated to protect the building concrete.

The two RVACS air outlet stacks are set diagonally opposite each other on top of the reactor building, while the one IRACS air outlet stack is installed above the reactor building as shown in Figure 6-2. The base structure of each RVACS stack is reinforced to withstand a hurricane and tornado and prevent complete blockage of the stack.

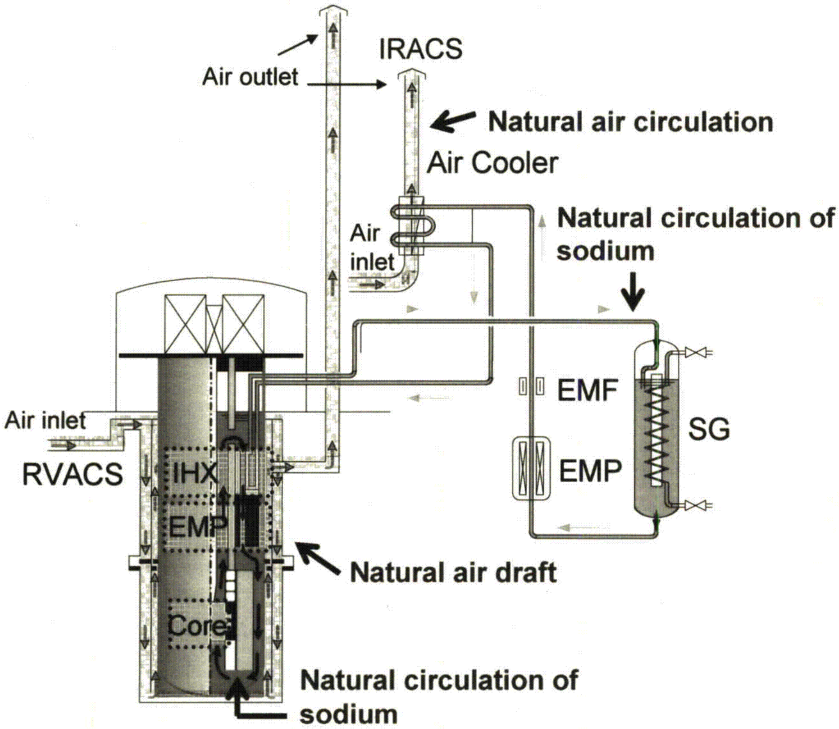

Figure 6-1 Schematic Diagram of Residual Heat Removal Systems

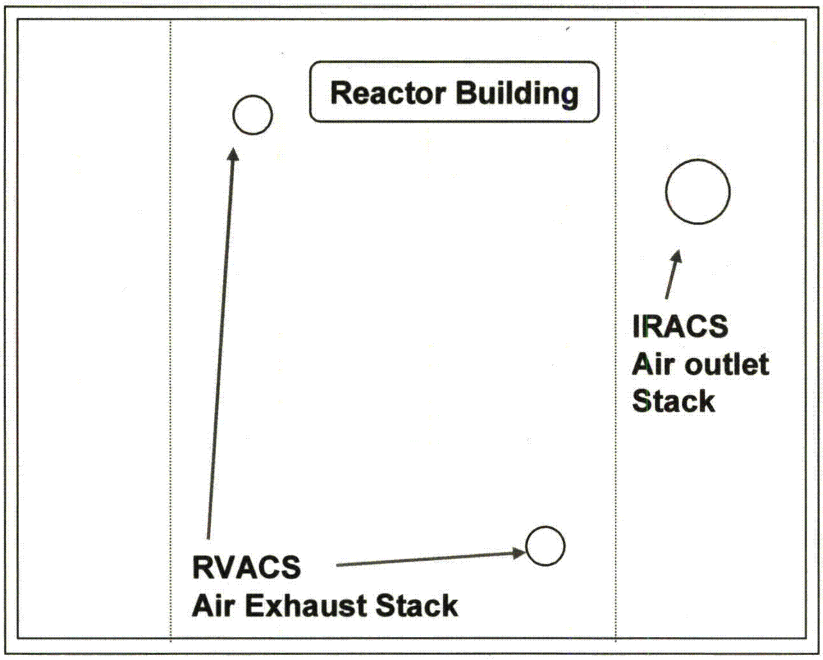

Figure 6-2 Top View of Stack Arrangement

6.2 Basic Heat Removal Performance

As described in Section 6.1, the residual heat removal systems use the natural air draft outside the guard vessel (RVACS) and both the natural circulation of sodium in the intermediate loop and the air draft at the air cooler (IRACS). Due to the passive residual heat removal capability of these systems, heat is removed from the reactor even in the case of a loss of power. Figure 6-3 shows the core temperature behavior during a loss-of-power event. This case shows that residual heat is successfully removed through the IRACS and RVACS using only natural circulation.

