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# Assessment of radioactive gaseous effluent released from Ninh Thuan 1 nuclear power plant under scenario of INES-level 6 nuclear accident

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**Abstract**: Based on guides RG 1.109, RG 1.111 published by United States Nuclear Regulatory Commission (USNRC) our research concentrates on assessing radiation doses caused by radioactive substances released from the Ninh Thuan 1 nuclear power plant (NPP) to the environment under scenario of an INES-level 6 nuclear accident caused by the Station Black Out (SBO) incident and the loss of coolant accident (LOCA) phenomenon using software RASCAL4.3 provided by the Emergency Operations Center of USNRC. The NinhThuan 1 plant is assumed to use the VVER-1200 technology with a total power of 2400 $MW_e$. The input data for the model calculations is based on building the accident scenario, the technical parameters of VVER-1200 technology and the meteorology. In this work the meteorological data on dry and rainy seasons which are typical for the NinhThuan region was considered. The maximum dose values were calculated within an area of 40 km radius from the NPP site. The obtained calculation results showed that the dose distributions affected by meteorological conditions. In the rainy season the dose values near the plant are higher than those in the dry season, especially at the distances less than 10 kilometers from the plant the total effective dose equivalence (TEDE) values can be from about 3.5 to 15 times higher than the dose limit for publics. As a result, it is requested to follow the evolution of the accident in order to issue timely the appropriate response measures based on the guidance specified by the Circular 25/2014/TT-BKHCN.

**Keywords:** *Loss of Coolant Accident (LOCA), Station Black Out (SBO), source term, radioactive release, maximum dose value, Ninh Thuan 1 nuclear power plant (NPP), VVER-1200, International Nuclear Event Scale (INES), RASCAL4.3.*

## I. INTRODUCTION

Currently, Vietnam is actively preparing infrastructure for the first two nuclear power plants (NPP) projects in the Ninh Thuan province, in which the plant Ninh Thuan 1 is planned to use the VVER-1200 technology with a total power of 2400 $MW_e$. When going into operation, the NPP will release radioactive nuclides into the atmosphere. The radioactive

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effluent undergoing dispersion in air and deposition on the ground will cause impact to the environment and human, especially for the occurrence of a nuclear accident. Therefore, the study of transport and dispersion of radioactive substances in the atmosphere, and assessment of radiation dose to the public are of essential requirement for an NPP project. In addition, the calculation results will provide the necessary data for the Environmental Impact Assessment (EIA) and support for regulatory organization in reviewing the Safety Analysis Report (SAR)

Radioactive releases from various nuclear facilities, in general, may contribute to radiation exposure through two main pathways: (1) External exposures by direct radiation from radioactive plumes or from radioactive nuclides deposited on the ground, and (2) Internal exposure due to inhalation and ingestion of radioactive substances. The magnitude of exposure is dependent on atmospheric dispersion and deposition processes [1].

In this work we concentrate on assessing maximum radiation doses as a result of radioactive release from a nuclear accident with wider consequences assumed to occur at the Ninh Thuan 1 NPP. The magnitude of the accident was evaluated at level 6 defined by the International Nuclear Event Scale (INES) [2]. The scenario of the accident was built based on two incidents: the Station Black Out (SBO) and the Loss of Coolant Accident (LOCA) induced by a rupture in the Reactor Coolant System (RCS) for the nuclear reactor. The accident leads to consequences starting from the damage of the reactor core to failure of the containment, and eventually the release of radioactive substances to the environment. The assessments for the accident have been performed using RASCAL4.3 developed by the Emergency Operations Center of USNRC [3,4]. Building the input for the model calculations consists of describing the accident scenario, the technical parameters characteristics of the VVER-1200 technology and the meteorology. The obtained calculation results include the maximum values of organ doses for the dry and rainy seasons within 80 km radius from the NPP site.

## II. RASCAL4.3 AND BUILDING DATA INPUT

For modeling a NPP accident the Source Term to Dose model in RASCAL4.3 is used to evaluate the projected radiation doses from the plume of the released radioactive substances to people downwind based on entering information about the plant conditions. The dose pathways consist of cloud shine from the plume, inhalation from the plume, and ground shine from the deposited radioactive nuclides.

Building the data input for the model calculations includes:

a. Meteorology: Meteorological data is needed to the model behavior of the radioactive plume in the atmosphere. The minimum required data includes wind speed and direction, atmospheric stability, precipitation, air temperature. The goal is to provide the best representation of the weather conditions for the model run in both time (up to 48 hours starting from the release) and space (up to a distance of 50 miles or 80 km from the plant site). The RASCAL4.3 requires the initial weather data to be entered within a 2 hour window before the start of the release.

