The Experience of Risk Assessment and its Future Utilization at Rokkasho Reprocessing Plant

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Abstract
Japan has conducted positively studies of utilizing the risk information of nuclear power plants in line with the counterparts of Europe and the United States. Performing PSA and utilizing the risk information for non-reactor nuclear facilities also has the same role in securing safe operation effectively and rationally as in the nuclear power plants. Taking into account the safety characteristics of reprocessing plants in which radioactive materials exist scattered in several chemical processes and storage facilities, we should evaluate risks of many events efficiently and systematically with various types, scenarios, frequencies and consequences in order to assess whole risk and its profile of the plant. A simplified PSA method for the Rokkasho Reprocessing Plant has been developed, incorporating previously conducted detailed PSA results of some representing events. Using the simplified PSA within a year or two the risk profile of the plant will be established so that the risk information can be utilized for the operation and management of the plant such as for classifying the components and systems in classes of importance so as to determine the terms of periodical inspections.

1. Introduction
In conducting PSA and utilizing risk information of nuclear power plants, reactor core, in which radioactivity and energy is centralized, is focus of concern and dominant risk necessary for assessment is well-limited in the core damage and following failure of containment function. On the other hand in a reprocessing plant, radioactive materials exist scattered in several chemical processes and storage facilities, therefore we should evaluate risks of many events with various types, scenarios, frequencies and consequences in order to know what is the greatest risk event, how much the event occupies among whole risk of the plant and so on. No instance can be found in any other country in which a risk profile has been established. Only for the purpose of understanding safety level of a plant, it would be sufficient to evaluate the risks by focusing on some important events, however, the risk profile is indispensable to make good use of the risk information to the plant operation. It is therefore important to establish the risk profile.
2. Identification of events to be assessed and PSA of Rokkasho Reprocessing Plant (RRP)

Many and various types of potential incidents or accidents, having the features of both nuclear and/or chemical, can be conceived throughout a reprocessing plant. Accordingly, the safety assessment of a reprocessing plant should start with the screening and identification of potential events specific to the reprocessing plant. One of the methods to screen and identify potentially credible events systematically and comprehensively is HAZOP (Hazard and Operability Study)\(^1\). In RRP prior to commencing the detailed design stage, HAZOP analysis was performed based on fundamental design information including process flow diagrams, unit descriptions and so forth. Every credible deviation or variation from the planned operational conditions of process parameters was scrutinized using the guide words for stream lines and tanks throughout the plant. As a result, several hundred potential incidents and accidents were screened. In parallel, not only events assessed in the safety analyses, but also actual incidents and accidents occurring in the past were investigated to prevent significant events from being missed. They were presented to the regulatory authority as the basis of deterministic safety evaluation for the approval of designation of the reprocessing business.

PSA works in JNFL had started from the HAZOP result and advanced in two steps. Firstly detailed PSA applying the method generally used in nuclear power plant were conducted based on fundamental design for 15 events selected according to the following aspects:

a) Events with potential escalation and large inventory of radioactivity among design-based events (named ‘Beyond Anticipated Transients’)

b) Events put out of design basis due to extremely low possibility of occurrence

c) Events with lower consequence but higher possibility of occurrence

These results\(^2\) showed us applicability of detailed PSA to RRP and quantified unavailability of utilities, electricity, cooling water and compressed air, those are commonly used in every processes. Some of the results were reflected upon the detail design works.

Having completed construction works, 3 representing events among 15 were updated based on relevant information.

In order to assess risk of many events efficiently and effectively seeking risk profile of the whole plant, a simplified PSA tool was developed\(^3\) because most part of events would have relatively simple sequence and low consequence and should not needs detailed PSA. As the following step, using the simplified PSA, assessment works on 655 events are on the way.

3. An example of detailed PSA - Loss of Hydrogen Gas Scavenging Function in Plutonium Solution Vessels\(^4\)

3.1. Outline of scavenging air supply system

At the reprocessing plant, there are many vessels to store radioactive solution. Therefore, scavenging hydrogen generated by radiolysis is one of major safety measures. Among the
vessels, the plutonium solution vessels, containing alpha emitter and higher generating rate of hydrogen, were selected and the frequency of total loss of the function was calculated. Here, “total loss of the function” means “the density of hydrogen gas in the vessel increased up to 4%”.

Figure 1 shows a schematic diagram of hydrogen scavenging system. Hydrogen is scavenged using compressed air generated by the safety compressors, which are also used for agitation in the tank as service air. The safety compressed air supply system has three units of compressors. A unit is continuously operated and another stands-by with automatic startup and the other unit waits necessary manual operation to startup. In the event of hydrogen scavenging system stops functioning properly, the hydrogen in the tank can be scavenged directly using the service air system. Moreover, in the event of three safety compressors ceasing to function properly, normal compressed air may be connected to the safety scavenging system through a bypass line.

