Estimation of radioactivity impact for RDE based on HTR-10 hypothetical accident - a case study

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Abstract. BATAN priority activity supported by the Center for Nuclear Reactor Technology and Safety is the conceptual design documents and evaluation of experimental power reactor (RDE). Based on the design established, the radiation safety involving the dispersion of radioactive into the site and environment shall be calculated. The objective of this study is to obtain the radioactivity impact of RDE due to hypothetical accident in Serpong II Nuclear Area (KNS-II) in Puspiptek Area. Postulated hypothetical accidents are water ingress and depressurization accident. The source term input data taken are based on HTR-10 hypothetical accident. Meteorological and environmental data are taken from available data of KNS Serpong. The calculation is carried out using PC-Cosyma code. The highest radioactivity of air dispersion for Kr-87 due to depressurization accident is 1.96E+04 Bq/m$^3$ and due to water ingress accident is 1.96E+04 Bq/m$^3$. The highest radioactivity of surface deposition due to depressurization accident for Cs-137 is 1.51E+03 Bq/m$^2$ and due to water ingress accident for I-131 is 1.5E+01 Bq/m$^2$. The impact of RDE radioactivity for hypothetical accidents on the KNS-II site shows lower than BAPETEN regulatory requirements.

Keywords: radioactivity impact, RDE, HTR-10, accident

1. Introduction

BATAN's policy and strategy focus in the energy sector for the period 2015-2019 is the design development of an experimental power plant RDE [1]. The planned RDE is a pebble-bed modular High Temperature Gas reactor HTGR [2,3,4,5] with thermal power of 10 MW. The RDE design is made with reference to small powered HTGR reactor (in accordance with the IAEA classification) that has operated, in this case the Chinese HTR-10 reactor [6].

Based on the design established, the radiation safety involving the dispersion of radioactive into the site environment shall ensure that in accident condition, exposure and radiation doses shall be as low as reasonably achievable according to the principle of As Low As Reasonably Achievable (ALARA) and below the specified limits [7,8]. Source term input data were taken from accidental water ingress source term data and depressurization [9,10,11,12].
The DLOFC (Depressurized Loss of Coolant Accident) accidents are accidental stress losses caused by pipe leaks on the reactor primary system. As a result of this pipe leakage, the pressure in the primary system will drastically decrease in a very short time. Loss of pressure on the primary cooler will result in diffusion events in TRISO fuel due to rising temperature, desorption, particle failure, and recoil. The fission products from TRISO fuel to the reactor core and inside the reactor core occur in the absorption process on the surface of the graphite as on the surface of the fuel element and the top of the reflector for the fission nuclides Cs, Sr and I [5,13]. The fission products released to the coolant are caused by the desorption process due to the pressure drop and corrosion after concrete decomposition [14]. In the surface of the primary cooling circuit, the process of deposition occurs and plate-out on the surface of metal and oxide, sorption on the reflector side, and the adhesion process on the aerosol fission products to the fission products Cs, Sr, Ag and I. In addition, plate-out process of dust borne activity for Cs and Sr nuclides, and off to containment. In containment gas the fission product undergoes plate-out, as well as aerosol and iodine deposition (Cs, Sr, I and Ag nuclides) on the surface of the containment, then into the environment through the chimney filter [9,10,11,12].

The fission products from TRISO to the reactor core due to corrosion and inside the reactor core occurs the absorption process on the graphite surface as on the surface of the fuel element and the top of the reflector for the fission nuclides Cs, Sr, and I. The fission products released to the coolant are caused by the desorption process, corrosion, wash-off, and elevator-off processes. In the surface of the primary cooling circuit occurs the process of deposition and plate-out on the surface of metal and oxide, sorption on the reflector side, and the adhesion process on the aerosol fission products to the fission products Cs, Sr, Ag and I. In addition, plate-out process of dust borne activity for Cs and Sr nuclides, and off to containment. On the surface of the containment, the fission product gas undergoes plate-out, as well as the deposition of aerosols and Iodine (nuclides Cs, Sr, I and Ag), discharges into the environment through a stack filter [12,14].

The objective of this study is to obtain of radioactivity impact of RDE due to hypothetical accident in Serpong II Nuclear Area (KNS-II) in Puspiptek Area. Postulated hypothetical accidents are water ingress and depressurization accidents. The source term input data is taken from accidental source term data that has been calculated from HTR-10 [12]. The calculations of atmospheric radioactivity was done by using an atmospheric disperse approach with a Gaussian model [15,16,17,18,19]. Meteorological and experimental input data such as population distribution, farm-livestock production are taken from available data of KNS Serpong. The calculations were carried out by PC-Cosyma software [5,7,8,16,20].

