APPLICATION OF THE SPEEDI SYSTEM TO THE CHERNOBYL REACTOR ACCIDENT

October 1986

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and Shigeru MORIUCHI
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APPLICATION OF THE SPEEDI SYSTEM
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The SPEEDI system is a computational code system to predict the radiological dose due to the plume released in a nuclear accident in Japan. This paper describes the SPEEDI's application to the Chernobyl reactor accident for the estimation of the movement of plume and the release rate of radioactive nuclides into the environment. The predicted results on the movement of plume agreed well with the monitoring data in Europe. The estimated results on the release rate showed that half of the noble gas inventory, about 5% of the iodine inventory and about 3% of the cesium inventory are released into the environment within 24 hours.

Keywords: SPEEDI System, Reactor Accident, Chernobyl Reactor, Environment, Plume, Release Rate, Europe, Noble Gases, Iodine, Cesium.
チェルノブイリ原子炉事故への SPEEDI の適用

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SPEEDI システムは、日本において原子炉事故が発生し、放射性プルームが環境中に放出された場合、それによる被曝線量を計算予測するシステムである。本報告では、このシステムをチェルノブイリ原子炉事故に適用し、放出されたプルームの拡散・移行経過の推定及び放出放射能値の評価を行った結果を示した。

プルームの拡散・移行に関する予測結果は、ヨーロッパ国内でのモニタリング結果とほぼ一致した。また、モニタリング結果との比較により推定した放出率から、事故後24時間以内に希ガスイベントの半分、ヨウ素イベントの5％、セシウムイベントの3％が環境中に放出されたと考えられる。
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1. Introduction
The Chernobyl reactor accident in USSR has caused the serious radioactive hazard all over Europe as well as USSR. The various measurements and computer simulation of environmental radioactivity performed in many countries have elucidated revealing the aspects of environmental contamination due to this accident, and the importance of the emergency systems for environmental safety is recognized again.

Japan Atomic Energy Research Institute has already completed the development of a computer-code system for the prediction of environmental radioactivity in emergency situations, named SPEEDI$^1$), by 1985, and also applied this system for an analysis of the environmental consequences due to the Chernobyl reactor accident. The purpose of this application is to predict the pass way of plume in Europe and to estimate the release rates of radioactive materials from the accident plant into the environment by comparing the calculated values with the monitoring data.

2. Calculational Method

2.1 Calculational Models

1) Windfield model WINDO4$^2$)

The windfield is calculated by using the meteorological data of the wind speeds and directions measured at the ground level and the 850 mb pressure level (about the height of 1500 m). In the first step of the calculation, the observed wind data are interpolated or extrapolated to the 2-dimensional (2-D) grid points at the height of ground level and 1500 m; in the next step, the 2-D grid data at the ground level and 1500 m are delivered to the 3-D grid points by interpolation. In the final step, 3-D grid data are corrected to satisfy the mass-conservation law by using a variational method.

2) Transport-diffusion model PRWDA$^3$)

PRWDA employs a particle-diffusion model to solve a transport-diffusion equation numerically. The plume is presented by a mass of particles. The advection of particles is calculated by the interpolation of the windfield generated by WINDO4 and the diffusion is calculated by Gradient-transfer theory. The diffusion coefficient is calculated from an atmospheric stability. The outputs of this code are the air-concentration and the deposition. Air-concentrations are presented by the density of the particles and the calculation of dry
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deposition is performed by the surface-depression model.

2.2 Calculational Conditions

SPEEDI has the topographical data only for Japanese nuclear power plants in the present status; thus, we assumed some data essential to the calculation tentatively. Assumed calculational conditions are as follows. The time in this report is standardized to GMT (Greenwich Mean Time).

1) Calculational region;

The calculational region covers Eastern Europe and Southern Scandinavia as shown in Fig.1. The horizontal length of the region is 2000 km and the height is 2000 m. This region is divided into 50x50x20; therefore, the mesh sizes are 40 km horizontally and 100 m vertically.

