Radiological Dose Assessment of Nigeria Research Reactor NiRR-1

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1. Introduction

NiRR-1 is a low power, tank-in-pool Miniature Neutron Source Reactor (MNSR) with nominal thermal power of 34kW under steady state condition. The reactor was designed by China Institute of Atomic Energy as the 8th MNSR in the world and was commissioned in 2004 which utilizes Highly Enriched Uranium (HEU) fuel, but later converted to Low Enriched Uranium (LEU) fuel in 2018. Mainly used for research and training, neutron activation analysis and limited isotope production [3]. Unlike other research reactors type, NiRR-1 has a good self-reliant ventilation system to control and minimize release or airborne radionuclides to the environment and also to protect operational personnel from excessive radiation exposure among others. The radionuclides in the form of gas or particulate might be released through the stack of the reactors ventilation system to the atmosphere and dispersed by wind to the surrounding environment [2]. The health effects resulting from such releases depends directly on the quantity and form of radionuclides. Dose Assessment of atmospheric dispersion of radionuclides during accident conditions from research reactors is crucial for ensuring public safety, which requires a scale of accidents, possible release of radionuclides and site specific meteorological conditions [1]. Such assessment is mainly the key approach in determining exposure to public dose. Radiological dose assessment shows the relationship between the radionuclide source term released into the environment and its potential effects on human health. This study therefore aims at assessing the Total Effective Dose Equivalent (TEDE) from accidental release of radionuclides to the public during severe accident condition from 34kW NiRR-1 using Hotspot Health Physics Computer Code. Fig. 1 below shows the location of NiRR-1 using google earth

Fig. 1. Showing location of NiRR-1 using google earth

2. Materials and Methods

2.1 Hypothetical Accident Scenario

For the purpose of understanding the nature of severe accidents and assessment of accident scenarios involving the release of radionuclides at NiRR-1, it is of outmost important to consider two categories of accident that might likely to occur during the lifetime of a nuclear reactor namely Design Basis Accident (DBA) and Beyond Design Basis Accident (BDBA). The BDBA scenario which is considered in this study is sometimes called the maximum hypothetical accident basically described for emergency planning purposes only because it is always considered as an accident more severe than the DBA [3]. The hypothetical accident scenario for the NiRR-1 was total station blackout, heavy earthquake caused the reactor building to collapse; the reactor was SCRAM and offsite power source was cut off and emergency diesel generator failed, reactor pressure vessel leaked water at a rate of 4 m^3/hr, thereafter the core remained uncovered with water which resulted in core meltdown and subsequent releases of radioactive materials to the surrounding atmosphere.

2.2 Atmospheric Stability Condition

Meteorologist differentiate various states of atmospheric surface layer as unstable, neutral or stable. These classifications accounts for the behavior of air when displaced in the vertical direction. Hotspot allows the choice of atmospheric stability classes. Pasquill stability class C (Slightly unstable atmospherics condition) in the east-northeast direction is reportedly observed frequently in the study area [1]. The present study considered all stability classes (A-F) in determining the plume centerline TEDE downwind distance and ground deposition. A conservative condition could also be applied when there is lack of site specific data.

2.3 Meteorology

A conservative meteorological model was used, fixing the meteorological conditions to Pasquill stability class F with 1 m/s of wind speed and a variable direction within a 22.5° sector for a time period [3].

2.4 Source Term

Radionuclides exposure in close proximity to reactor site is one of the major safety concern in the nuclear reactor because of unavoidable presence of personnel within the reactor facility and the onsite population, hence the need for routine radiological dose assessment. Such assessment involves calculation of radionuclide released with the aid of computer code and experimental measurement. The source term for radioactivity in the air of the reactor hall is the inventory of one fuel assembly multiplied by the transfer factor from the fuel to the matrix material, the transfer factor from the matrix material to water and the transfer factor from water to air [3]. The modified LEU core inventory for the selected isotopes in one fuel assembly multiplied by 347 number of fuel rods, times the transfer factor to air gave the resulting LEU source terms for use in the dose calculation as presented in Table I below.

Table I: Radiological source term of NiRR-1 Extracted from IAEA TECDOC 1844 [3].

