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Preliminary Radioactive Dispersion Modeling in the Arabian Gulf
Using the ADMS-5 Gaussian Plume Model

Philip A. Beeley a* and Sung-yeop Kim b

a Nuclear Engineering Department, Khalifa University of Science, Technology and Research, PO Box 127788, Abu Dhabi, United Arab Emirates

d Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology (KAIST), 291 Daehak-ro, Yuseong-gu, Daejeon, 305-701, Republic of Korea

*Corresponding author: philip.beeley@kustar.ac.ae

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Abstract
The commencement of nuclear reactor operations (Bushehr, Iran) and new build (Barakah, UAE) in the Arabian Gulf make it timely to investigate the potential environmental impact of these developments in the region. This study therefore examined the potential radioactive dose impacts of a reactor accident, using the ADMS-5 Gaussian dispersion code and worst case Chernobyl and Fukushima radioactive release source terms, at Bushehr or Barakah. In both cases radioactive plumes would move in a south to south-easterly direction and dose contours indicate a Chernobyl type accident would result in ten times higher doses than a Fukushima type accident. For a Fukushima type release, doses of less than 100 mSv/year are estimated beyond 100 km from the reactors.
1. INTRODUCTION

As a safe, clean, economical and sustainable energy source to support a significant portion of the energy mix in the near future, nuclear energy has gained a lot of attention in the Arabian Gulf region. The Iranian Bushehr-1 nuclear power plant (NPP) started commercial operation on the 30th July 2012 and Bushehr-2, 3 and 4 units are planned. Four units of the Korean APR-1400 reactor are under construction and are planned to start delivering electricity in UAE from Barakah unit 1 in 2017. Saudi Arabia has also established King Abdullah City for Atomic and Renewable Energy (K.A.CARE) in April 2010 and is showing a special interest in nuclear energy. The locations of the Bushehr and Barakah reactors are shown in Figure 1. To guarantee the safety of nuclear power is the first essential term for maintaining it as a sustainable energy source. Environmental impact assessment of NPPs assuming hypothetical accident should be carried out to evaluate the transport of radioactive materials in the environment and the radiological effect to humans in the accident scenario. The results from these assessments would be the useful source to increase the understanding about specific environments where nuclear power plants exist or are planned, the necessary data to establish the emergency plan and actions to mitigate exposure in severe accident scenarios. Such work also supports regulatory and licensing work and the necessary feedback data to enhance the safety design of NPPs.

Hypothetical accidents of NPPs were assumed in this study with reference to Chernobyl and Fukushima accident source terms applied to Barakah (UAE) and Bushehr (Iran) respectively. The atmospheric dispersions of radionuclides in Arabian Gulf region have been simulated using the Gaussian plume model ADMS5. Iodine-131 and Cesium-137 were selected as the key fission product radionuclides considering their health effects to humans. Meteorological data have been acquired from the UAE National Center of Meteorology & Seismology (NCMS) for Barakah case and from WindAlert for Busheher case. Total Effective Dose (TED) including Effective Dose (ED) from external exposure and 50 year Committed Effective Dose (CED) from inhalation has been calculated. For TED calculation,
Dose Conversion Factors (DCFs) in US Federal Guidance Report No. 13 (FGR 13) were utilized which is applying the new ICRP-66 lung model, ICRP series 60/70 methodologies.

2. SOURCE TERM

The definition of the source term includes the magnitude and duration of radioactive material released from nuclear facility. The physical and chemical properties and the location of the release point is considered as well. The source terms analyzed from both Chernobyl and Fukushima accidents have been chosen to be the hypothetical source terms in this study, for both the Barakah and Bushehr sites. From the source term analyses reports and papers published after those accidents, both Chernobyl and Fukushima source terms given in Table 1 were used. Average release rates have been calculated regarding the total amount of the radionuclides (I-131 and Cs-137) released and the period of the release. The height of release was assumed to be ground level (0 m) and thermal plume rise was not considered, thus representing a conservative worst case scenario.