2) Topographical data;

SPEEDI does not have the topographic data around Chernobyl. Since the objective region is, however, almost flat, the flat terrain is assumed in the simulation.

3) Meteorological data;

We used surface wind data of forty points observed every 6 hours in USSR, Poland and Sweden and used upper wind data (at 850 mbar) of fifty-five points observed every 12 hours in calculational region. Figures 2(a) and 2(b) illustrate the distributions of meteorological observatories for the measurements of surface winds and upper winds respectively. The measurements of surface winds are performed at 0000, 0600, 1200 and 1800 GMT. Furthermore the measurements of upper wind are at 0000 and 1200 GMT. Therefore we have calculated the windfield on the assumption of the constancy of winds for the period of 6 hours. These data were obtained from Meteorological Agency of Japan. In successive meteorological data, the data at 0000 GMT 27th April, 0000 GMT 1st May, 0000 GMT 2nd May and 1200 GMT 5th May are missing. Although the missing data are filled up by using the previous and the later data, the missing at 0000 GMT 27th April especially affects the simulation of the plume movement across Europe.

4) Turbulence condition;

The plume movement is simulated for one week. Thus, it is likely that the plume experienced the various turbulent conditions. However the data on turbulent condition are not available. Therefore the turbulent
condition is assumed neutral (Pasquill D) through 1 week tentatively and the mixing-layer height of 2000 m is assumed.

5) Source data:

The release was assumed to start at 2100 GMT 25 April. The release height is 1000 m for 12 hours from the start of the release and 200 m after the first 12 hours. The release rate of noble gases or iodine is 1 Ci/h. In this simulation, the plume released continuously is divided into the segments for the period of 24 hours so as to discuss how each segment covered Europe. The each segment is traced for several days till the cloud is swept away from the calculational area.

6) Deposition:

The value of deposition velocity of 0.3 cm/s is assumed. The wet deposition is not considered in this simulation.

3. Results and Discussion

3.1 Calculated Results

1) Temporal changes of windfield

Figure 3 depicts the horizontal distributions of windfields at the height of 1000 m at 1200 GMT on successive days from 26th April to 4th May. The length of arrow presents the wind speed and the direction presents the airflow. Around Chernobyl, a southern wind was dominant on 26th and 27th April and then, the direction changed to the north during the period from 29th April to 1st May. After 2nd May, a north wind blew successively.

2) Temporal changes of concentration distributions

SPEEDI has calculated the 6-hour averaged air-concentrations of noble gases and iodine and the deposition of iodine for 8 days from the start of the release. In the calculation, the plume is divided into eight segments to study how the segments cover Europe. The eight segments represent the plume which is released in a day over the period from 26th April to 3rd May, respectively. Figures 4 to 11 show the noble gas distributions at the ground level in eight segments, respectively. In each page of these figures, the upper and the lower depict the distributions of the mid-day and the mid-night on successive days, respectively. The Chernobyl reactor is located on the point (0.0, 0.0) in
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the map. Although the plume which left the computational area could turn around into the area again, this is not considered in the transport-diffusion model.

The outline of the plume movement near the ground level is as follows.

(1) The first segment released on 26th April (Fig.4);

26th April: The plume flowed northwestwards and reached Baltic Sea in the night, passing through Northeastern Poland.

27th April: The plume went across Baltic Sea and reached the Swedish coast in the night. However, the upper part of plume already existed over Finland in the evening. This phenomenon was caused by wind shear.

28th April: The plume reached Northern Sweden and Western Finland.

29th April: The plume around the Gulf of Bothnia covered Sweden and Finland, and moved southwards slowly with the change of wind direction to the north in the night. In Eastern Europe, the southern part of plume covered Warsaw and approached Wien and Budapest.

30th April: The plume which covered Sweden turned around southeasterly and remained only around the Swedish east coast in the afternoon. The southern part of the plume, which had been released in the second half of 26th April, reached Northern Yugoslavia in the evening.

