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An approach for estimating the radiological significance of a hypothetical major nuclear accident over long distance transboundary scales

D. Mitrakos*, C. Potiriadis, C. Housiadas

Greek Atomic Energy Commission, Patriarxou Grigoriou & Neapoleos, 15310 Agia Paraskevi, Athens, Greece

HIGHLIGHTS

- Actions may be warranted after a major nuclear accident even at long distances.
- Distance may not be the decisive parameter for longer term radiological impact.
- Remote impact may vary orders of magnitude depending on the meteorological conditions.
- The potential impact can be assessed using computationally inexpensive calculations.

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ABSTRACT

After the Fukushima accident important initiatives were taken in European level to enhance the nuclear safety level of the existing and planned nuclear reactors, such as the so-called nuclear “stress-tests” and the amendment of the Nuclear Safety Directive. A recent work of HERCA and WENRA focused on the need for a more consistent and harmonized response in a transboundary context in case of a hypothetical major nuclear accident in Europe. Such an accident, although very improbable, cannot be totally excluded and so, should be considered in emergency preparedness arrangements among the various European countries. In case of a hypothetical severe Fukushima-like accident in Europe, the role of the neighboring countries may be important, since the authorities should be able to provide information and advice to the government and the public, but also can contribute to the overall assessment of the situation be their own means. In this work we assess the radiological significance of a hypothetical major nuclear accident for distances longer than 300 km that are not typically covered by the internationally accepted emergency planning zones. The approach is simple and computationally inexpensive, since it is based on the calculation of only a few release scenarios at dates selected within a whole year on the basis of bounding the deposition levels at long distances in relation to the occurrence of precipitation. From the calculated results it is evident that distance is not the only decisive parameter in estimating the potential radiological significance of a severe nuclear accident. The hypothetical case examined shows that the most significant radiological impact for large distances is in the longer term and is directly related with the deposition of the radionuclides under adverse meteorological condition. A radiologically significant impact cannot be excluded even at such distances, and so it is possible that some response arrangements may need to be activated, in order the authorities to be able to assess the situation and provide information and/or guidance to the public or the government.

1. Introduction

According to the World Nuclear Association 2014 database, there are 131 operating reactors in 14 countries in the European Union, covering about 30% of the total electricity production. Four new reactors are under construction, while plans for a number of new reactors also exist. A significant number of reactors and plans for new constructions also exist in EU neighboring countries (WNA, 2015). As the European Commission has concluded, nuclear energy is expected to continue to be an important contributor in Europe’s energy mix in the foreseeable future (EC, 2014).

The nuclear accident at Fukushima-Daichi NPP (FDNPP) in March 2011, following the great earthquake and tsunami, raised worldwide concerns on the safety of the existing and future

* Corresponding author. Tel.: +30 2106506782.
E-mail address: dimitris.mitrakos@eeae.gr (D. Mitrakos).

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reactors. The Fukushima accident is, after the Chernobyl accident, the second INES Level 7 nuclear accident since the origin of commercial nuclear energy production. An accident of level 7 in INES scale (major accident) is generally defined as an accident with "major releases of radioactive material with widespread health and environmental effects requiring implementation of planned and extended countermeasures" (IAEA, 2008). As a more specific activity criterion is suggested the release of radioactivity radiologically equivalent to more than 50,000 TBq of ^{131}I (IAEA, 2008). In the Chernobyl accident, a considerable amount of the released radioactivity reached and deposited in areas within an extensive zone, covering several countries, due to the high release height and the pattern of the meteorological conditions (Benamrane et al., 2013; Pudykiewicz, 1989). The radioactive atmospheric releases from the FDNPP damaged reactors are estimated to be of the order of 10% of those of the Chernobyl accident (Steinhauser et al., 2014). Moreover, as it is estimated only about 20% of the ^{137}Cs released to the atmosphere from FDNPP was transported toward the land (the rest 80% was transported offshore; e.g. Steinhauser et al., 2014; Stohl et al., 2012), limiting this way the land contamination and keeping the resulting doses to the public at low levels. As it has been estimated, a hypothetical Fukushima-like accident at a different nuclear site (Ten Hoeve and Jacobson, 2012) or under different meteorological conditions (Evangeliou et al., 2014) might have had higher radiological impact.