In this work the assessment of the radioactive dispersion and consequence of the accident was carried out at two times of the year: on the days of 17$^{th}$ January and 26$^{th}$ September 2013 which are typical for the weather of the dry and rainy seasons in the Ninh Thuan region. Short descriptions for the observed meteorological data are summarized in Tables I&II.

**Table I**: The observed meteorological data on 17th January, 2013 at Ninh Thuan

| Summary of data at release point | Type | Direction Degree | Speed (m/s) | Stability Class | Precip. | Temp. (°C) |
|---|---|---|---|---|---|---|
| 2013/01/17 03:00 | Obs | 327 | 2 | C | None | 23.0 |
| 2013/01/17 04:00 | Obs | 0 | 5 | C | None | 23.2 |
| 2013/01/17 05:00 | Obs | 0 | 3 | C | None | 23.0 |
| 2013/01/17 06:00 | Obs | 23 | 4 | C | None | 23.8 |
| 2013/01/17 07:00 | Obs | 0 | 4 | C | None | 24.8 |
| 2013/01/17 08:00 | Obs | 0 | 4 | C | None | 26.9 |
| . . . | | | | | | |
| 2013/01/19 00:00 | Obs | 0 | 5 | C | None | 22.9 |

**Table II:** The observed meteorological data on 26th September, 2013 at Ninh Thuan

| Summary of data at release point | Type | Direction Degree | Speed (m/s) | Stability Class | Pricip | Temp (°C) |
|---|---|---|---|---|---|---|
| 2013/09/26 03:00 | Obs | 225 | 1 | D | None | 26.0 |
| 2013/09/26 04:00 | Obs | 225 | 0 | D | None | 26.0 |
| 2013/09/26 05:00 | Obs | 335 | 1 | D | Rain | 25.9 |
| 2013/09/26 06:00 | Obs | 295 | 2 | D | Light rain | 25.8 |
| 2013/09/26 07:00 | Obs | 245 | 3 | D | None | 25.6 |
| 2013/09/26 08:00 | Obs | 270 | 2 | D | Light rain | 26.1 |
| … | | | | | | |
| 2013/09/28 00:00 | Obs | 270 | 0 | D | None | 24.8 |

**Table III**: The VVER-1200technical parameters assumed to use at NPP NinhThuan 1 [5]

| **Event Type** | Nuclear Power Plant |
|---|---|
| Location | Phuoc Dinh |
| Name: | Ninh Thuan 1 |
| City, country, state | Ninh Phuoc, Ninh Thuan, Vietnam |

| | |
|---|---|
| Lat/Long/Elev: | 11.3963$^{o}$N, 109.0037$^{o}$E, 20 m |
| **VVWR-1200 Reactor parameters** | |
| Reactor power | 3,200 MWt |
| Peak rod burn-up | 60,000 MWd/MTU |
| Containment type | PWR Dry Ambient |
| Containment volume | 2.50E+06 $ft^3$ |
| Design pressure | 72.52 $lb/in^2$ |
| Design leak rate | 0.2%/day |
| Coolant mass | 2.9E+05 kg |
| Assemblies in core | 163 |
| Steam generator | U-type |
| SG water mass | 52,220 kg |
| **Source term** | |
| Type | Time core is uncovered |
| Shutdown | 2013/01/17 at 0:00 |
| Core uncovered | 2013/01/17 at 3:00 |
| Core recovered | 2013/01/17 at 7:00 |

b. Description of the scenario of the accident: Due to a Station Black Out (SBO) incident at the Ninh Thuan 1 NPP the LOCA phenomenon occurred and led to the reactor core to be uncovered. In this scenario it is assumed that there was a rupture in the RCS and this made the LOCA to be occurred more quickly. For the evolution of the accident, it is assumed that the reactor was shut down at 0:00 on 17 January 2013, the core was uncovered at 03:00 and recovered at 07:00. During four hours the core was uncovered the fuel rods was heated up and melt down due to the decay heat. This caused release of the fission products from the core to the reactor containment via the rupture in the RCS and consequently makes it possible to increase temperature and pressure in the containment. As a result, the containment has failed and caused the radioactive release to the atmosphere which is assumed 2% per day in this scenario. The data on the VVER-1200 technological characteristics needed to build the input for the RASCAL4.3 calculations is summarized in table III [5].