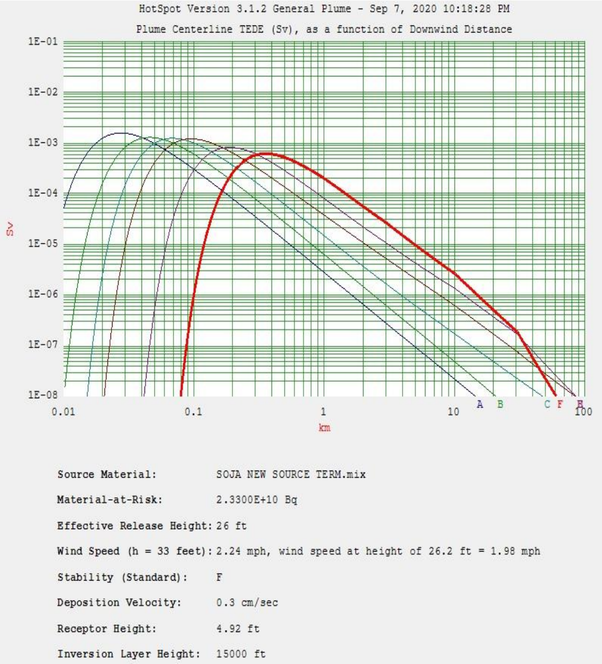
Isotopes	Categories	LEU Core Inventory (Bq) x 347	Transfer Factor to Air	LEU Source Term (Bq)
^{83m}Kr	Noble Gas	6.56E+12	2.00E-02	1.31E+11
^{85m}Kr	Noble Gas	1.54E+13	2.00E-02	3.08E+11
^{85}Kr	Noble Gas	4.89E+11	2.00E-02	9.79E+09
^{87}Kr	Noble Gas	3.12E+13	2.00E-02	6.25E+11
^{88}Kr	Noble Gas	4.41E+13	2.00E-02	8.81E+11
^{131m}Xe	Noble Gas	3.50E+11	2.00E-02	7.01E+09
^{133}Xe	Noble Gas	8.19E+13	2.00E-02	1.64E+12
^{135}Xe	Noble Gas	7.32E+13	2.00E-02	1.46E+12
^{137}Xe	Noble Gas	7.29E+13	2.00E-02	1.46E+12
^{138}Xe	Noble Gas	7.60E+13	2.00E-02	1.52E+12
^{131}I	Halogens	3.54E+13	1.00E-04	3.54E+09
^{132}I	Halogens	5.27E+13	1.00E-04	5.27E+09
^{133}I	Halogens	8.19E+13	1.00E-04	8.19E+09
^{134}I	Halogens	9.26E+13	1.00E-04	9.26E+09
^{135}I	Halogens	7.63E+13	1.00E-04	7.63E+09
^{137}Cs	Alkali Metal	4.16E+12	1.00E-06	4.16E+06
^{99}Mo	Alkali Metal	7.29E+13	1.00E-06	7.29E+07
^{89}Sr	Alkali metal	5.79E+13	1.00E-06	5.79E+07
^{90}Sr	Alkali Metal	3.99E+12	1.00E-06	3.99E+06

2.5 Simulation

HOTSPOT Health Physics Computer Codes (3.1.2) developed by Lawrence Livermore National Laboratory (LLNL) provides a first-order approximation of the radiation effects associated with the short term atmospheric release of radioactive materials to the environment [4]. The General Plume Model estimate the total effective dose equivalent due to release of radionuclides to the environment. The above source terms were added to the mixture library of hotspot code and are used as part of the input data alongside other parameters such as atmospheric stability class, wind speed and wind direction to determine radiological doses from NiRR-1.

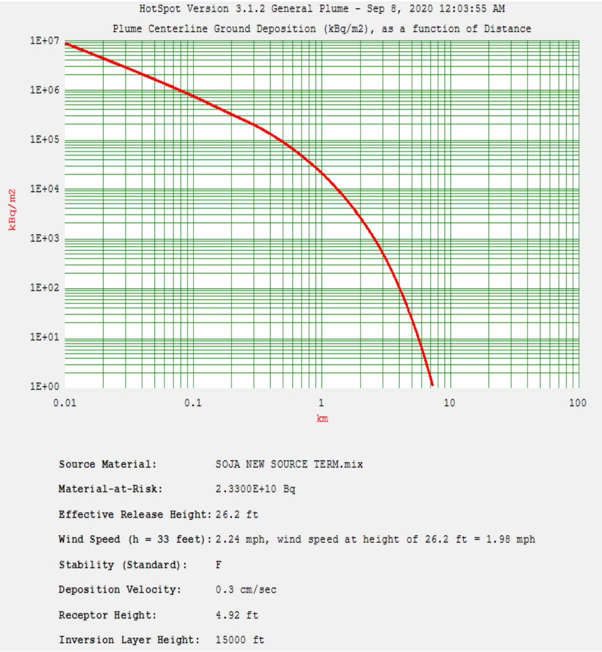
3. Results and Discussion

The result of the simulation using hotspot computer codes are presented in the Figures below.