<table>
<thead>
<tr>
<th>Source Terms Adopted in this Report</th>
<th>I-131 [Bq/h]</th>
<th>Cs-137 [Bq/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fukushima</strong> (Average)**</td>
<td>1.04×10^{15}</td>
<td>2.08×10^{13}</td>
</tr>
<tr>
<td><strong>Fukushima</strong> (Maximum)**</td>
<td>7.20×10^{15}</td>
<td>1.50×10^{14}</td>
</tr>
<tr>
<td><strong>Chernobyl</strong> (Average)***</td>
<td>7.50×10^{15}</td>
<td>3.54×10^{14}</td>
</tr>
</tbody>
</table>

Data Sources:
* TEPCO, “Estimation of the released amount of radioactive materials into the atmosphere as a result of the accident in the Fukushima Daiichi Nuclear Power Station,” 24 May 2012 [1]
3. ATMOSPHERIC DISPERSION MODELING

3.1. Meteorological Data
Hourly meteorological data of Al Rowais climate post (UAE National Center of Meteorology and Seismology) was used for the calculation of the Barakah case. To calculate the Bushehr case, hourly meteorological data of Bushehr was acquired from the open source WindAlert [4]. One year data for 2012 was used for both cases. The meteorological data input consists of wind speed, wind direction, ambient temperature, cloud amount, precipitation. Surface roughness length of both sites was entered as 0.1 cm considering the desert and coastal environment in both regions. Figure 2 represents typical averaged data wind roses for both sites indicating wind blowing from the north-north-west and north-north-east in the case of Barakah and north-north-west in the case of Bushehr.

3.2 Atmospheric Dispersion Modeling
The Atmospheric Dispersion Modeling System 5 (ADMS-5) developed by Cambridge Environmental Research Consultations (CERC) [5] has been used in this study to calculate not only atmospheric transport of materials but also plume depletion including wet/dry deposition and decay of radionuclides. ADMS-5 represents a new generation Gaussian plume air dispersion model using a skewed Gaussian concentration distribution to simulate dispersion under convective meteorological conditions. Therefore, the credibility of the dispersion results from this model extends beyond the 10 km for a simple Gaussian plume model, such as Hotspot [6]. Various modeling function of ADMS-5 are illustrated in Figure 3 [7].

3.3. Results
The activity concentration distributions of I-131 and Cs-137 after the dispersion assuming both hypothetical Chernobyl and Fukushima accident in both Barakah and Bushehr site are illustrated in figure 4, 5, 6 and 7.
4. DOSE ASSESSMENT

4.1 Methodology
Total Effective Dose (TED) is the sum of Effective Dose (ED) of external exposure and Committed Effective Dose (CED) of internal exposure. Normally, 50 years are considered for the CED. Three exposure pathways considered in this study are: (1) direct external exposure to radioactive material in the plume (cloud-shine or submersion); (2) exposure from inhalation of radionuclides in the cloud (cloud inhalation); (3) exposure to radioactive material deposited on the ground (ground-shine). Thus:

\[
TED = ED(\text{Cloudshine}) + ED(\text{Groundshine}) + CEDE(\text{Inhalation})
\]

The average breathing rate of the Reference Worker recommended from International Commission of Radiological Protection (ICRP) is 1.2 m\(^3\)/h and this value was used to calculate CEDE of inhalation [8]. Ingestion dose and the dose from re-suspended material have not been considered in this study. The Dose Conversion Factors (DCFs) following US Federal Guidance Reports FGR-12 and FGR-13 have been adopted in this study. FGR-12 was used for external submersion and ground shine DCF values [9] and FGR-13 follows the new ICRP-66 lung model and ICRP series 60/70 methodologies for inhalation [10].