Following FDNPP accident important initiatives were taken for nuclear safety reassessment and enhancement in European and International level. In Europe, the so called nuclear "stress-tests" was completed in 2012 providing an assessment of the safety of the existing nuclear plants in Europe and their resistance against extreme events, such as total station blackout and loss of ultimate heat sink (ENSREG, 2012; EC, 2012). A number of technical measures were identified and corresponding action plans for their implementation were developed and commenced for each plant (ENSREG, 2015). In legislative level, the Nuclear Safety Directive was amended in 2014 (EU, 2014), aiming at reflecting the lesson learned from the FDNPP accident and the European nuclear stress tests. Among others, a legally binding ambitious safety objective is introduced in the amended Directive to prevent accidents and avoid radioactive releases.

A severe nuclear accident in Europe with significant radioactive releases, although very improbable, it cannot be totally excluded and should be considered in emergency preparedness and response plans. In addition, such an accident in Europe, unlike the Fukushima accident, may potentially have a considerable cross-border impact due to the higher density of countries and the number of reactors located near national borders. The Fukushima accident showed that emergency preparedness and response if implemented promptly may protect the population in terms of radiation protection and mitigate the radiological hazards, yet the measures themselves may also have a significant cost on people's health, welfare and life quality (UNSCEAR, 2014; Omoto, 2015) or as the Head of World Nuclear Association (WNN, 2015) stated: "Experience has taught us that some measures to prevent radiation dose can be more damaging that the dose avoided. They also exacerbate fears that lead to social and economic suffering. We need practical measures for protecting people that also help them get on their live when the emergency is over". Such related radioactivity fears or stigma or even social and economic implications are expected for the accident country, and in particular for the areas near the accident location, however, there are also relevant to neighboring countries with the potential to be reached and contaminated by the radioactive plume.

It has to be noticed that emergency preparedness is commonly based on scaling the radiological impact within successive zones that are typically suggested to extend up to 20 km for evacuation and 100 km for sheltering and iodine prophylaxis (HERCA-WENRA, 2014), while they may reach 300 km for the food planning restriction zone around a reactor (e.g. IAEA, 2003; Schnadt and Ivanov, 2012). Although many works have been performed, in particular for European nuclear power plants at national level, to the best of our knowledge there are only a few works published dealing with the assessment of a potential, more remote impact of a nuclear accident (Baklanov et al., 2002; McMahon et al., 2013; Seibert et al., 2013). Such an assessment is of importance from an emergency point of view for both nuclear and no nuclear countries, in order the authorities to be able to evaluate the potential impact of a nuclear accident abroad. This is relevant to neighboring countries, but also it may be relevant to relatively distant countries (Haywood and Majerus, 2014), where the authorities may still be under considerable pressure during a nuclear emergency irrespectively of the actual radiological impact (e.g. Potiriadis et al., 2013). Under such circumstances the authorities should be able to assess the situation and provide adequate and credible information to its public in order to maintain the necessary trust (Krieger et al., 2014). A first step of such an assessment can be an investigation of the potential impact of a distant nuclear accident based on appropriate bounding scenarios. During a nuclear reactor emergency, where the authorities are facing increasing pressure and public concerns and limited information for the reactor situation and accident progression is available, such scenarios can serve as a reference basis for a quick estimation of the potential impact.

In this work, we perform an assessment of the potential cross-border radiological impact of a hypothetical severe, nuclear accident over relatively long distances. The assessment is based on calculations of atmospheric transport and dispersion of radioactivity and on the estimation of the potential radiological impact in terms of radionuclide deposition and dose population calculations. The calculations are performed using an advanced long-range numerical atmospheric transport and dispersion model and using archived re-analysis meteorological data. Our focus is on evaluating the effect of the meteorological conditions on the potential radiological impact at relatively long distances (more than 300 km) that are not typically taken into account in the emergency planning, and not on assessing quantitatively the hazards posed by any existing European NPP. The dispersion and dose calculations are performed only for a few representative dates selected on the basis of simple qualitative meteorological criteria providing some characteristic-bounding cases regarding the possible cross border impact of a nuclear accident at relatively long distances. The source terms employed are inferred from the Fukushima accident (Katata et al., 2015; Terada et al., 2012; Saunier et al., 2013) and are not necessarily associated with any accident scenario credible for any existing European nuclear power plant, in particular given the significant post-Fukushima efforts taken in Europe for the enhancement of the nuclear safety of the existing plants.

The calculations show that the transboundary radioactivity transport and, in particular, cesium deposition and the resulting population doses, following a Fukushima-like radioactivity release could reach, depending on the meteorological conditions, radiologically significant levels that may even warrant some kind of intervention measures even at long distances beyond 300 km. The approach is simple and computationally inexpensive and can be employed for deriving appropriate reference scenarios for emergency preparedness for both national and trans-boundary arrangements.

2. Modeling and data

2.1. Source term

As mentioned previously the source terms considered for the hypothetical releases are inferred from the Fukushima accident