3.2 Data base for equipment failure and human error

The frequency of occurrence of each event was quantified with event tree (ET) and fault tree (FT) analysis in consideration of uncertainty related to the equipment failure rate and human error data. Reliability data for components of which the operational environment was similar to those of NPPs were selected from published literature. Those appropriate to reprocessing plants such as steam jet pumps and cooling coils were set referring THORP’s PSA and operational experience of the Tokai reprocessing plant, respectively. In this assessment, compressor and air-activated valve are from THORP. For a series of operator actions, THERP was applied to quantify the human error rate.

3.3 Result of the assessment

3.3.1 Occurrence frequencies of initiating events and the loss of function

Leakage from piping and valves in safety air supply system, stopage of 3 units of compressor and so on are identified as initiating events, and the summation of these occurrence
frequencies is $4 \times 10^{-3}$/year. Contribution of each event is proportional to the length of piping and numbers of valves. Summation of occurrence frequencies every path from the initiating event to the loss of function is calculated as $8 \times 10^{-6}$/year.

3.3.2 Uncertainty of the frequency
Uncertainty of equipment failure rate and human error rate are considered and the reliability of the frequency is evaluated as $1 \times 10^{-6}$ to $2 \times 5 \times 10^{-6}$/year at 90% reliability level. Error factor 4.2 is comparable with the PSA of NPP.

3.3.3 Relative importance of components, systems and operations
In addition, an importance evaluation using Fussell-Vesely index (hereinafter FV) and Risk Achievement Worth (hereinafter RAW) was conducted for each basic input events and related systems, such as a contribution to occurrence frequency of various type of equipment and piping that constitute the hydrogen scavenging system, and of the operation performed by the operator, and of the systems as a whole. Furthermore through sensitivity analysis, such as the influence of change of maintenance periods was obtained. These information might be of use for operational management.

4. Development and application of the Simplified PSA
Based on the FTA results of utility facilities, etc. obtained from detailed PSA, a simplified PSA method, which can systematically evaluate the risk of the reprocessing plant and the importance of systems, components and human action, has been developed.

In this chapter, the outline of simplified PSA and comparison of the result between this method and detailed PSA is explained.

4.1 Outline of simplified PSA procedure
The flow chart in Figure 2 demonstrates the procedure of simplified PSA. It is possible to use the MS Excel sheet for the evaluation of simplified PSA. The formulas corresponding FTA are inputted beforehand in the Excel sheet. Therefore, an analyst could evaluate only by adding design information related to initiating events and safety functions. Thus, this method provides high consistency throughout all assessment works of more than six hundreds events. It consist of several MS Excel sheets as working sheets, (a) Safety function/System Matrix, (b) Utilities/Systems datasheet, (c) Consequence evaluation sheet, and as output sheets, (d) Event tree display sheet for each event, (e) Consequence evaluation result display sheet for each event, (f) Importance evaluation result display sheet for each event, (g) Risk of all events display sheet, (h) Importance related to risk of reprocessing plant.

First of all, accident sequences and safety functions should be identified. Afterward, systems, components, and human action related to safety functions are identified from the design and
operation information. As thus far explain, there is no difference from detailed PSA procedure. Design and operation information used for reliability analysis is summarized in (a) Safety function/System Matrix. Analyst inputs prescribed failure rates for system, component and human action related to initiating events and safety function into the (a) Matrix selecting from a list “Database of system, component and human action” that have been set conservatively based on the published documents (IEEE-std 500, NUREG-1363, etc.). Human error rate was determined based on detailed PSA. In case of a redundant system such as blowers, analyst enters the operating information such as component type, redundancy, maintenance period and test interval, and so on into (b) Utilities/Systems datasheet in order to calculate the system's unavailability. The calculated result is entered into (a) Safety function/System Matrix.

Unavailability of such support systems as utilities, which related to many events, has been set in (a) Safety function/System Matrix beforehand, with simplified fault tree equation based on detailed PSA results. The other information such as time margin to accident occurrence from initiating event, relation of initiating events and detection should be entered in (a) Safety function/System Matrix. Finally by running macro program of it, calculated result is automatically shown in form of event tree in (d) Event tree display sheet.

In the simplified PSA, consequence is represented as radiation dose to the public. The radiation dose is calculated in (c) Consequence evaluation sheet and is showed on (e) Consequence evaluation result display sheet based on five-factors formula\(^7\).

