Available online at www.elixirpublishers.com (Elixir International Journal)

Nuclear and Radiation Physics

ISSN: 2229-712X

Elixir Nuclear and Radiation Phys. 57 (2013) 14343-14347

Preliminary investigation of TEDE following a hypothetical release from a commercial NPP at Akosombo site using Maccs2 code

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ARTICLE INFO

Article history:
Received: 4 February 2013;
Received in revised form:
10 April 2013;
Accepted: 18 April 2013;

Keywords
Total Effective Dose Equivalent (TEDE),
Radiological Consequence,
Hypothetical Release,
MELCOR Accident Consequence Code Systems 2 (MACCS2),
AP1000.

ABSTRACT

The world energy demand is on the increase allowing many countries to find a viable solution to this quandary. Many of such countries are adopting a way to deal with such crisis by considering other conservative means of source of energy. One of such country having difficult to generate enough energy for its economic growth is Ghana. Currently Ghana's total installed electricity generation capacity stands at 1810MW, with her population estimated to be 24.4 million, based on the 2010 census. Therefore, there is the need for a radical change in energy mix to propel the country's economic growth. For a brighter future, the country must explore unconditional means to secure cheap and reliable energy resource to satiate the desire of future industrial accomplishments. In this regard, nuclear energy is a descent choice without compromising environmental quality. Given that nuclear power is an important choice in the face of the threat of climate change, the public's perceptions need to be changed at any cost considering the catastrophic accident at Japan's Fukushima Daiichi Nuclear Power Plant in March 2011. This paper addresses subjective uncertainty on health effect in hypothetical release using accident analysis code MACCS2 to estimate TEDE (total effective dose equivalent) for postulated accident scenario. The code is for preliminary work on the proposed AP1000 MW(e) NPP at the proposed site, Volta Point Unit 1 in Akosombo, Ghana.

1.Introduction

The demand on energy in the world is on the rise and is affecting many countries due to lack adequate supply. This energy crisis is really affecting the economic growth in most of such countries facing energy crisis.

One of such country which has been hit by this crisis is Ghana. Her energy supply is inadequate and causing a major problem for its socio-economic development. How far is the energy situation in Ghana? The next section discusses the energy situation in Ghana.

1.1 Energy picture of Ghana

Ghana's macro-economic objective is to transform the economy from a low-income status into a middle-income with a per capital income of at least US$1000 by 2020. The government therefore seeks to create the enabling environment to attract investments and re-plough its revenue from the domestic oil industry to boost industrial growth and other economic activities in order to achieve this macro-economic objective. Ghana's conventional sources of energy are neither adequate nor varied.

It has no coal resources and the current reserves of oil and natural gas have been estimated to last for about twenty years. In addition, the country's hydropower resources have almost been exploited. Installed total electricity capacity generation in Ghana currently stands at 1810MW (Birikorang S.A et al, 2012). Fig.1 shows the projected energy demand of Ghana from now to 2030.

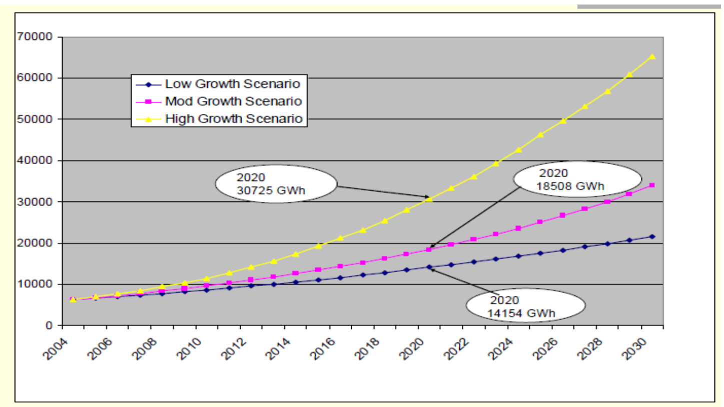

Fig.1-1 Projected Electricity Demand using Model for Analysis of Energy Demand (MAED) Model

The problems associated are quite obvious. Therefore, there is the need for a radical change in energy mix to propel the economic growth. For a brighter future, Ghana must explore unconditional means to secure cheap and reliable energy resource to satiate the desire of future industrial accomplishments. In this regard, nuclear energy is a descent choice without compromising environmental quality. The country is now considering constructing a AP1000 MW(e) NPP at a proposed site, Volta Point Unit 1 Akosombo. The section below considers a brief description of the proposed AP1000 MW(e) Nuclear Power Plant (NPP).