2. Methodology

The assessment in this work was based on atmospheric dispersion calculation [15,16]. The reactor source term used was based on HTR-10 accident source term [12], the radioactivity calculation used PC-Cosyma [5,7,8,16]. Through various pathways, source terms release will get into the human body depending on the type and behaviour of nuclides as well as meteorological and environmental conditions.

2.1. Depressurization accident in HTR-10

In the depressurization accident, it was assumed that the fission products in coated particles are not released during the accident. When the accident occurs, the following four sources of radioactivity released to the environment are involved: the radioactivity in primary helium, the desorption of fission products deposited on the primary circuit surface, the mobilization of dust-bound radioactivity deposited in ‘dead-water regions’, the release of the radioactivity bound in the helium purification system [12].
2.2. Water ingress accident in HTR-10

In the accident analysis, it is conservatively assumed that a two-end rupture of two heat transfer tubes of the steam generator happens and the initiating steam relief system for the steam generator fails simultaneously. Water enters into the primary circuit through the leak. Due to the oxidizing reaction of graphite with water, the pressure of the primary circuit increases, and the safety valves will open. Approximate 23% of the primary helium is released into the reactor building [12]. The source term due to depressurization and water ingress accident were described in Table 1 [12].

| Nuclide  | Depressurization accident | Water ingress accident |
|----------|---------------------------|------------------------|
| Kr-83m   | 6.3E8                     | 1.7E8                  |
| Kr-85m   | 1.9E9                     | 3.7E8                  |
| Kr-85    | 1.5E8                     | 9.0E5                  |
| Kr-87    | 4.4E9                     | 1.1E9                  |
| Xe-131m  | 1.9E8                     | 2.9E6                  |
| Xe-133m  | 4.1E8                     | 2.6E7                  |
| Xe-133   | 2.2E10                    | 6.5E8                  |
| Xe-135   | 3.7E9                     | 6.6E8                  |
| I-131    | 2.5E7                     | 2.2E8                  |
| I-132    | 3.4E8                     | 1.3E8                  |
| I-133    | 7.9E7                     | 1.9E8                  |
| I-135    | 1.5E8                     | 1.4E8                  |
| Ag-110m  | 5.1E4                     | 4.9E4                  |
| Cs-134   | 8.9E5                     | 2.3E6                  |
| Cs-137   | 1.3E8                     | 3.1E8                  |
| Sr-90    | 1.4E3                     | 2.9E3                  |
| C-14     | 3.2E6                     | 1.9E4                  |
| H-3      | 1.1E10                    | 1.7E9                  |

2.3. Radioactivity calculations

The mathematical models used to get the generic data sets are atmospheric dispersion using a Gaussian plume model, dry and wet deposition. A Gaussian Modification (Segmented Gaussian) atmospheric dispersion code PC-Cosyma were used to estimate the radiological doses of the released radionuclide [5,7,8,16]. The segmented Gaussian plume model is accurate on the 0-50 km scale. The model requires the following input data and parameters: time and location, atmospheric data (wind speed and wind direction, air temperature, relative humidity, cloud cover, mixing layer height), stability class of the atmosphere (proposed by the model based on meteorological data), roughness length and information about the release (air pollutant, duration of release, amount of released material, source height). The distribution of Pasquille Guifford atmospheric stability classes as an annual base of the Serpong site were processed hourly. Radionuclide is released through the ventilation stack of 60 meters height. The doses were calculated by area within 5 km around the site for five distances (0.5; 1.5; 2.5; 3.5; and 4.5 km) and 16 directions sectors at different wind speed.

3. Results and Discussion

The radioactivity impact of accident was calculated by depressurization accident and water ingress accident postulation. Based on accident source term on Table 1, radioactivity was calculated by PC-Cosyma. The calculation result is shown on Figure 1 to Figure 4.
3.1 Depressurization Accident radioactivity

Radioactivity on site due to depressurization accident was calculated by PC-Cosyma are shown on Figure 1 and Figure 2. Figure 1 describes about radioactivity dispersed on atmosphere, and radioactivity deposited on Figure 2. Radioactivity in Fig 1 is the result of a maximum dispersion radioactivity towards the South of the site. The trend radioactivity each radionuclide dispersed on atmosphere on Figure 2 showed decreased with the increased distance radius. The highest radioactivity of dispersed due to depressurization accident for noble gas: Kr-87 is 1.96E+04 Bq/m$^3$. The highest radioactivity for I-131 is 1.87E+02 Bq/m$^3$; for Cs-134 is 7.80E+00 Bq/m$^3$; for Cs-137 is 1.14E+03 Bq/m$^3$ and for Ag-110m is 4.47E-01 Bq/m$^3$. All of this radionuclide is dispersed within 500m radius.

