# Probabilistic examination of in-cell fire occurrence at a reprocessing plant

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**Abstract**

The in-cell solvent fire has been considered to be an important postulated accident at a reprocessing plant in all countries. In this paper, the result of probabilistic examination of the accident is shown. An occurrence frequency was obtained by use of the PSA method as less than $10^{-8}$/yr showing that its occurrence is incredible. Moreover, it was confirmed with reference of the results of the fire simulation code of FIRST that, even if it occurred, an amount of solvent burnt would be limited as less than 500 liters because of lack of oxygen in the cell. Therefore the fire would not put the general public a significant radiation exposure. We hope that these results would cause international reexamination about an importance of the in-cell solvent fire.

## 1. Introduction

In reprocessing plants the PUREX method has been adopted for over 50 years, in which high-level radioactive solution and organic solvent are mixed for extraction. Therefore, it is important to take the necessary measures against the in-cell solvent fire, and in the UK[1)], France[2], and Japan[3,4)] safety measures such as fire extinguishing system and so on have been installed. Then the fire has been treated as an important item for safety assessment. Probabilistic approach was also used in the UK and France.

In this paper, the in-cell solvent fire was assessed by use of probabilistic approach to reexamine its importance from safety viewpoint. The occurrence frequency and consequence to the general publics were evaluated.

## 2. Safety functions against the in-cell solvent fire and its accident scenario

The in-cell solvent fire can be prevented if the following three conditions do not occur simultaneously.

a) Leakage of organic solvent in a cell

A significant amount of organic solvent has to leak from welded equipment of stainless steel (pulsed column, mixer-settler and these piping) that have sufficient corrosion-allowance.

b) Heat source

Leaked organic solvent collected in a drip tray has to be heated over its flash-point temperature.

c) Ignition source

Heated solvent has to be ignited for some reason, although significant ignition sources are removed and equipment is earthed.

If the fire breaks out irrespective of efforts to remove the above conditions, it will be extinguished quickly by use of an extinguisher (at the Rokkasho plant $CO_2$ extinguisher is installed), and combustion smoke containing radioactive materials is purified through high-efficiency particulate filters and then discharged from a high stack. They are the mitigation measures of fire.

Figure 1 shows schematically the safety measures at the Rokkasho reprocessing plant. A drip tray made of stainless steel is provided in a cell. If leakage is detected at a drip-tray pot, an operator will recover leaked solvent to a temporary storage vessel by starting a steam jet pump.

There are three heat sources in the cell. One is hot-water (353K) for heating solvent to 323 K to improve extraction efficiency, the second one is steam (approximately 463K; used on-demand) to drive steam jet pump and the third one is decay heat of radioactive materials. The ignition sources are removed except unexpected electrostatic spark irrespective of grounded equipment. If some organic solvent burned up in the cell, operators would percept the fire by warning from any of 16 thermal detectors and would extinguish it quickly by starting the $CO_2$ extinguishing system.

