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Dose assessment of radionuclides dispersion from Bushehr nuclear power plant stack under normal operation and accident conditions

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ABSTRACT

Assessment of individual and collective doses around the unit-1 of Bushehr nuclear power plant (BNPP-1) site during normal nuclear reactor operation and under reactor accident conditions which are essential for safety and environmental analyses is presented in this paper. Release of radioactive materials to the environment following a design basic accident (DBA) (e.g. LBLOCA) is evaluated using HOTSPOT health physics computer code. In the normal operation conditions, atmospheric dispersion of radioactive material is calculated using CAP88-PC code. These codes utilize a Gaussian dispersion air transport plume model to simulate the atmospheric dispersion of radionuclides in different atmospheric stability classes and various wind speeds and directions. To calculate the doses under normal operation using CAP88 code, the surrounding area of the BNPP-1 within a radius of 30 km is gridded into 12 concentric rings and 16 sectors and the distribution of population and data of agricultural products are calculated for each grid. The meteorological data on atmospheric stability conditions, wind speed and the frequency distribution of wind direction based on data collected near the reactor site are also analyzed and applied. The results illustrate that the maximum total effective dose equivalent (TEDE) and committed effective dose equivalent (CEDE) values for personnel and public around the BNPP-1 site are lower than the annual effective dose limits for workers and public in normal operation and under accident conditions. Also, the results of the radiological impacts of the BNPP-1 in normal and accidental radioactive materials releases are compared with the dose values given in the Final Safety Analysis Report (FSAR) of the BNPP-1.

Introduction

One of the most crucial safety and health physics concerns in research and power nuclear reactors is the radioactive material release around the nuclear reactor site. Due to the unavoidable presence of personnel within the reactor site and the population outside the site, the release should be monitored frequently and properly for both normal operation and

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accidental conditions, especially for design basic accident (DBA[1]) scenarios [1,2]. Nuclear power plants release radioiodine, noble gases and other radionuclides into the atmosphere during a normal operation and under accident conditions [1,2]. The most important released radionuclides are noble gases and iodinated compounds. ^{131}I and ^{133}I comprise a large percentage of fission products (FPs[2]) which 30% of them are absorbed in thyroid [3]. Large amounts of ^{134}Cs and ^{137}Cs are also released which can be spread in soft tissues all over the body in case of uptake [4]. The radioactive materials in the form of gas and particulate which is a function of atmospheric and weather conditions are released into the air and transported by the wind to the environment. Their concentration in air and deposition on ground surface depend on key parameters such as the amount of released radionuclides, the wind speed, the atmospheric stability, the precipitation, and etc. The release of radioactive materials from a nuclear reactor causes the dose which may be external or internal to the body. The total effective dose equivalent (TEDE[3]) is the sum of the effective dose equivalent (EDE[4]) that is caused by the external materials such as cloud submersion and ground shine along with the committed effective dose equivalent (CEDE[5]) which involves the internal materials as a result of inhalation and ingestion [5]. In this study, the TEDE values are calculated using HOTSPOT health physics codes in an accidental condition and the CEDE values are calculated by CAP88 code under the normal operation.

The BNPP-1[6] which is a VVER-1000 pressurized water reactor has been recently commissioned and is now operational. It has been located in a relatively low population zone, with the basic objective of limiting the dose received by the members of the public as a whole under normal and accident conditions [6]. In literature review, besides the data which has been reported in the Final Safety Analysis Report (FSAR[7]) of the plant that covers the radiological effects of the BNPP-1 on public under normal reactor operation conditions and from accidental release, there are a few studies which have evaluated the radioactive material dispersion around the BNPP-1 site [6]. The radiological impact of the BNPP-1 on the public under normal reactor operation conditions by applying the PC-CREAM 98 computer code for dose calculation has been assessed by Sohrabi et al. [7]. In another study, radiation doses received by the public living around the site of BNPP-1 due to an accidental release of radionuclides into the environment in a hypothetical accident caused by the primary coolant leakage to the secondary circuit has been studied using PC COSYMA code [8]. Also the calculation of TEDE and collective dose in the event of a LOCA[8] in Bushehr nuclear reactor using a Gaussian diffusion model and a slightly modified version of AIREM computer code has been carried out by Raisali et al. [9].

In this work, dose calculations are performed for population in case of the worst possible DBA from the viewpoint of radionuclides release to the environment in the BNPP-1. The worst DBA is considered to be a large break loss of coolant accident (LBLOCA[9]) which results in the radionuclides dispersion into the atmosphere [6]. According to the accident scenario of LBLOCA, the reactor containment is not broken and radioactive materials are released to the environment through the stack [6]. Herein, the area around the BNPP-1 within a radius of 30 km is gridded into 12 concentric rings and 16 sectors. Then using Version 3.0 of HOTSPOT code in the LBLOCA condition and Version 4.0 of CAP88-PC code in the normal operation the TEDE and CEDE values received by the members of public are calculated.

Materials and methods

Released radioactivity

During the LBLOCA in BNPP-1 the radioactive materials are released into the environment through the stack in the form of gas and particulate and then are dispersed in the atmosphere [6]. Depending on the physicochemical state of a radionuclide, its behavior in the confining system may be different, therefore in the FSAR of BNPP-1 four states of FPs in terms of their behavior including aerosols, inert radioactive gases (IRG[10]), molecular iodine and organic iodine are considered [6]. Based on the thermal-hydraulic analysis of LBLOCA in Bushehr nuclear reactor by the end of the first day the pressure is reduced actually to the atmospheric pressure [10]. Therefore, in calculating the release of FPs it is conservatively assumed that the daily leakage from the steel containment in the first day is 0.25% whereas in the rest period is 0.11 percent of the containment volume [6]. In the case of fuel elements loss of tightness, IRG and iodine are entirely released from the fuel claddings, while cesium release makes up 30% of the accumulated amount of FPs under fuel claddings. Since the rate of the molecular iodine removal from the containment atmosphere is less than for aerosols, it is conservatively assumed that during the coolant leak 99% of the iodine is released into the containment atmosphere as molecular iodine. According to recommendations it is assumed that 1% of the iodine is released into the containment as organic iodine compositions and all cesium is released as aerosol [6]. Table 1 provides the FPs release into the environment in case of accident involving the rupture of the largest primary circuit pipeline (e.g. D_{in} 850 mm) taken from the FSAR of plant.

In normal operation gas aerosol waste are produced and released from the reactor building (ZA/B), auxiliary reactor building (ZC) and active gas purification system (TS system). The critical source of gas-aerosol release is the air of ZA building. Table 2 presents average annual gas-aerosol release of radionuclides into the environment in the normal operation. According to the operation data for VVER type reactors, activity of ^{14}C in the primary coolant fluctuates within 15–1000 Bq/m^3 which is 6–40% of the allowable specific activity of ^{14}C for the public. So, it is not a precarious source of

[1] Design basis accident.
[2] Fission products.
[3] Total effective dose equivalent.
[4] Effective dose equivalent.
[5] Committed effective dose equivalent.
[6] Unit-1 of Bushehr nuclear power plant.
[7] Final Safety Analysis Report.
[8] Loss of coolant accident.
[9] Large break loss of coolant accident.
[10] Inert radioactive gases.