1st May: Sweden has escaped the cloud. The cloud spread extensively southwards, covering over Poland, Czechoslovakia, Hungary, Austria, and Yugoslavia.

2nd May: The plume stretched to the west and probably covered Switzerland and West Germany.

3rd to 4th May: The plume is stagnant and covered over almost all Eastern Europe. Sweden was covered again by low-level concentration plume.

(2) The second segment released on 27th April (Fig.5);

27th April: The plume moved northwestwards.

28th April: Until the afternoon, the plume moved northwestwards and reached the eastern area of Warsaw. However the central part of the segment began to move westwards and the later part began to move eastwards of Chernobyl in the night.

29th April: The plume which moved toward the northwest turned around and the dispersed westwards and eastwards. The second
segment overlay the first segment at the region between Warszawa and Budapest.

30th April : The plume moved southwards and covered Ukraina, Rumania, Hungary and Austria.

1st May : Poland has escaped the cloud. The cloud spread extensively southwards, covering over Czechoslovakia, Hungary, Austria, Rumania and Yugoslavia.

2nd May : Almost all the plume left the map area to the south.

(3) The third segment released on 28th April (Fig.6):

26th April : The plume moved to the east of Chernobyl, passing close to the south of Moscow.

29-30th Apr. : The movement was almost the same as that of 28th April.

1st May : Almost all the plume left the map area to the east.

(4) Other segments released after 29th April (Figs.7 to 11):

The plume flowed southwards, southeastwards or southwestwards and probably covered Rumania, Balkan, Ukuraina and the eastern region of Chernobyl.

On the basis of these results, we found that the plume which covered Europe in April is released within two days from the start of the release, i.e., 26th and 27th April. In particular, the plume which covered Scandinavia is probably released in the first half of 26th April. It is noted that, by wind shear, the plume transported by upper wind reached Finland from USSR directly at 27th April, although the plume near the ground level reached Finland during the period from 28th to 29th April, passing through Northeastern Poland and Sweden.

The summary of the movements of plume is shown in Table 1 and Fig.12. The table shows the stagnant period of the plume and the segment number at each country, and the figure shows the area which is covered by the plume by 4th May. The simulated results agreed roughly with the monitoring results in Scandinavia and Eastern Europe. However, some doubts still exist about the movements of plume at the edge of the map area, because the surface wind data used are almost located in the center of the map area as shown in Fig.2 (a).

3.2 Estimation of Radioactivity Emitted to the Environment

In this section, we discuss the release rate of the radioactivity into the environment by the comparison between the monitoring data^{4),5}
in the Scandinavia area and the calculated results on the assumption of 1 Ci/h release. As described above, the plume which covered Scandinavia was released on 26th April. Thus, we have discussed the release rate by using the distribution of the first segment in this report. The estimated release rate is as follows.

1) Noble gases
   In Middle and Northern Sweden and in Western Finland, the exposure rates from 20 μR/h to a few hundreds μR/h are measured on 26th and 29th April. These values of the external radiation level are caused by the gamma radiations from noble gases in air and radioactive materials deposited on the ground. The comparison of the temporal variation of exposure with continuous dust monitoring data suggests that the contribution rate of noble gases to the exposure is about 20 %, i.e., the exposure rate due to noble gases is 4-20 μR/h. This exposure rate corresponds to the level of 10^{-7} Ci/m^3 by the submersion model on the assumption of average γ-energy of 0.1 MeV considering the travel time of 3 days.

   By the comparison between the value of 10^{-7} Ci/m^3 estimated by monitoring and the value of 5×10^{-15} Ci/m^3 (10^{-14}-10^{-15} Ci/m^3) in the same area by the SPEEDI calculation assumed 1 Ci/h release, the release rate of noble gases in the early stage is estimated at 2×10^7 Ci/h.