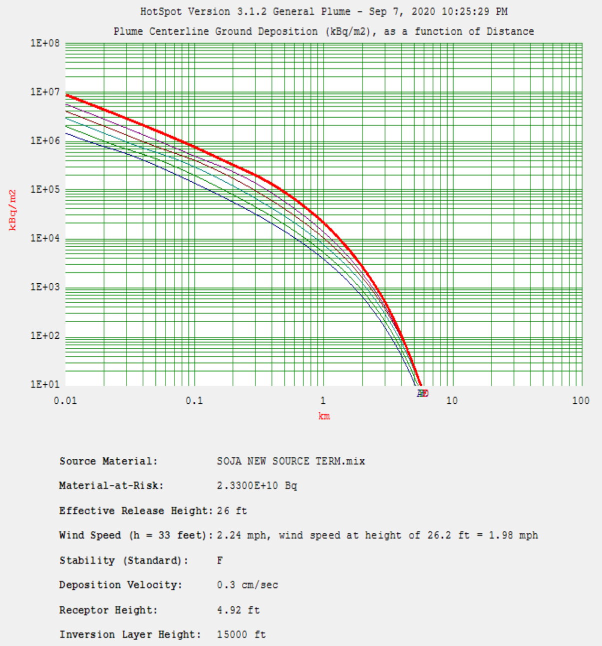
```
Source Material:           SOJA NEW SOURCE TERM.mix
Material-at-Risk:          2.3300E+10 Bq
Effective Release Height: 26 ft
Wind Speed (h = 33 feet): 2.24 mph, wind speed at height of 26.2 ft = 1.98 mph
Stability (Standard):      F
Deposition Velocity:       0.3 cm/sec
Receptor Height:           4.92 ft
Inversion Layer Height:    15000 ft
```

Fig. 2. Plume centerline TEDE downwind distance for all stability classes A–F under normal condition.



```
Source Material:           SOJA NEW SOURCE TERM.mix
Material-at-Risk:          2.3300E+10 Bq
Effective Release Height: 26.2 ft
Wind Speed (h = 33 feet): 2.24 mph, wind speed at height of 26.2 ft = 1.98 mph
Stability (Standard):      F
Deposition Velocity:       0.3 cm/sec
Receptor Height:           4.92 ft
Inversion Layer Height:    15000 ft
```

Fig. 3. Plume centerline ground deposition for single stability class.



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HotSpot Version 3.1.2 General Plume - Sep 7, 2020 10:25:29 PM
Plume Centerline Ground Deposition (kBq/m2), as a function of Distance

Source Material:          SOJA NEW SOURCE TERM.mix
Material-at-Risk:         2.3300E+10 Bq
Effective Release Height: 26 ft
Wind Speed (h = 33 feet): 2.24 mph, wind speed at height of 26.2 ft = 1.98 mph
Stability (Standard):     F
Deposition Velocity:      0.3 cm/sec
Receptor Height:          4.92 ft
Inversion Layer Height:   15000 ft
```

Fig.4. Plume centerline ground deposition for all stability classes.

The output of the simulation for radiological dose assessment of NiRR-1 using Hotspot code 3.1.2 for Plume Centerline Total Effective Dose Equivalent (TEDE) Downwind Distance in Fig. 2 above shows that the maximum TEDE is 0.0013 Sv or 1.3 mSv at a distance of 0.05 km for stability classes A, while stability classes B, C and D shows the maximum TEDE of approximately 1.1mSv equivalent at distance from 0.05 to 0.1 km respectively. Both values were slightly above the International Commission for Radiological Protection (ICRP) public dose limit of 1mSv, whereas stability classes E and F are slightly below 1 mSv at a distance of approximately 0.5 km under normal weather condition. Therefore, maximum value of TEDE occurs at a shorter distance. For Ground Deposition in Fig. 3, and Fig. 4**,** the maximum value for ground contamination is between 1E+06 to 1E+07 kBq/m^2 at a distance of 0.01 km for all stability classes with a maximum deposition distance of approximately 8km from the release point with effective release height of 26 ft. and deposition velocity of 0.3 cm/sec for single and all stability classes. Therefore, maximum value of TEDE for downwind distance and ground deposition occurs at a shorter distance.

4. Conclusion

Radiological dose assessment of NiRR-1 was conducted to assess the TEDE from dispersion of radionuclides during accident condition using Hotspot code version 3.2.1. This is due to the fact that radionuclides released to the atmosphere are transported downwind and distributed to the environment by usual atmospheric mixing phenomenon resulting to offsite dose. The result of the assessment shows the TEDE downwind distance for stability class A, B, C and D are slightly above the ICRP recommended dose limit of 1mSv for the general public whereas for stability classes E and F are slightly below the public dose limit of 1mSv at shorter distance. Thus, the offsite population within the distance of 0.05 to 1km from the release point receive higher dose due to inhalation of radionuclides and external dose as a result of beta and gamma radiation for stability classes A to F. In this situation, protective measure should be adopted to avoid inhalation of radionuclides in the case of reactor accident.

Acknowledgement

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