Source Term = \(\text{MAR} \times \text{DR} \times \text{ARF} \times \text{RF} \times \text{LPF}\) \(\text{(1)}\)

\(\text{MAR}\) (material-at-risk) are determined by design information of components for evaluation and kind of the accident. \(\text{DR}\) (damage ratio, MAR actually impacted by a phenomenon of accident) are conservatively determined based on form of MAR and given physical stress caused by accident. \(\text{ARF}\) (airborne release fraction) and \(\text{LRF}\) (leak path factor) are determined by phenomenon of accident scenarios, respectively. \(\text{RF}\) (respirable fraction) is assumed as “1” through all events., taking into account relative concentration \((X/Q)\) referred from Application for Designation by the Prime Minister for Reprocessing Business, dose coefficient for ingestion and inhalation referred from ICRP pub.72\(^8\). Results of consequence are automatically entered in (d) Event tree display sheet by running macro, risks of each accident scenarios are calculated at the same time. In case of evaluation of risk importance, risk importance of system, component and human action related to accident for evaluation are automatically shown in (f) Importance evaluation result display sheet.

Occurrence frequency, consequence and risk of all accidents is summarized in (g) Risk of all events display sheet by accumulating simplified PSA for all events. Total risk of reprocessing plant and risk profile will be obtained from this spreadsheet. Moreover, risk importance (FV and RAW) of system, component and human action for total risk of reprocessing plant will be calculated by running macro of (h) Importance related to risk of reprocessing plant.
Figure 2 Flow chart of simplified PSA procedure
4.2 Comparison of the Results of Simplified Method and Detailed PSA Method

As results of the simplified PSA method and the detailed PSA, frequency and fraction of initiating events of "loss of scavenging air in Pu solution vessel" are shown in Figure 3. The frequency calculated by the simplified PSA method is $2 \times 10^{-5}$/year and well agrees with the result, $8 \times 10^{-6}$ with the reliability of 90% $1 \times 10^{-6}$~$2 \times 10^{-5}$/ year of detailed PSA method in spite of the simplification above mentioned.

![Comparison of the results between simplified PSA method and detailed PSA method](image)

**Results of Simplified PSA method**

- Leakage of piping or valves in Pu facility: $37%$
- Leakage of piping or valves in safety air supply system: $57%$
- Leakage of piping of valves in denitrification facility: $1%$
- Stop of 3 units of compressors: $3%$
- Total: $2 \times 10^{-5}$/year

**Results of detailed PSA method**

- Leakage of piping or valves in Pu facility: $22%$
- Leakage of piping of valves in denitrification facility: $1%$
- Stop of 3 units of compressors: $3%$
- Leakage of piping or valves in safety air supply system: $73%$
- Total: $8 \times 10^{-6}$/year

Figure 3 Comparison of the results between simplified PSA method and detailed PSA method

(Frequency and fraction of initiating events of "loss of scavenging air in Pu solution vessel")

5. Possible utilization of risk information obtained by the simplified PSA

A risk profile will be obtained from the simplified PSA and shown on a figure of distribution with X-axis of occurrence frequency and Y-axis of consequence. We consider it a useful tool:

a) To discriminate insignificant events from others definitely among the whole risk of the plant,

b) To specify events that have higher risk relatively and to decrease the risk if necessary,

c) To provide information repositioning events that have been regarded as representative accidents at a reprocessing plant.

An example of risk profile is shown as Figure 4, dotted according to the calculated results up to September 2007.
Furthermore a risk profile shows relative risk importance of each components, systems and operations using FV and RAW simultaneously. Figure 5 shows an example.

Utilizing the risk importance information, we plan:

a) To classify components and systems into three classes of risk importance that are presently distinguished merely as “safety-related” from non-related ones. This classification could be useful toward rational management of operation and maintenance.

b) To determine allowable outage time (AOT) of redundant components and systems from sensitivity analysis of risk on the change of AOT. Furthermore on-line maintenance during AOT would be examined using this information.
6. Future plan
Within a year or two a risk profile of the RRP will be obtained and the risk information will be utilized for the operation and management of the plant. Besides above-mentioned plan inspection period could be examined in future. Concurrently responding to regulatory request for up-grading and reconfirming a seismic design of the nuclear facilities in Japan, seismic PSA method for RRP is under development in order to grasp “residual risk” brought by maximum conceivable earthquake exceeding design basis one. On the way to seismic PSA we think that internationally cooperative works are desirable and necessary on realistic parameters related to environmental release of radioactive materials such as airborne release fraction and/or leak path factor, which are enough for deterministic evaluation but too much conservative for realistic evaluation necessary for risk estimation.

7. References
8) Aged-dependent Doses to Members of the public form intake of Radionuclides: part5 Compilation of Ingestion and Inhalation Dose Coefficients, ICRP PUBLICATION 72 (1996)