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Atmospheric dispersion assessment of radioactive materials during severe accident conditions for Bushehr nuclear power plant using HYSPLIT code

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ABSTRACT

In nuclear power plants and nuclear research reactors, radioactive material release into the environment and the dose received by individuals are the main concerns during a severe accident. Thus, calculation of expected dose at reactor perimeters and surrounding area in the event of an accident is a basic requirement for the safety of these facilities. This study uses the HYSPLIT code to simulate the consequences of the worst hypothetical accident scenario of Station Blackout (SBO) and Large Break Loss-of-Coolant Accident (LBLOCA) in Bushehr nuclear power plant unit-1 (BNPP-1). The concentration of released radioactive material and external effective doses received by populations within 30 km radius of facility are computed. Dispersion of radioactive materials is simulated using of Global Data Assimilation System (GDAS) meteorological data. Particle behavior in different stages of dispersion and annual dispersion along each of the 16 geographic directions are obtained from trajectory calculations. The concentration of different radionuclides is determined and the resulting annual external effective dose at different locations are computed as well. All calculations are performed for four different release time durations including 4, 12, 24 and 48 h. Given the distribution of population around the NPP facility, the highest doses are expected at 3 km north and 4 km northwest of the reactor location. The maximum dose for 4, 12, 24, and 48-h long emission at different points of Bushehr city is calculated and compared with the allowable dose limits.

1. Introduction

The main concern in regard to nuclear power plants (NPPs) safety is the release of radioactive materials from the containment structure to the surrounding environment (IAEA, 2006). In the event of an accident, release of radioactive materials will first threaten the staff, residents, animals and the environment in the immediate vicinity of the plant. Ensuring the safety of people and the environment against such hazards is the main objective of nuclear safety and the biggest responsibility of organizations supervising NPP operations (IAEA, 2006). When a living tissue is irradiated, the radiation-tissue interaction can develop into cancers or even death of the organism, thus concentration prediction of dispersed particles, the resulting dose, and the required protective measures in the event of a severe nuclear accident is of essential importance (World Health Organization, 2012).

Atmospheric transport and dispersion models (ATDM) are able to predict the transport of radionuclides in the atmosphere and their deposition on the ground, and can therefore be applied to estimate the radiation dose to the population. These models can serve as a powerful tool for the study of radionuclides dispersion in the atmosphere in the event of an accident. There are several models for simulating the dispersion of particles. Olivier Connan et al. have compared three atmospheric dispersion models (i.e. HYSPLIT, RIMPUFF and ADMS) and reported that ADMS estimation of radioactive particles concentrations are lower than the experimental results, but HYSPLIT and RIMPUFF both yield accurate estimations (Connan et al., 2013). This study also reports that simulation of atmospheric dispersion using HYSPLIT after the Fukushima accident is consistent with the results of Radiological Protection Institute of Ireland (RPII). In another work, Srinivas et al. have utilized FLEXPART (i.e. a Lagrangian particle dispersion model for calculating the long-range and mesoscale dispersion of air pollutants from point sources, such as after an accident in a nuclear power plant) and HYSPLIT to study the dispersion and deposition of radioactive particles after the Fukushima Daiichi reactor accident (Srinivas et al., 2012). Also the dispersion and deposition of radioactive particles after the Fukushima Daiichi accident using various ATDMs and meteorological data has been analyzed by Draxler et al. and shown that the performance of different ATDMs depends strongly on the applied meteorological model (Draxler et al., 2015).

Release and dispersion of radioactive materials, radionuclides

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Table 1
Fission products release to the environment for four different release time duration [Bq] (Atomic Energy Organization of Iran, 2007).

Physical-Chemical Radionuclides forms	Time. [hr]				Physical-Chemical Radionuclides forms	Time. [hr]			
	4	12	24	48		4	12	24	48
Molecular iodine					**Organic iodine**				
I-131	1.00E+13	1.90E+14	4.00E+14	6.50E+14	**I-131**	1.20E+12	2.40E+13	5.70E+13	1.20E+14
I-132	4.90E+12	3.90E+13	4.10E+13	4.20E+13	**I-132**	5.50E+11	4.60E+12	5.00E+12	5.10E+12
I-133	2.20E+13	3.80E+14	6.90E+14	9.10E+14	**I-133**	2.50E+12	4.70E+13	9.60E+13	1.50E+14
I-134	1.40E+12	5.10E+12	5.10E+12	5.10E+12	**I-134**	1.60E+11	5.90E+11	5.90E+11	5.90E+11
I-135	1.50E+13	1.90E+14	2.70E+14	2.90E+14	**I-135**	1.60E+12	2.40E+13	3.60E+13	4.00E+13
Aerosols					**IRG**				
Cs-134	5.30E+13	9.20E+14	1.70E+15	2.30E+15	**Kr-85m**	1.90E+13	2.40E+14	3.10E+14	3.20E+14
Cs-137	1.10E+13	1.90E+14	3.50E+14	4.70E+14	**Kr-87**	1.30E+13	6.70E+13	6.80E+13	6.80E+13
I-131	1.00E+14	1.70E+15	3.10E+15	4.20E+15	**Kr-88**	5.10E+13	4.80E+14	5.50E+14	5.50E+14
I-132	4.80E+13	3.60E+14	3.80E+14	3.80E+14	**Xe-133**	2.80E+14	5.80E+15	1.40E+16	2.80E+16
I-133	2.20E+14	3.50E+15	5.50E+15	6.50E+15	**Xe-135**	2.70E+13	4.30E+14	7.20E+14	8.80E+14
I-134	1.40E+13	4.90E+13	4.90E+13	4.90E+13	**Xe-138**	7.40E+09	9.70E+09	9.70E+09	9.70E+09
I-135	1.40E+14	1.80E+15	2.30E+15	2.40E+15					