1.2 Brief Description of AP1000 MW(e)

The AP1000 design is a single pressurized water reactor (PWR) capable of generating nominally 1117 megawatts (MW)

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of electricity, with a claimed 60 year design life. AP stands for 'advanced passive', as it is claimed that the AP1000 uses passive safety systems such as natural circulation and gravity. Westinghouse claims that the AP1000 safety systems are designed to mitigate the consequences of plant failures, ensuring the reactor shuts down, decay heat is removed, and releases of radioactivity are prevented. In the reactor core, the uranium oxide fuel (enriched up to 4.95 per cent of uranium-235) is cooled by water in a pressurized circuit, the primary circuit. This water also acts as the neutron moderator necessary for a sustained nuclear fission reaction. The primary circuit includes two steam generators where heat is transferred from this primary coolant circuit to a secondary circuit, producing steam. This steam then drives a turbine-generator to produce electricity, is condensed, and the condensate returned to the steam generators. The AP1000 reactor is a plant design incorporating six buildings (Figure 1). The design comprises the nuclear island (containment/shield building, and auxiliary building), annex, diesel generator, turbine generator, and radioactive waste buildings. The main auxiliary facilities include a spent-fuel storage pool, water treatment systems for maintaining the chemistry of the primary and secondary water circuits, two diesel generators for providing power in the event of loss of grid supplies, and waste treatment and storage facilities. For the purpose of generic design assessment, turbine condenser cooling water is provided by a once through system using seawater (http://publications.environmentagency.gov.uk)

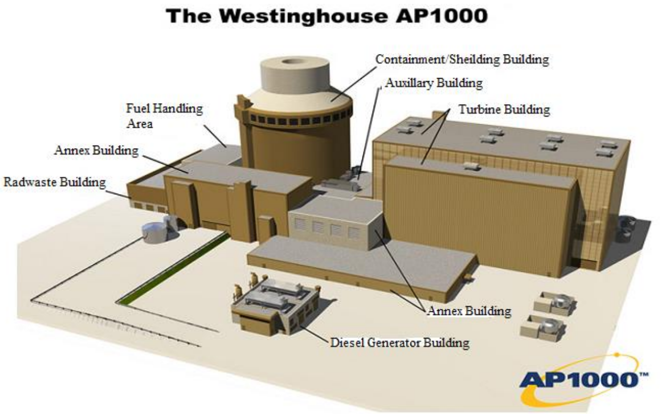


Fig.1 AP1000 PWR Schematic Building Design

The AP1000 PWR is certified by the U.S. Nuclear Regulatory Commission, and is the only Generation III+ reactor to receive such certification. The European Utility Requirements (EUR) organization also certified that the AP1000 PWR is compliant with European Utility Requirements, confirming that the AP1000 PWR can be successfully used in Europe.

Although Westinghouse claims that the AP1000 safety systems are designed to mitigate the consequences of plant failures. But public perception about the release of radiation from a hypothetical accident scenario is on the rise due to some past nuclear accident, and how the release travels by virtue of the prevailing wind. For Ghana considering the introduction of nuclear into her energy mix, it is therefore imperative to estimate the Total Effective Dose Equivalent (TEDE) of the proposed AP1000 PWR nuclear plant using more reliable and versatile accident analysis code for the public to be rest assured by their safety. The aim of this work is therefore to address the environmental safety by estimating the TEDE during hypothetical release of radiation as a result of radiological consequence using safety accident analysis code MACCS2. The next section gives brief summary on MACCS2 code.

1.3 *Maccs2 code*

MELCOR Accident Consequence Code Systems 2 (MACCS2) code is based on the straight-line Gaussian Plume Model (GPM) which was developed originally for the Nuclear Regulatory Commission (NRC). MACCS2 evaluates doses and health risks from the accidental atmospheric releases of radionuclides. The principal phenomena considered in MACCS2 are atmospheric transport and deposition under time-variant meteorology, short-term and long-term mitigative actions and exposure pathways, deterministic and stochastic health effects, and economic costs. MACCS2, distributed by government code centers since 1990, was developed to evaluate the impacts of severe accidents at nuclear power plants on the surrounding public. MACCS2 was developed as a general-purpose tool applicable to diverse reactor and nonreactor facilities licensed by the Nuclear Regulatory Commission or operated by the Department of Energy or the Department of Defense. The MACCS2 package includes three primary enhancements: A more flexible emergency-response model, an expanded library of radionuclides and a semi-dynamic food-chain model (Chanin, et al. 1998).