## III. RESULTS AND DISCUSSION

For each scenario of the NPP accident the RASCAL4.3 calculations give two main results: (1) Source term for radioactive nuclides released tothe atmosphere, and (2) Distribution of maximum dose values (rem, mSv) up to 50 miles (80 km) from the plant. For the scenario described above for the Ninh Thuan 1 NPP there may have up to 60 radioactive nuclides that can be predicted by the RASCAL4.3 for the released source term. All these nuclides are used to consider the radioactive dispersion and assess maximum dose distribution due to the NPP accident. However, only the radioisotopes that have been detected in two accidents Chernobyl and Fukushima are used to evaluate the magnitude (level) of accident defined by the INES [2]. In this work the radioactive nuclides from the RASCAL4.3 obtained source term which were used to evaluate magnitude of the accident are presented in Table IV.

**Table IV:** The radioactive nuclides used to evaluate the magnitude of the accident described above for the Ninh Thuan 1 NPP.

| Nuclide | Activity, $A_i$ (Ci) | $F_i$ | Nuclide | Activity, $A_i$ (Ci) | $F_i$ |
|---|---|---|---|---|---|
| $^{140}$Ba | 1.6E+4 | none | $^{106}$Ru | 3.3E+2 | 6 |
| $^{144}$Ce | 5.5E+2 | none | $^{132}$Te | 3.0E+4 | 0.03 |
| $^{134}$Cs | 1.3E+4 | 3 | $^{133}$Xe | 4.2E+5 | 0 |
| $^{137}$Cs | 8.9E+3 | 40 | $^{89}$Sr | 8.1E+3 | 20 |
| $^{131}$I | 4.6E+4 | 1.0 | $^{90}$Sr | 1.3E+3 | 20 |
| $^{99}$Mo | 6.3E+2 | 0.08 | $^{241}$Am | 1.5E-4 | 8000 |

In principle the magnitude of a nuclear accident is evaluated as follows: Firstly the activity $A_i$ of each released radionuclide has to be attributed to the radiological equivalent one of radioisotope $^{131}$I by multiplying with factor $F_i$, and then a total released radioactivity ($A_{total}$) is summed from all the obtained equivalent ones [2]. Therefore, from the data shown in Table IV the total value of the equivalent radioactivity is calculated as:

$$A_{total} = \Sigma(A_i \times F_i)$$

$$= 62.9 \times 10^4 \text{Ci} \sim 232.73 \times 10^{14} \text{Bq} = 23273 \text{ TBq}$$

This is the radiological equivalence to $^{131}$I for release to the atmosphere. This value shows that the accident is graded at the INES level 6: Serious Accident [2].

Based on the obtained result for the released source term the distributions of maximum dose values within a radius of 25 miles (40.2 km) around the plant were calculated as a function of dispersion time at 3, 10, 20, 30, 40 and 48 hours starting from the release. The obtained results showed that for the dispersion time less than 20 hours the maximum dose values increase slightly with respect to time. After this time and up to 48 hours the maximum dose values remain unchanged. So, for discussion, we show in Tables V&VI the maximum dose distributions typically for the dry and rainy seasons at the dispersion time of 20 hours, respectively.

**Table V:** Calculation results for distribution of maximum dose values (mSv) at the dispersion time of 20 hours for the dry season up to 25 miles (40.2 km) from the plant.

| Distance from release | Mile | 3 | 4 | 5 | 7 | 10 | 15 | 25 |
|---|---|---|---|---|---|---|---|---|
| | Km | 4.8 | 6.4 | 8 | 11.3 | 16.1 | 24.1 | 40.2 |
| Dose (mSv) | Total EDE | 9.4 | 9.9 | 8.1 | 3.5 | 1.2 | 0.44 | 0.029 |
| | Thyroid CDE | 67.0 | 73.0 | 62.0 | 26.0 | 8.5 | 2.9 | 0.2 |
| | Inhalation CDE | 7.8 | 8.7 | 7.3 | 3.2 | 1.1 | 0.39 | 0.026 |
| | Cloudshine | 0.17 | 0.18 | 0.15 | 0.056 | 0.016 | *** | *** |
| | 4-day groundshine | 1.3 | 1.0 | 0.65 | 0.25 | 0.11 | 0.044 | *** |
| | Inter Phase 1$^{st}$Yr | 23.0 | 18.0 | 12.0 | 4.9 | 2.3 | 0.9 | 0.064 |
| | Inter Phase 2$^{nd}$Yr | 13.0 | 10.0 | 6.5 | 2.7 | 1.2 | 0.5 | 0.035 |