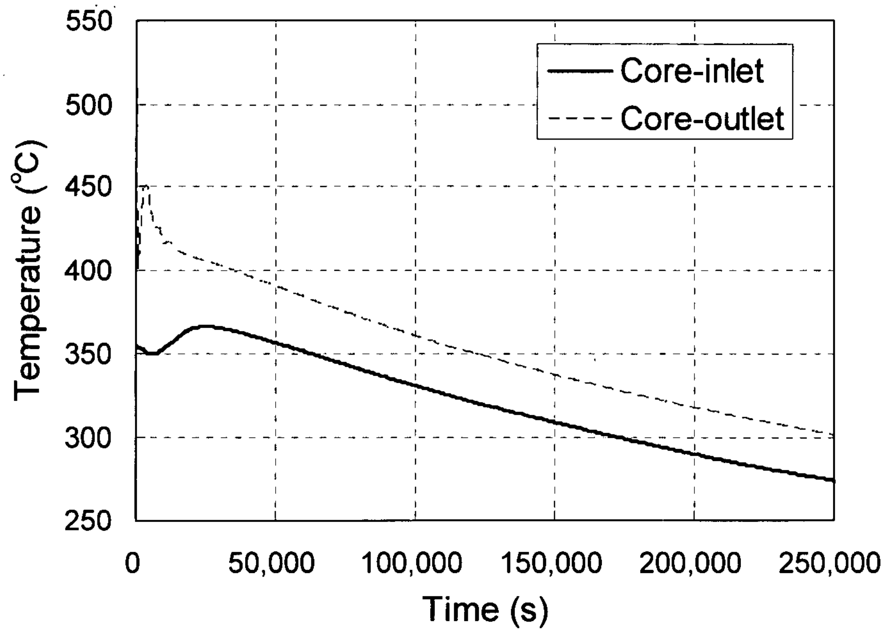

Figure 6-3 Analysis Result for Heat Removal by IRACS and RVACS with Natural Circulation

The plant thermal-hydraulic parameters of the 4S used for the analysis are shown in Table 6-1. These parameters are presented in 4S Safety Analysis Report [8].

Table 6-1 Plant Thermal-Hydraulic Parameters

Item	Design Value
Reactor thermal power	30 MWt
Primary coolant outlet/inlet temperature	510 / 355°C
Primary coolant flow	5.47×10^5 kg/h
Intermediate coolant outlet/inlet temperature	485 / 310°C
Intermediate coolant flow	4.82×10^5 kg/h
Feed water/steam temperature	210 / 453°C
Steam generator water/steam flow	4.6×10^4 kg/h
Steam pressure	10.45 MPa

6.3 Degradation of Heat Removal Systems (Case 1): Failure of IRACS

Failure of the IRACS is assumed to confirm RVACS performance in case of aircraft impact. Figure 6-4 shows the analysis scenario and schematic image for IRACS failure. In this case, only the RVACS is conservatively assumed as a heat sink.