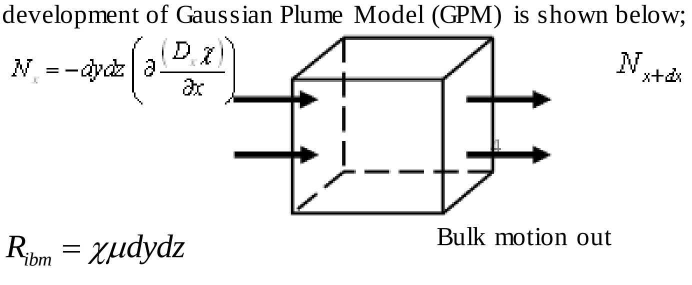
MACCS2 is divided into three primary modules: ATMOS, EARLY, and CHRONC. There is also another fundamental division in the code's calculations. This division is based on the sequence of societal responses that would follow the occurrence of an accident. These phases are defined by the Environmental Protection Agency (EPA) (1992) in its *Protective Action Guides*, and referred to as the *emergency*, *intermediate*, and *long-term phases*.

Firstly, ATMOS performs all of the calculations pertaining to atmospheric transport, dispersion, and deposition, as well as the radioactive decay that occurs prior to release and while the material is in the atmosphere. The results of the calculations are stored for use by EARLY and CHRONC. Secondly, EARLY performs all of the calculations pertaining to the emergency phase. Lastly, CHRONC performs all of the calculations pertaining to both the intermediate.

Weather data for one calendar year with hourly data of wind speed, wind direction, Pasquill class (stability class) and if possible precipitation is needed as part of the inputs (Gregory J.J, 1998).

2. Theory

Suad Al-Adwani, 2013, treated the site under study as a box in which pollutants are emitted and undergo physical and chemical transformation. The schematic diagram for the development of Gaussian Plume Model (GPM) is shown below;



The mass rate of diffusion N_x of a gaseous species in the x-direction at some cross-sectional area A is given by the expression

$$N_x = -A\left(\partial \frac{(D_x\chi)}{\partial x}\right) \quad 1$$

Eqn. [1] can be expression as

$$N_x = -dy\,dz\frac{\partial(D_x\chi)}{\partial x} \quad 2$$

For a small change in x

$$N_{x+dx} = -dy\,dz\frac{\partial(D_x\chi)}{\partial x} + \frac{\partial}{\partial x}\left[\left(\frac{\partial D_x\chi}{\partial x}\right)dy\,dz\right]dx \quad 3$$

The time rate of change in concentration is

$$\frac{\partial\chi}{\partial t} = -\frac{\partial}{\partial x}(\chi\mu) + \frac{\partial}{\partial x}\left(\frac{\partial(D_x\chi)}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\partial(D_y\chi)}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{\partial(D_z\chi)}{\partial z}\right) \quad 4$$

where

x - Along-wind coordinate measured in wind direction from the source $[m]$

y - Cross-wind coordinates direction $[m]$ and z - Vertical coordinate measured from the ground $[m]$, $\chi(x,y,z)$ - Mean concentration of diffusing substance at a point (x,y,z) $[kg/m^3]$

$D_y D_z$ - Mass diffusivity in the direction of the y - axis and z - axis $[m^2/s]$ and μ - Mean wind velocity along the x - axis $[m/s]$ (Suad Al-Adwani, 2013).

Hence, the overall concentration χ of gas or aerosols at x,y,z from a continous source with an effective emission height (H) is given by the following equation (Macdonald R., 2003):

$$\chi(x,y,z;H) = \frac{Q}{2\pi\sigma_y\sigma_z\mu}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \quad 5$$

where

H - is the Height of the plume $[m]$, σ_y and σ_z - are respectively horizontal and vertical deviations of plume concentration distribution $[m]$, Q - is the uniform emission rate of pollutants $[kg/s]$, x - Along-wind coordinate measured in wind direction from the source $[m]$, y - Cross-wind coordinates direction $[m]$, z - Vertical coordinate measured from the ground $[m]$, $\chi(x,y,z)$ - Mean concentration of diffusing substance at a point (x,y,z) $[kg/m^3]$ and μ - Mean wind velocity affecting the plume along the x - axis $[m/s]$.

MACCS2 model is based more importantly on Eqn. [5] for calculation the concentration of the release gases (Suad Al-Adwani, 2013).