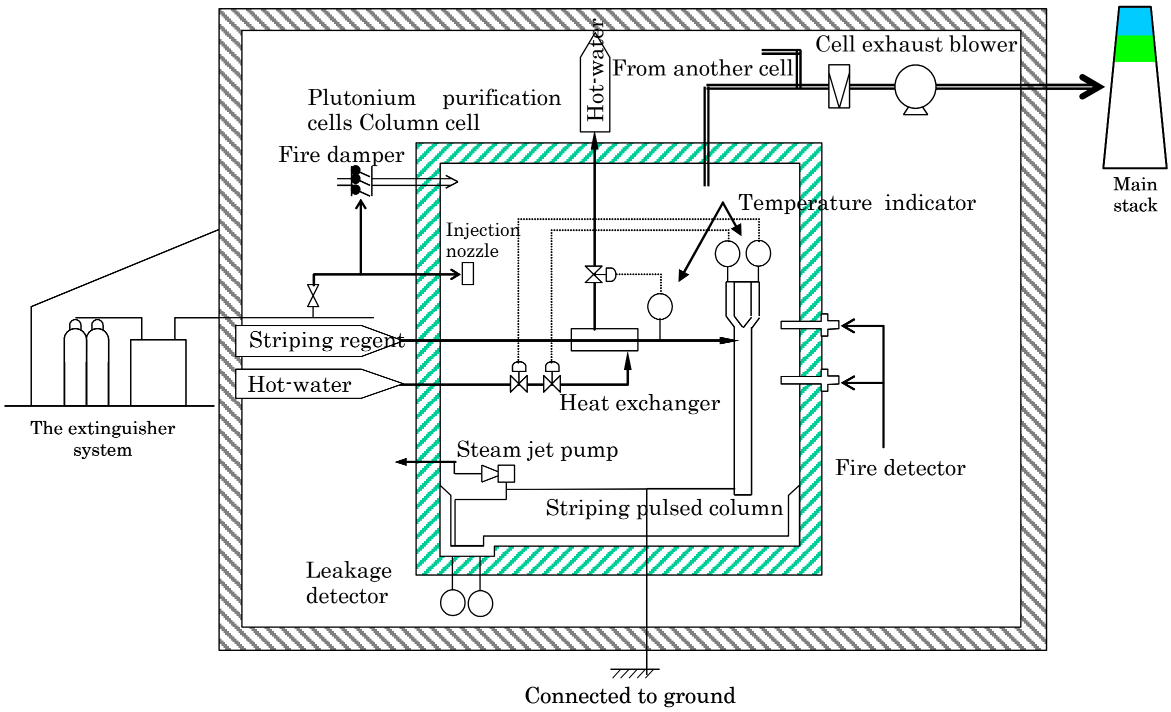



Figure 1 The outline of safety measures against the in-cell solvent fire

## 3. Calculation of frequency of in-cell fire occurrence

The accident scenario is simply described as follows:

a) Initiating event

Significant amount of solvent, i.e., more than 10 liters, leaks from equipment into the cell. A frequency of this event was set to be $10^{-3}$/yr based on literature values[1)].

b) Failure of safety functions

If the following safety functions fail following to the above initiating event, the in-cell fire will breaks out.

Safety function 1: removal of heat source to heat leaked solvent over its flashpoint temperature

Safety function 2; removal of ignition source to ignite leaked solvent during its temperature being over its flashpoint.

The items mentioned below can be enumerated as the cause of failure of safety function 1.

1) Temperature of organic solvent in equipment (a pulsed column or a mixer-settler) which is normally heated to about 323 K to improve extraction efficiency is over its flashpoint before the leakage due to some abnormality of temperature controller.
2) Leaked solvent in a drip tray is heated above its flashpoint with steam flowing back from the steam jet pump due to clogging of the outlet pipe during recovery.
3) Leaked solvent is heated by decay heat of radioactive materials.

In the UK and in France, the item 1) was assumed as the reason of heating the solvent. However, the flashpoint of 30% TBP/ n-dodecane is approx. 353 K[5]. Since the temperature of hot water is 353 K (at the Rokkasho Rprocessing Plant) and the temperature of leaked solvent will decrease during leakage and in contact with a drip tray at room temperature, the possibility of solvent temperature in a drip tray being over its flashpoint would be negligibly small.

Concerning item 2), it seems that the steam back flow to a drip tray is a seldom case among failures of steam jet pump. However, it is considered conservatively that the reported all-mode failure rate of a steam jet pump would be attributed to that of steam back flow. Thus we obtained $10^{-3}$ as a probability of temperature of leaked solvent exceeding over its flash point.

Concerning item 3), it was confirmed by using 3 dimensional thermal hydraulic analysis code of FLUENT that the temperature rise is only a few degrees even for Pu nitrate solution with the highest thermal density of 0.5 W/l in a pulsed column or a mixer/settler. Since the decay heat dosen’t raise temperature of leaked solvent over its flash point, item 3) can be omitted from the heat source of this examination.

Even if the temperature of leaked solvent exceeds over its flash point due to the steam back flow during recovery, the temperature will decrease by heat dissipation to the floor of cell and cell atmosphere. The duration of temperature over its flash point is calculated as several hours. We assume that the ignition probability of hot solvent increases linearly with time by electrostatic spark and so on, and after 1 year it reaches 100%. That is, an ignition probability per hour is $1/8{,}760=1.2\times10^{-4}$. Therefore, the ignition probability due to the back flow of steam be $10^{-3}$.

c) The fire occurrence frequency

The frequency of occurrence of the in-cell solvent fire was obtained as less than $10^{-8}$/yr based on the results stated above.