4.2 Results
The results of the dose assessment for the four cases are illustrated in Figure 8, 9, 10, and 11. Because of the wind distribution, the possibility of a southerly and south easterly dispersion of radioactivity predominates. Due to the 7 – 10 times larger amount of source activity from the Chernobyl source term than that from the Fukushima source term, the results when assuming the hypothetical accident happening with Chernobyl source shows significantly higher dose levels compared to the Fukushima case. When the hypothetical Chernobyl accident is applied to both sites, the dose level of about 1000 mSv appears in 100 km region. Closer to the source, the higher
the dose. If Fukushima source is assumed to be released, the results shows 100 mSv dose level in 100 km region for both sites. But still there is high possibility of some contamination along the coastline. Whereas, the migration of radionuclides inland has higher possibility in Barakah case because of the southerly migration into the Western region and into the Saudi Arabian desert. Some activity release onto islands surrounding the coastal regions around Barakah is also predicted.

5. LIMITATIONS AND RECOMMENDATIONS

**Source Term:** In reality the actual source may not be released with a constant release rate. In this study the average release rates were approximated considering total released amount and the major period of release. However, time varying source terms could not have significant meaning when using a Gaussian plume model because it provide time independent statistical results with sampling of weather input of the period in consideration. Time varying source terms could be applied using a Gaussian plume model if a cyclic pattern is known. However, recent safety analysis methodologies are not considering deterministic source terms, as presented in this study, but are considering probabilistic source terms assessing various accident scenarios. This Probability Safety Assessment (PSA) methodology is also under investigation and source terms will be calculated and categorized in Level 1 & 2 PSA.

**Dispersion Model:** Lagrangian puff or Lagrangian particle model could be used for time varying source and the analyses for further distance. However results from these models are highly time dependent and every input parameter is also time dependent. Therefore, it is difficult to obtain meaningful statistical results with such models because meteorological condition may change daily, monthly and yearly. Deterministic modeling using Lagrangian models will however be considered in future work.

**Dose Assessment:** Exposure to re-suspended material and ingestion
of radionuclides were not included in this study but are the basis for future work. Sensitivity analysis is underway on how much re-suspension can affect to dose given the desert environment in the Gulf region.

6. CONCLUSION

Northerly and northwesterly wind were found to be dominant for both Barakah and Bushehr accident simulations from the statistical meteorological data. Therefore the radioactive materials which were released to the air tend to migrate in the south or southeast direction. The dose level above 100 mSv/yr have appeared within about 100 km from the sources. There was the trend of farther dispersion in Arabian Gulf region because of not only lower ground surface roughness of the desert and sea environment but also low probability of precipitation. Less density within 100 km distance than that of other environments has been apparent because farther dispersion means more dilution in the air at the same time. Further study using Lagrangian models are necessary to obtain credible results on the macro scale (1,000-2,000 km) modeling. While the present study is mainly focused on deterministic modelling, PSA methodologies will also be used to consider radionuclide dispersion.

References

Figure 1. The Location of Nuclear Power Plants in the Arabian Gulf – Barakah, UAE and Bushehr, Iran –

Figure 2. The Wind Rose of Al Rowais Climate Post for Barakah Site (a) and Bushehr (b)
Figure 3. Various Modeling Functions of AMDS-5 [6]
Figure 4. Estimated Concentration of (a) I-131 and (b) Cs-137 with Chernobyl Source Released in Barakah Site [Bq/m³]

Figure 5. Estimated Concentration of (a) I-131 and (b) Cs-137 with Fukushima Source Released in Barakah Site [Bq/m³]
Figure 6. Estimated Concentration of (a) I-131 and (b) Cs-137 with Chernobyl Source Released in Bushehr Site [Bq/m$^3$]

Figure 7. Estimated Concentration of (a) I-131 and (b) Cs-137 with Fukushima Source Released in Bushehr Site [Bq/m$^3$]
Scientific Forum: Peaceful Use of Nuclear Energy and Its Impact on Environmental Security
Royal College of Bahrain Police, Bahrain, 18-20 March 2014

Figure 8. Estimated Dose with Chernobyl Source Released in Barakah Site

Figure 9. Estimated Dose with Fukushima Source Released in Barakah Site
Figure 10. Estimated Dose with Chernobyl Source Released in Bushehr Site

Figure 11. Estimated Dose with Fukushima Source Released in Bushehr Site