2) Iodine
   The release rate of iodine can be estimated by comparing the data of measured and calculated radioactivity in air or on the ground. In the the northern area of Stockholm and Western Finland, the maximum concentration of 131I measured on 28th and 29th April was about 2×10^2 Bq/m^3 and the average in a maximum day was 40 Bq/m^3 (1×10^{-9} Ci/m^3); furthermore the measured average deposition of 131I till 30th April was about 1×10^4 Bq/m^2 (2.5×10^{-7} Ci/m^2) and the maximum exceeded 1×10^5 Bq/m^2 by precipitation scavenging.

   On the other hand, the calculated 131I concentration in air and dry-deposition in the same area, assuming the continuous release of 1 Ci/h of total iodine, are 5×10^{-16} Ci/m^3 (10^{-15}-10^{-16} Ci/m^3) and 2.5×10^{-13} Ci/m^2 (5×10^{-13}-10^{-13} Ci/m^2) at the same time as shown in Fig.13 and Fig.14, respectively.

   Consequently, the release rate of iodine can be estimated at 2×10^6 Ci/h by the comparison between the measured average air-concentration and the calculated one and at 1×10^5 Ci/h by the comparison between the
measured average deposition and the calculated one. The difference between two estimated release rates is caused by the uncertainty of deposition velocity and the ignorance of precipitation scavenging. Since the amount ratio of $^{131}$I to total iodine is 10% at the shut-down (shown in Table 4), the release rate of $^{131}$I is $1\times10^5$-$2\times10^5$ Ci/h.

3) Other nuclides

The release rates of other radioactive nuclides were estimated by using the ratio of the air-concentration of each nuclide to that of $^{131}$I in environment. If it is assumed that the diffusion and deposition system of other nuclides is the same as that of $^{131}$I, the air-concentration ratio of each nuclide to $^{131}$I at the shut-down is estimated from the ratio in environment by considering the radioactive decay during the period from the shut-down to the measurements in environment. The release rate of each nuclide can be obtained by multiplying the ratio at the shut-down by the release rate of $^{131}$I. The release rates of other nuclides estimated by above method and the amounts released in 26th April, by using the $^{131}$I release rate of $2\times10^5$ Ci/h, are listed in Table 2. The radioactivity released in 26th April is calculated by multiplying the release rate by 24 hours. Although it is difficult to evaluate how long these release continued, the same level of release probably continued at least in 26th April because the plume released in the second half of 26th April caused the same levels of radioactive contamination in Eastern Europe as those in Scandinavia.

Table 3 shows the ratios of amounts released in 26th April to the inventories. Half of noble gas inventory is probably discharged on 26th April and about 5% of $^{131}$I inventory is released. Furthermore $^{137}$Cs is released about 3% of its inventory. However the release rate after 26th April cannot be estimated in this stage, because the plume released after 26th April flowed to the area where the monitoring data are not available.

The core inventories used are shown in Table 4. In this discussion, the short-life nuclides are excluded from the table. Consequently, the short-life noble gases and iodine isotopes are not contained in their inventories. The table presents the values of inventories per U (Uranium ton) and Uranium of 180 t is assumed. The inventories are calculated by the ORIGEN 2 code under the following conditions:

Specific power : 17.5 MW/tU,
Burnup : 7000 Mwd/tU.

- 7 -
Reactor type: BWR.

The burnup rate is adjusted to satisfy the observed isotope ratio of 0.577 of $^{134}$Cs/$^{137}$Cs.

4. Conclusions

In this report, we have discussed the movement of the Chernobyl plume over Eastern Europe and Scandinavia by dividing the plume into the segments during 24 hour period. Furthermore we have discussed the release rate into the environment of noble gases, iodine and cesium based on the calculated results and the monitoring data at Scandinavia.

The essential results in this report are as follows;
1. The distribution of cloud simulated by SPEEDI agreed well with monitoring data in Eastern Europe and Scandinavia area.
2. Half of the noble gas inventory has been discharged within 24 hours from the release start. $^{131}$I and $^{137}$Cs have been released about at the rate of $4.8\times10^6$ Ci per day and $1.3\times10^5$ Ci per day, respectively.