## 4. Quantification of consequence

### 4.1 Fire analysis in the cell

As stated above, occurrence of the in-cell solvent fire seems extremely small. However its consequence was evaluated as follows referring to the results of the fire analysis code of FIRST[6)].

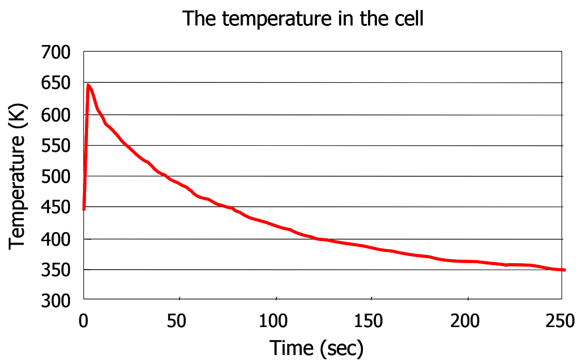
a) Analysis model

The geometric data on the cell are modeled based on the design information of the Rokkasho reprocessing plant. The cell ventilation speed was set at two times of the cell volume per hour. Large-scale fire and small-scale fire were analyzed. In the former case solvent burns over all area of a drip tray, but in the latter case solvent burns at only a limited area.

（２） Results of analysis

Figure 2 shows the results of large-scale fire, i.e., the temperature of the atmosphere in the cell and the height of hot layer zone as a function of continuation time of fire. As can be seen in the figure the temperature of the hot layer zone rose to 650 K quickly and then decreased gradually nearly to the initial room temperature of 300 K, since the fire was extinguished naturally at 350 seconds after its occurrence because of lack of oxygen in the cell. The higher temperature zone spread from the top to the bottom of the cell in seconds. The small-scale fire was also analyzed and the following results were obtained. The combustion continued corresponding to oxygen amount in the cell-ventilation flow and the temperature of the cell atmosphere reached to the constant temperature of about 380 K after one hour and longer.

The real fire may be a mix of large and small scale ones, that is, at first a large scale one occurs and with time it changes to a small scale one because oxygen in the cell becomes insufficient for large scale fire. Thus the fire continues until the solvent is used up. The consequence of fire to the general publics will increase corresponding to the duration of fire. It will increase suddenly when the purification function of HEPA filter fails due to clogging by soot. We consider that 3-hour fire will be sufficient for the consequence evaluation because the fire will be extinguished due to lack of oxygen if an operator stops the cell exhaust blower, closes a fire-damper installed at the inlet of



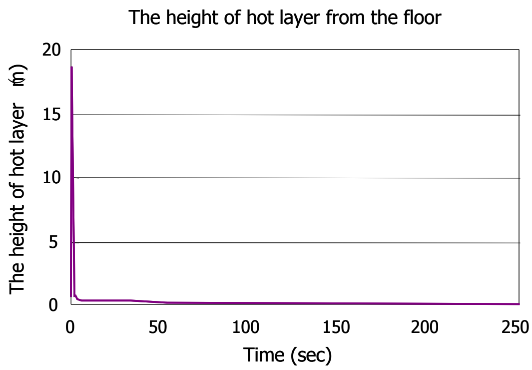




Fig. 2　Temperature of cell atmosphere and a position of hot layer zone vs. time (Large-scale fire)

the cell-ventilation system or releases $CO_2$ gas of the fire extinguishing system. Thus the amount of solvent combustion is less than 500 liters. At the Rokkasho plant soot generated by combustion of 500 liters solvent will not decrease the efficiency of HEPA significantly[7,8].

### 4.2 Evaluation of consequence to the general publics

As stated above, amount of organic solvent burnt will be less than 500 liters and the filter function will not be degraded. In case that 500-liter fire occurs in the plutonium purification cell where the consequence will become the largest, the consequence is evaluated as 0.1 mSv.

## 5. Conclusion

The risk of in-cell solvent fire was evaluated as an occurrence frequency of less than $10^{-8}$/y and a small consequence of 0.1 mSv.

We hope that the reexamination is made not only for the fire described above but also for other postulated accidents, based on the recent knowledge accumulated in the world, and the results are reflected to a near future reprocessing plant after international discussion and agreement.

## 6. Reference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