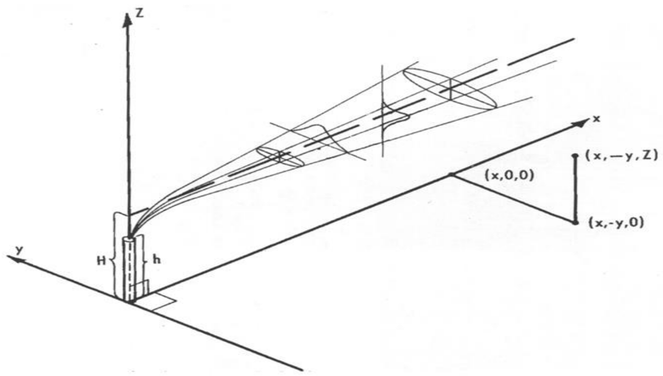


Fig. 1-3 Coordinate system showing Gaussian distributions in the vertical and horizontal

3. Methodology

3.1 Accident Scenario

The hypothetical accident scenario considered in this work was loss of coolant accident leading to 100% of fuel rods failing (they crack open) due to station blackout and all auxiliary power supply failing (US NRC Criteria). The location of release and released path considered was the containment building. There was an assumption that the leakage was from the core to the containment and from containment to the environment.

3.2 Boundary condition for Analysis

The selection of site (Volta Point Unit 1, Akosombo) was considered because of it closeness to the existing hydropower plant also at Akosombo. The NPP would utilize the existing grid, and also utilize dedicated power connection to hydro power plant for safety. The dose from the postulated radiological consequence of the DBAs was identified at the Exclusion Area Boundary (EAB) and Low Population Zone (LPZ) (NRC: 10 CFR 100.11). A reasonable number of distances of 1km for EAB and 10km LPZ were taken.

3.3 Meteorological data File from Site

The file consists of one calendar year of hourly recordings (8760h) of:

1. Wind direction= 16 wind regions (from N= 1 to NNW= 16)
2. Wind speed = 1 to 300 (10ths of meters per second)
3. Atmospheric Stability= Pasquill-Gifford Class (from A to F)
4. Accumulated precipitation = 0 – 999 (100ths of inches).

A weather data for one calendar year with hourly data of average wind speed of 9MPH approximately 4.0233m/s and wind direction of 251 degrees was taken from the weather station at Akosombo.

3.4 Source Term

An assumption of LBLOCA (large break-loss of coolant accident) in PWR with core inventory as in MACCS2 input deck of 3412 MW(th) PWR core (equivalent to AP1000 PWR thermal power). Core inventory release fractions by radionuclide groups for a gap release and early in-vessel damage phases for DBA (design basic accident) LOCAs for PWR (NRC-RG 1.183) were considered for LOCA. For leaks from containment to the environment: we assume the dimension of the containment to be 8.8E04 m^3 for a typical AP1000 PWR. There was also an assumption for existence homogenous mixture of all radionuclides from containment to atmosphere. A reasonable leakages from containment (0.1 – 1% Vol percent / day) plus 20% for containment bypass was assumed. The release, which is the source term, was calculated for 24 hours. The input deck contained all the above information provided for the simulation work.

4. Results And Discussion

The results obtained after the runs of the MACCS2 code shows that the TEDE (total effective dose equivalent) found on the various spatial grids are below the NRC guidelines. The results are within what is stated in Chapters 2 and 5 of the EPA *Manual-Protective Action Guides and Protective Actions for Nuclear Incidents* (EPA 400-R-92-001) which discuss the protective action guide (PAG) for early phase. PAG has expressed a range of 1-5 rems for TEDE where Evacuation (or for some situations, sheltering) should normally be initiated at 1 rems TEDE or 5 rem thyroid CEDE (committed effective dose equivalent). The table below shows the mean and percentile TEDE at the various spatial grid points used in Roentgen (rem).

Table 1: TEDE (rem) released at the various spatial grid distances

Dose found on Spatial grid	Mean	50^{th} Percentile	90th Percentile	95^{th} Percentile
0-4 Km (Effective-rems)	0.0541	0.0282	0.128	0.2
4-8 Km (Effective-rems)	0.00546	0.00264	0.0114	0.0212
8-12 Km (Effective-rems)	0.0251	0.0126	0.0614	0.0881

The results shows that for hypothetical release of radiation in the course of radiological consequence there would be no cause of any harm to both on-sit and off-site populace at the Akosombo site because of low dose release. Figure 1-3 show the TEDE results for the release at a height of 6m at the 50th percentile level, 90th percentile level and 95th percentile level, respectively.