These corresponds to about 5% and 3% of each inventory. This estimation is very rough because the monitoring conditions in detail are not available and the precipitation scavenging is not considered in the model. Therefore we will continue the discussion on the release amount into the environment.

Now, we are carrying out the discussion of the movement of plume in the whole area of Europe and the environmental consequences based on the release amount described in this report.

We would like to acknowledge the guidance and encouragement of Dr. Miyanaga of JAERI, and thank Dr. Sakamoto of JAERI for the calculation of the inventories by ORIGEN-2.
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Fig. 1 Computational region in Europe.
Fig. 2(a) The position of meteorological stations of surface wind.

(b) The position of meteorological stations of upper wind.
Fig. 3 The calculated windfields at 1200 GMT on successive days from 26th April to 4th May.
Fig. 3 Continue.
Fig. 3 Continue.
Fig. 3 Continue.
Fig. 4 The calculated air-concentration distributions of the plume released on 26th April. In each page, the upper and the lower show the noble gas distributions at the ground level at the mid-day and the mid-night on successive day, respectively. Contour levels from inside to outside (unit: Ci/m$^3$/Ci/h); 10$^{-14}$, 10$^{-15}$, 10$^{-16}$ and 10$^{-18}$. In the case where the number of contour lines is two or three, these levels correspond to latter two or three values.
Fig. 4 Continue.
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Fig. 4 Continue.
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Fig. 5 The calculated air-concentration distributions of the plume released on 27th April. In each page, the upper and the lower show the noble gas distributions at the ground level at the mid-day and the mid-night on successive day, respectively. Contour levels from inside to outside (unit: Ci/m³/Ci/h); $10^{-14}$, $10^{-15}$, $10^{-16}$ and $10^{-18}$. In the case where the number of contour lines is two or three, these levels correspond to latter two or three values.
Fig. 5 Continue.
Fig. 5 Continue.
Fig. 5 Continue.
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Fig. 6 The calculated air-concentration distributions of the plume released on 28th April. In each page, the upper and the lower show the noble gas distributions at the ground level at the mid-day and the mid-night on successive day, respectively. Contour levels from inside to outside (unit: Ci/m³/Ci/h); $10^{-14}$, $10^{-15}$, $10^{-16}$ and $10^{-18}$. In the case where the number of contour lines is two or three, these levels correspond to latter two or three values.
Fig. 7  The calculated air-concentration distributions of the plume released on 29th April. In each page, the upper and the lower show the noble gas distributions at the ground level at the mid-day and the mid-night on successive day, respectively. Contour levels from inside to outside (unit: Ci/m$^3$/Ci/h); 10$^{-14}$, 10$^{-15}$, 10$^{-16}$ and 10$^{-18}$. In the case where the number of contour lines is two or three, these levels correspond to latter two or three values.
Fig. 7 Continue.
Fig. 7 Continue.
Fig.8 The calculated air-concentration distributions of the plume released on 30th April. In each page, the upper and the lower show the noble gas distributions at the ground level at the mid-day and the mid-night on successive day, respectively. Contour levels from inside to outside (unit: Ci/m³/Ci/h); $10^{-14}$, $10^{-15}$, $10^{-16}$ and $10^{-18}$. In the case where the number of contour lines is two or three, these levels correspond to latter two or three values.
Fig. 9 The calculated air-concentration distributions of the plume released on 1st May. In each page, the upper and the lower show the noble gas distributions at the ground level at the mid-day and the mid-night on successive day, respectively. Contour levels from inside to outside (unit: Ci/m\(^3\)/Ci/h): 10\(^{-14}\), 10\(^{-15}\), 10\(^{-16}\) and 10\(^{-18}\). In the case where the number of contour lines is two or three, these levels correspond to latter two or three values.
Fig. 10 The calculated air-concentration distributions of the plume released on 2nd May. In each page, the upper and the lower show the noble gas distributions at the ground level at the mid-day and the mid-night on successive day, respectively. Contour levels from inside to outside (unit: Ci/m$^3$/Ci/h); 10$^{-14}$, 10$^{-15}$, 10$^{-16}$ and 10$^{-18}$. In the case where the number of contour lines is two or three, these levels correspond to latter two or three values.
Fig.10 Continue.
Fig.11 The calculated air-concentration distributions of the plume released on 3rd May. In each page, the upper and the lower show the noble gas distributions at the ground level at the mid-day and the mid-night on successive day, respectively.
Contour levels from inside to outside (unit: Ci/m³/Ci/h); 10⁻¹⁴, 10⁻¹⁵, 10⁻¹⁶ and 10⁻¹⁸. In the case where the number of contour lines is two or three, these levels correspond to latter two or three values.
Fig. 11 Continue.
Fig. 11 Continue.
Fig. 12 The region which is covered by radioactive nuclides emitted during the period from 26th April to 3rd May.
Fig. 13 The calculated air-concentration distributions of $^{131}$I released on 26th April. In each page, the upper and the lower show the distributions at the ground level at the mid-day and the mid-night on successive day, respectively. Contour levels from inside to outside (unit: Ci/m$^3$/Ci/h); $10^{-15}$, $10^{-16}$ and $10^{-18}$. 
Fig. 14 The calculated deposition distributions of $^{131}$I released on 26th April over the period from the start of the release to the mid-night on 30th April.
Contour levels from inside to outside (unit: Ci/m$^2$/Ci/h);
10$^{-12}$, 10$^{-13}$, 10$^{-14}$ and 10$^{-16}$. 
Table 1 The stagnant period of the plume in each country.