concentration in atmosphere, radionuclides deposition on the ground and the subsequent dose assessment for a worst case hypothetical severe accident scenario at Bushehr nuclear power plant unit 1 (BNPP-1) which is a VVER-1000/V446 pressurized water reactor is investigated in this study. There are several studies in the literature which have assessed the release of radioactive material into the environment (Sohrabi et al., 2013; Raisali et al., 2006; Pirouzmand et al., 2015; Zali et al., 2017). These works are limited to normal operation and design basis accident scenarios which are not the worst case from the viewpoint of radionuclides release into the environment. According to Fukushima Diachi accident and its impact in the people and the environment, the importance of atmospheric dispersion assessment of radioactive materials during severe accident conditions is clarified. Also in these studies, Gaussian models are applied which are not accurate enough. Key parameters in the Gaussian plume model for estimating downwind concentrations of airborne pollutants are the coefficients of lateral and vertical dispersion. The model assumes that the atmospheric turbulence is both stationary and homogeneous. In reality, none of these conditions is fully satisfied (Draxler et al., 2013).

The simulation of atmospheric dispersion, transport and deposition of nuclear materials released from a hypothetical accident in Bushehr nuclear power plant have been studied using HYSPLIT code by F. Kavani et al. (Kaviani et al., 2017). The Hysplit code has been applied to assess the radionuclides dispersion and transport for limited number of released fission products under a hypothetical accident. Its calculations are limited to air radionuclides concentration and ground radionuclides deposition. The internal and external dose calculations which determine the risk of accident for surrounding population have not been addressed. Also, the accident type and the radioactive materials released are based on Chernobyl accident which due to the differences between VVER-1000 and RBMK-1000 designs such as the reactor structure, safety characteristics (e.g. Containment structure) and safety functions is not realistic.

Considering the capabilities and the frequent use of HYSPLIT code in the literature, the present study uses this code to simulate the dispersion of released radioactive particles into the surrounding environment. The main features of HYSPLIT include the use of Lagrangian model for diffusion and advection calculations and the utilization of Euler model for concentration calculations (thereby combining the advantages of both models), the use of PARTICLE and PUFF models or both for dispersion calculations, the ability to utilize different meteorological data to predict particles dispersion and deposition (Draxler and Hess, 1997).

As mentioned, HYSPLIT code can use various meteorological data as input, and according to study of Olivier Connan et al. uncertainties in predictions of ATDMs (such as HYSPLIT) stems from their high dependence on the details of weather conditions (Connan et al., 2013). Also Draxler et al. have suggested that combination of ATDM with a suitable meteorological model can yield more accurate predictions of particle dispersion and deposition (Draxler et al., 2015). Their research shows that combination of dispersion simulation models with meteorological model of Global Data Assimilation System (GDAS) can yield better performance than other combinations. Lin Su et al. have also recommended the use of HYSPLIT with GDAS1 meteorological model (Su et al., 2015). Thus, the present study has applied this meteorological model.

In this study, particle dispersion after a hypothetical severe accident scenario at BNPP-1 is simulated, and the concentration of radionuclides in air and individual dose within 30 km radius of the facility are investigated. The hypothetical accident is the Station Blackout (SBO) accompanied with Large Break Loss-of-Coolant Accident (LBLOCA), which is one of the worst case scenarios for the release of radioactive materials into the environment (Atomic Energy Organization of Iran, 2007).

2. Material and methods

2.1. Source term specifications

One of the most important parameters that determines the atmospheric dispersion of radioactive particles after an accident is the definition of radionuclides which are released from the NPP stack (source term). The radionuclides related factors that have a significant impact on the individual dose assessment and must be considered in the calculations are the time of release, release duration, height of release, chemical form, particle size, activity, half-life and type of radionuclides. The type of released radionuclides from the facilities depends highly on the type of reactor, performance of containment structures, and the type of accident. Thus source term specifications vary with the type of accident and type of nuclear power plants (Awan et al., 2012).

This study assumes that after LBLOCA, 23 radionuclides with the presented specifications in Table 1 according to the data given in the Final Safety Analysis Report (FSAR) of the plant releases from the stack at an altitude of 100 m above the ground for four different release time duration (Atomic Energy Organization of Iran, 2007). These radionuclides are classified into four categories of molecular iodine, organic iodine, inert radioactive gases (IRG) and aerosols which release at a constant rate over the duration of the release time. According to FSAR