**Table VI:** Calculation results for distribution of maximum dose values (mSv) at the dispersion time of 20 hours for the rainy season up to 25 miles (40.2 km) from the plant.

| Distance from release | Mile | 3 | 4 | 5 | 7 | 10 | 15 | 25 |
|---|---|---|---|---|---|---|---|---|
| | Km | 4.8 | 6.4 | 8 | 11.3 | 16.1 | 24.1 | 40.2 |
| Dose (mSv) | Total EDE | 15.0 | 7.1 | 4.7 | 4.0 | 3.3 | 1.0 | 0.09 |
| | Thyroid CDE | 64.0 | 36.0 | 26.0 | 18.0 | 9.7 | 5.3 | 0.47 |
| | Inhalation CDE | 7.2 | 4.0 | 3.5 | 2.2 | 1.0 | 0.38 | 0.027 |
| | Cloudshine | 0.18 | 0.097 | 0.063 | 0.042 | 0.022 | 0.011 | *** |
| | 4-day groundshine | 7.2 | 4.5 | 3.5 | 3.2 | 2.6 | 0.63 | 0.06 |
| | Inter Phase $1^{st}$Yr | 120.0 | 81.0 | 69.0 | 67.0 | 42.0 | 8.4 | 0.44 |
| | Inter Phase $2^{nd}$Yr | 67.0 | 46.0 | 40.0 | 39.0 | 23.0 | 4.4 | 0.21 |

*Note: Symbol "***" in Tables V&VI implies that the dose value < 1.0E-2 (0.01) mSv.*

From the obtained calculation results for the maximum dose distributions shown in Tables V&VI we can see:

- In general, the dose decreases properly with respect to distance. However, for the dry season there may have a slight increase of the dose at some kilometers near the plant, for example, the dose values in Table V at 3 miles (4.8 km) and 4 miles (6.4 km). This can be due to the meteorological characteristics.

- In the rainy season the total EDE values near the plant are higher than those in the dry season. This is consistent with expectation which is due to the strong deposition in the rainy season.

- The maximum dose values, total EDEs, reach to about 1 mSv at 16.1 and 24.1 km for the dry and rainy seasons, respectively. It should be noticed that the annual limit sof the total EDE for occupational and public exposures are, respectively, 50 and 1 mSv specified by USNRC and Vietnam Agency for Radiation and Nuclear Safety [7,8].

From the calculation results shown in Tables V&VI we can see that at the distances less than 10 kilometers from the plant the total EDE values are from about 3.5 to 15 times higher than the limit value for publics. The consequences of the accident are really serious. It is requested to inform and coordinate closely with the Emergency Response Authority of the Ninh Thuan province in order to follow the evolution of the accident and issue timely the appropriate response measures. The consumption of food and milk in the region must be immediately stopped until getting the results of sample testing. The public communication, procedure for radiation emergency preparedness and people evacuation must be considered and implemented under the guidance of Circular 25/2014/TT-BKHCN [9].

## IV. CONCLUSION

Based on the Station Black Out (SBO) incident and Loss of Coolant Accident (LOCA) we proposed the scenario of a nuclear accident assumed to occur at the Ninh Thuan 1 NPP. The source term of the released radioactivity, dispersion and consequences of the accident were calculated using the RASCAL4.3 code developed by the Emergency Operations Center of USNRC.

The data input for the code calculations was built consisting of the technical parameters of the VVER-1200 technology assumed to use for the Ninh Thuan 1 NPP project, the evolution of the accident and the meteorology within 48 hours covering the release. The calculations on the maximum dose distributions were carried out up to 25 miles (40 km) from the plant site for two meteorological conditions on the dry and rainy seasons which are typical for the annual weather in the Ninh Thuan region.

The obtained result on released source term made it possible to assess the considered accident at the INES level 6: Serious accident.

The dose distributions can be affected by meteorological conditions. In the rainy season the total EDE values near the plant are higher than those in the dry season. This is due to the strong deposition in the rainy season.

At the distances less than 10 kilometers from the plant the total EDE values are normally from about 3.5 to 15 times higher than the limit value for publics. It is requested to coordinate closely with the Emergency Response Authority of the Ninh Thuan province in order to follow the evolution of the accident and issue timely the appropriate response measures. The public communication, the consumption of food and milk, the procedure and actions for radiation emergency preparedness must be considered and implemented under the guidance of Circular 25/2014/TT-BKHCN.

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