<table>
<thead>
<tr>
<th>Country</th>
<th>Stagnant period</th>
<th>Segment number of the plume</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Russia</td>
<td>26th April to 4th May</td>
<td>1 and 2</td>
</tr>
<tr>
<td>Poland</td>
<td>26th April to 4th May</td>
<td>1 and 2</td>
</tr>
<tr>
<td>Sweden</td>
<td>28th to 30th April, 3rd to 4th May</td>
<td>1</td>
</tr>
<tr>
<td>Finland</td>
<td>29th April to 4th May</td>
<td>1</td>
</tr>
<tr>
<td>Norway</td>
<td>28th to 30th April</td>
<td>1</td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>29th April to 4th May</td>
<td>1 and 2</td>
</tr>
<tr>
<td>Hungary</td>
<td>29th April to 4th May</td>
<td>1 and 2</td>
</tr>
<tr>
<td>Austria</td>
<td>29th April to 4th May</td>
<td>1 and 2</td>
</tr>
<tr>
<td>Yugoslavia</td>
<td>30th April to 4th May</td>
<td>1 and 2</td>
</tr>
<tr>
<td>Rumania</td>
<td>30th April to 4th May</td>
<td>1, 2, 3, 4, 5 and 6</td>
</tr>
<tr>
<td>Ukurania</td>
<td>29th April to 4th May</td>
<td>1, 2, 3, 4, 5, 6, 7, 8 and 9</td>
</tr>
<tr>
<td>Nuclide</td>
<td>Radioactivity released in 26th April (Ci)</td>
<td>Core inventory (Ci)</td>
</tr>
<tr>
<td>---------------</td>
<td>------------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>131I</td>
<td>8.5 x 10^7</td>
<td>4.8 x 10^6</td>
</tr>
<tr>
<td>133I</td>
<td>1.8 x 10^8</td>
<td>6.7 x 10^6</td>
</tr>
<tr>
<td>134Ba</td>
<td>1.5 x 10^8</td>
<td>1.1 x 10^5</td>
</tr>
<tr>
<td>134Cs</td>
<td>2.6 x 10^8</td>
<td>2.6 x 10^5</td>
</tr>
<tr>
<td>135Cs</td>
<td>4.5 x 10^8</td>
<td>4.5 x 10^6</td>
</tr>
<tr>
<td>132Te</td>
<td>1.2 x 10^8</td>
<td>6.7 x 10^5</td>
</tr>
</tbody>
</table>