The performance of the RVACS in this scenario is shown in Figure 6-5. This result indicates that RVACS operation without the IRACS is capable of removing the reactor residual heat.

Table 6-2 Sequence of Events for IRACS Failure

Time (s)	Events
0	Manual trip
0	Trip of the primary and intermediate loop and feedwater pumps
0	Switch of status of the primary pumps from normal operation to flow coastdown
0	AC damper open failure
0	Loss of SG as a heat sink
60	Finish of the flow coastdown state of the primary pumps, start of natural circulation state of the primary coolant flow
2180	Loss of IHX and secondary system as a heat sink*

Note:

* IHX = intermediate heat exchanger. These systems are assumed to be adiabatic when secondary flow becomes zero.

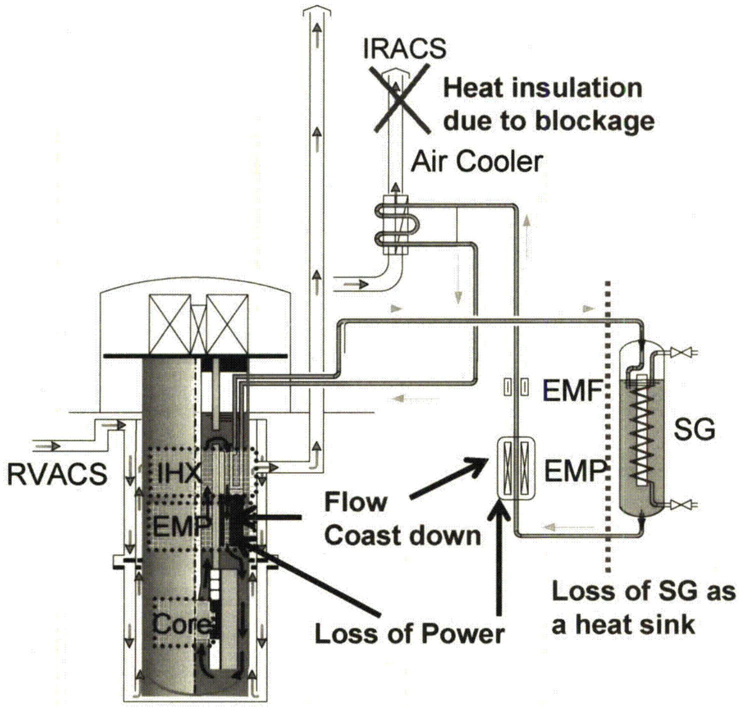

Figure 6-4 Analysis Scenario and Conditions with IRACS Failure

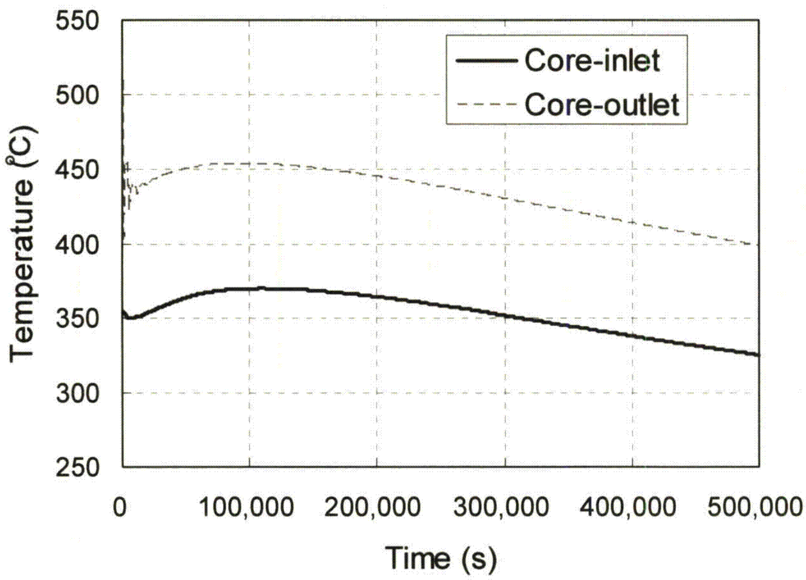

Figure 6-5 Analysis Result for IRACS Failure

6.4 Degradation of Heat Removal Systems (Case 2): RVACS Blockage

In case of an aircraft impact, in addition to assuming the failure of the IRACS, an additional conservatism can be introduced by assuming that the RVACS could be affected by blockage of the flow path. The scattering wreckage would cause a certain amount of blockage of RVACS air flow path although the base structure of the stacks is reinforced to withstand a massive impact and avoid complete blockage.

Table 6-3 and Figure 6-6 show the analysis scenario and schematic image for RVACS blockage in addition to the previously assumed IRACS failure. In the case of an aircraft impact, an unprotected loss of heat sink is assumed due to failure of the water steam system. An immediate