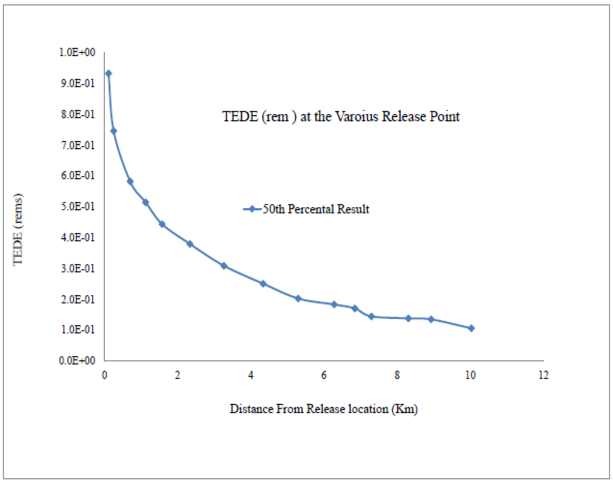


Figure 1: 50^{th} Percentile resulting TEDE for a release height of 6m

The graphical results from fig.1-3 shows that the contribution from the ground level releases are much greater at distances close to the release location. The reason was that more material are leaving the building at ground level. In addition, the plume from the elevated stack is initially separated from the ground such that the plume essentially passes over the receptor at the ground near the stack.

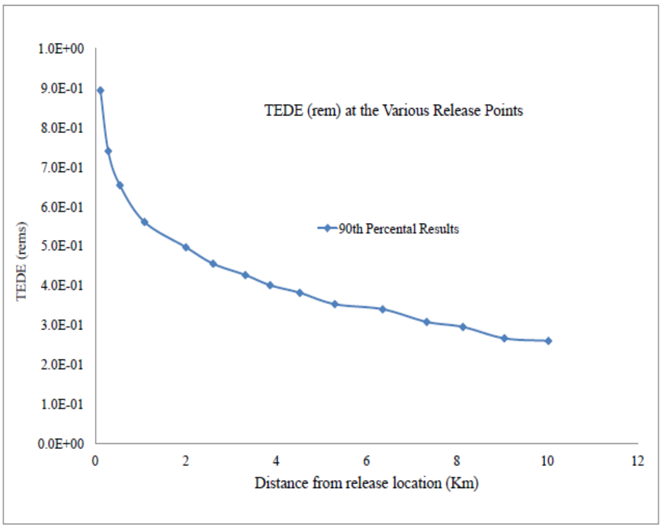


Figure 2: 50^{th} Percentile resulting TEDE for a release height of 6m

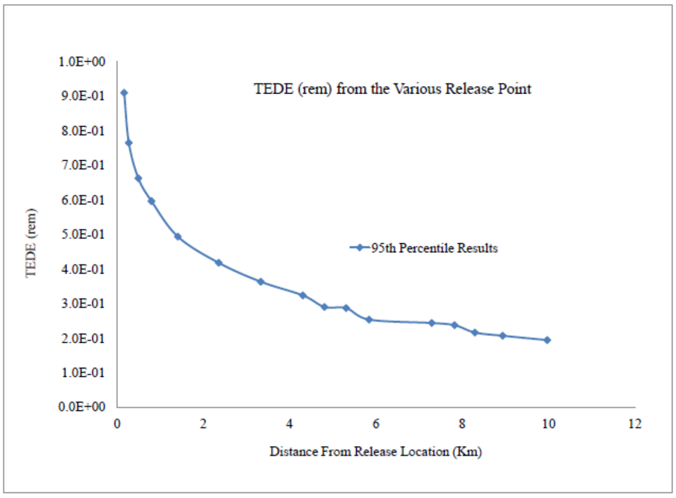


Figure 3: 95th Percentile resulting TEDE for a release height of 6m

Conclusion

Dispersion model is an important first step in a successful assessment of stack designs. The model predicts how contaminants emitted from a stack will disperse in the outside air and the effect it would have on the environment. The model determines the stack parameters needed to keep the contaminants from impacting on fresh air intakes and other sensitive locations. One of such kind model is MACCS2 employed for this work. Based on analysis it can be concluded in this work that the use of MACCS2 offers a robust method to assess consequences for various configurations found in reactor and non-reactor facilities. The released doses into the atmosphere from MACCS2 simulation shows that TEDE were below the recommended dose range in which people must be evacuated. Hence, the work is in agreement which what is stated in PAG manual.

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