Table 2: Estimated release rates of various nuclides into the environment.
Table 3 The ratios of radioactivity of dominant nuclides released in 26th April to their inventories

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Radioactivity Released in 26th April (Ci)</th>
<th>Inventory(Ci)</th>
<th>Release rate to the inventory in 26th April (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noble gases</td>
<td>$4.8 \times 10^8$</td>
<td>$9.9 \times 10^8$</td>
<td>48</td>
</tr>
<tr>
<td>Iodine group</td>
<td>$3.2 \times 10^7$</td>
<td>$6.4 \times 10^6$</td>
<td>5</td>
</tr>
<tr>
<td>Cesium group</td>
<td>$2.8 \times 10^6$</td>
<td>$9.2 \times 10^6$</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 4 Inventories used in this report

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Inventory(Ci/tU)</th>
<th>Nuclide</th>
<th>Inventory(Ci/tU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{131m}$Xe</td>
<td>$5.214 \times 10^3$</td>
<td>$^{129}$I</td>
<td>$7.405 \times 10^3$</td>
</tr>
<tr>
<td>$^{133}$Xe</td>
<td>$9.724 \times 10^5$</td>
<td>$^{131}$I</td>
<td>$4.699 \times 10^5$</td>
</tr>
<tr>
<td>$^{133m}$Xe</td>
<td>$3.026 \times 10^4$</td>
<td>$^{132}$I</td>
<td>$6.820 \times 10^5$</td>
</tr>
<tr>
<td>$^{135}$Xe</td>
<td>$3.121 \times 10^5$</td>
<td>$^{133}$I</td>
<td>$9.718 \times 10^5$</td>
</tr>
<tr>
<td>$^{136m}$Xe</td>
<td>$1.894 \times 10^5$</td>
<td>$^{134}$I</td>
<td>$1.064 \times 10^6$</td>
</tr>
<tr>
<td>$^{137}$Xe</td>
<td>$8.444 \times 10^5$</td>
<td>$^{135}$I</td>
<td>$9.039 \times 10^5$</td>
</tr>
<tr>
<td>$^{138}$Xe</td>
<td>$8.062 \times 10^5$</td>
<td>$^{136}$I</td>
<td>$4.218 \times 10^5$</td>
</tr>
<tr>
<td>$^{139}$Xe</td>
<td>$6.305 \times 10^5$</td>
<td>Total</td>
<td>$4.521 \times 10^5$</td>
</tr>
<tr>
<td>Total</td>
<td>$3.786 \times 10^5$</td>
<td>$^{134}$Cs</td>
<td>$1.447 \times 10^4$</td>
</tr>
<tr>
<td>$^{83}$Kr</td>
<td>$6.239 \times 10^6$</td>
<td>$^{136}$Cs</td>
<td>$1.189 \times 10^4$</td>
</tr>
<tr>
<td>$^{85}$Kr</td>
<td>$2.502 \times 10^3$</td>
<td>$^{137}$Cs</td>
<td>$2.509 \times 10^4$</td>
</tr>
<tr>
<td>$^{85m}$Kr</td>
<td>$1.343 \times 10^5$</td>
<td>Total</td>
<td>$5.104 \times 10^4$</td>
</tr>
<tr>
<td>$^{87}$Kr</td>
<td>$2.592 \times 10^5$</td>
<td>$^{140}$Ba</td>
<td>$8.406 \times 10^5$</td>
</tr>
<tr>
<td>$^{88}$Kr</td>
<td>$3.660 \times 10^5$</td>
<td>$^{132}$Te</td>
<td>$6.719 \times 10^5$</td>
</tr>
<tr>
<td>$^{89}$Kr</td>
<td>$4.495 \times 10^5$</td>
<td>Total</td>
<td>$1.717 \times 10^6$</td>
</tr>
<tr>
<td>$^{90}$Kr</td>
<td>$4.429 \times 10^5$</td>
<td>Total</td>
<td>$5.104 \times 10^4$</td>
</tr>
</tbody>
</table>