reactor shutdown is assumed by detecting failure of the water steam system. A flywheel-equipped motor-generator set provided for the electromagnetic pumps (EMPs) serves to prolong flow coastdown when the normal power supply is stopped. The motor-generator set provides enough power to the pumps to support the required flow coastdown [9]. As in Case 1, the AC damper is assumed to fail due to the aircraft impact; therefore, the IRACS is not available as a heat sink.

Table 6-3 Sequence of Events for IRACS Failure and RVACS Blockage

Time (s)	Events
0	Manual trip
0	Trip of the primary and intermediate loop and feedwater pumps
0	Switch of status of the primary pumps from normal operation to flow coastdown
0	AC damper open failure
0	RVACS blockage
0	Loss of SG as a heat sink
60	Finish of the flow coastdown state of the primary pumps, start of natural circulation state of the primary coolant flow
2180	Loss of IHX and secondary system as a heat sink*

Note:

* These systems are assumed to be adiabatic when secondary flow becomes zero.

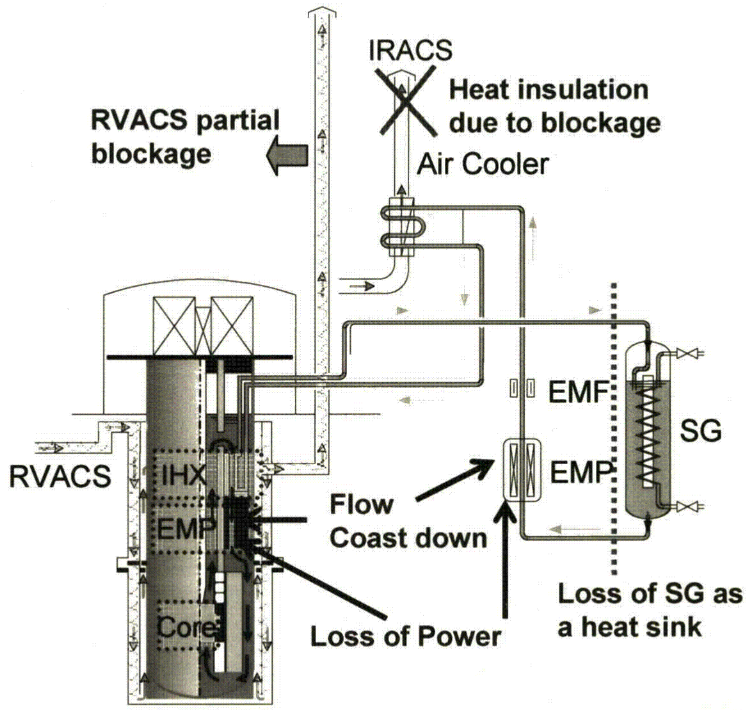

Figure 6-6 Analysis Scenario and Conditions for IRACS Failure and RVACS Blockage

With respect to the safety analysis for General Electric's PRISM sodium fast reactor, which has been previously evaluated by the NRC, the NRC imposed a bounding event defined as "*Loss of forced cooling plus loss of ACS/RVACS with 25% unblocked after 36 hours*" [10]. By considering this requirement, this analysis assumes a uniform 75% blockage of the RVACS airflow pathways, plus the loss of forced cooling as shown in Table 6-3 and Figure 6-6. An indefinite period of time is conservatively assumed for this analysis.