The dispersed nuclides in the atmosphere relate to the nuclides in the source term and the magnitude of the source term activity. The activity of nuclides in the atmosphere is affected by meteorological conditions and the contour of the site, following the weather stability model in the site. The activity of nuclides dispersed in the atmosphere, following the pathway paths such as cloud shine and ground shine, will contribute radiation doses to the population around the site.

Figure 2 shows the distribution map for the surface deposition of radionuclide except noble gas (Kr and Xe) accumulated over the whole simulation period. The areas where there was a large amount of surface deposition within south regions. Radioactivity in Figure 1 is the result of a maximum surface deposition radioactivity towards the South of the site. The trend radioactivity surface-deposited each radionuclide in Figure 2 are proportional to those dispersed in the atmosphere in Fig 1. The highest radioactivity of surface deposition due to depressurization accident for I-131 is 1.85E+00 Bq/m$^2$; Cs-134 is 7.80E+00 Bq/m$^2$; Cs-137 is 1.51E+03 Bq/m$^2$ and Ag-110m is 4.47E-01 Bq/m$^2$. All of this radionuclide is deposited within 500m radius. Aerosols and iodine can also be terrestrial deposited on soil by wet and dry deposition.

![Figure 1. Radioactivity of air dispersion for depressurization accident](image-url)
The highest radioactivity of dispersed due to water ingress accident is shown in Figure 3 were the value of Kr-87 activity for noble gas is 1.96E+04 Bq/m³. The highest radioactivity for I-131 is 1.51E+03 Bq/m³; Cs-134 is 7.80E+00 Bq/m³; Cs-137 is 1.51E+03 Bq/m³ and Ag-110m is 4.47E-01 Bq/m³. All of these radionuclides are dispersed within 500m radius.

Figure 4 shows that the highest radioactivity of surface deposition due to water ingress accident which the value of I-131; Cs-134; Cs-137 and Ag-110m are 1.5E+01 Bq/m²; 7.80E-03 Bq/m²; 2.72E+00 Bq/m² and 4.47E-04 Bq/m² respectively. All of these radionuclides are deposited within 500m radius.

**Figure 3.** Radioactivity of air dispersion for water ingress accident

**Figure 2.** Radioactivity of surface deposition for depressurization accident

### 3.2 Water ingress accident radioactivity

The highest radioactivity of dispersed due to water ingress accident is shown in Figure 3 were the value of Kr-87 activity for noble gas is 1.96E+04 Bq/m³. The highest radioactivity for I-131 is 1.51E+03 Bq/m³; Cs-134 is 7.80E+00 Bq/m³; Cs-137 is 1.51E+03 Bq/m³ and Ag-110m is 4.47E-01 Bq/m³. All of these radionuclides are dispersed within 500m radius.

Figure 4 shows that the highest radioactivity of surface deposition due to water ingress accident which the value of I-131; Cs-134; Cs-137 and Ag-110m are 1.5E+01 Bq/m²; 7.80E-03 Bq/m²; 2.72E+00 Bq/m² and 4.47E-04 Bq/m² respectively. All of these radionuclides are deposited within 500m radius.
The radionuclide deposition at the soil surface will contribute to the acceptance of external radiation from ground shine and internal radiation through the food and beverage path. Noble gas nuclides such as Kr and Xe will provide external doses if their activity is high. Noble gases do not interact with matter so they do not contribute to receiving internal radiation doses such as inhalation, immersion or ingestion through food and drink. Acceptance of radiation dose by inhalation or breathing inhalation, while through immersion is through the skin.

Figure 4. Radioactivity of surface deposition for depressurization accident

Nuclides besides noble gases can provide external doses and internal doses. Group I nuclides can contribute to the acceptance of internal radiation such as inhalation, immersion or ingestion through food and drink. Based on the toxicity of radionuclide I is an indicator radionuclide for radioactive release of accident condition. Nuclide Cs has properties similar to I that can contribute radiation reception via external and internal, with the difference of external radiation from Cs higher than internal radiation. Generally the radioactivity of dispersion and deposition decreases with increasing of radius distance from reactor.

4. Conclusion
The radioactivity impact of RDE due to hypothetical accident in Serpong II Nuclear Area (KNS-II) in Puspiptek Area has been studied. Postulated accidents investigated are water ingress and depressurization accidents which based on HTR-10 hypothetical accident. The highest radioactivity dispersed in atmosphere due to depressurization accident is Kr-87 is 1.96E+04 Bq/m³ and due to water ingress accident for Kr-87 is 1.96E+04 Bq/m³. The highest radioactivity of surface deposition due to depressurization accident for Cs-137 is 1.51E+03 Bq/m² and due to water ingress accident for I-131 is 1.5E+01 Bq/m². The impact of RDE radioactivity for hypothetical accidents on the KNS site shows lower than BAPETEN regulatory requirements.

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