The analysis result is shown in Figure 6-7. This result demonstrates that RVACS is tolerant to a wide range of postulated events.

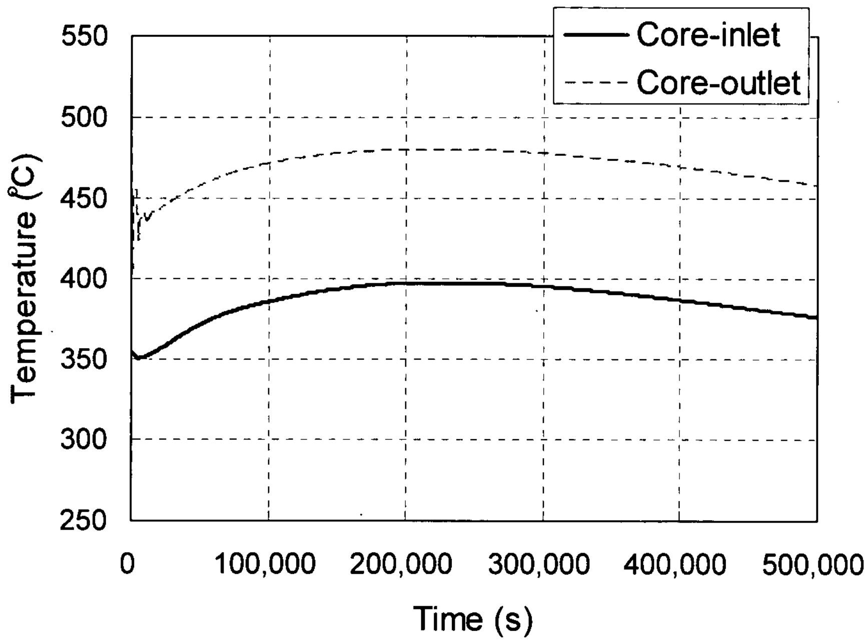

Figure 6-7 Analysis Result for RVACS 75% Blockage

7 CONCLUSION

The current basis for an aircraft impact assessment was reviewed. The assessment requirements for 4S were identified and the following structures and systems were evaluated to meet regulation requirements:

- Containment structures
- Residual heat removal systems

This preliminary study was performed to validate confidence around aircraft impact by considering 4S's design-specific conditions. The discussion and analysis presented here follow the NEI Guideline, non-safeguards Information edition.

The 4S plant configuration of thick-walled below-grade structures is expected to provide excellent protection against direct aircraft impact. This configuration also suggests that an aircraft crash-induced fire in the reactor vessel could be avoided by preventing aircraft perforation of the reactor building. The physical and fire impacts induced by aircraft crash and fuel leakage into the building were identified and their provisions were presented.

Two independent, redundant, and passive systems, the IRACS and RVACS, are provided for reactor heat removal. The analysis results showed that residual heat will be successfully removed through the IRACS and RVACS using only natural circulation, in the absence of electric power.

Failure of IRACS was then assumed to show the robustness of the residual heat removal capability in case of aircraft impact. Finally, as a worst-case scenario regarding degradation of the heat removal capability, the case of RVACS blockage with IRACS failure was considered. In this case, 75 percent blockage of the RVACS airflow pathways was assumed. This analysis result also indicated that RVACS is tolerant to a wide range of postulated events and the reactor core would remain cooled.

In conclusion, the study has determined that the structures that house the reactor can withstand physical and fire impact due to aircraft attack therefore the reactor and containment remain cooled and intact.

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