Progress in Nuclear Energy 71 (2014) 160–171

Contents lists available at ScienceDirect

Progress in Nuclear Energy

journal homepage: www.elsevier.com/locate/pnucene

Revising the Emergency Management Requirements for new generation reactors

Federica C.V. Mancini [a], Eduardo Gallego [b], Marco E. Ricotti [c,*]

[a] ENEL, Engineering and Research Division, Nuclear Area, v. Mantova, 24, 00198 Rome, Italy
[b] Departamento de Ingenieria Nuclear, Universidad Politecnica de Madrid, C. Jose Gutierrez Abascal, 2, Madrid E-28006, Spain
[c] Politecnico di Milano – Technical University, Department of Energy, Nuclear Engineering Division, via La Masa, 34, 20156 Milan, Italy

A R T I C L E I N F O

Article history:
Received 1 April 2013
Received in revised form
10 November 2013
Accepted 1 December 2013

Keywords:
EMR
Risk-informed
SMR
GenIII+

A B S T R A C T

The paper presents the application of a new risk-informed methodology for the identification of the Emergency Management Requirements (EMR) to a Generation II, Large size Reactor and a Generation III+ Small Modular Reactor.

The results obtained in this test case demonstrate that the actual EMR is conservative, as expected, for the GenII reactor, while the new methodology could be applied for the definition of EMRs for the new generation Nuclear Power Plants, with a possible reduction of the emergency area without loss of safety level.

By adopting both probabilistic and deterministic approaches, the study addresses possible accidents and corresponding release scenarios for the two types of reactor, calculates the areas where the accidents have an impact on the population and defines the new EMR considering the health effects on the population.

1. Introduction

IAEA Safety Fundamentals (IAEA, 2010) for Nuclear Power Plants (NPPs) and site selection require that adequate protective measures can and will be taken in the event of a radiological emergency. Historically, the Emergency Management Requirements (EMR) were defined according to very conservative parameters independent from the design and the actual safety level of each specific nuclear power plant, e.g. evaluated through Probabilistic Risk Assessment and Deterministic Analysis (IAEA, 1999; NRC, 2003). This conservative approach does not take into account the significant safety improvements in plant operation and design achieved since.

Moreover as a consequence of this conservative approach, the EMR may also pose a significant burden on plant owner, both in the construction and in the operation phase.

During construction, it may be needed to build large infrastructures (e.g. enhanced highways) to comply with the requirement. During operation, it is necessary to maintain an evacuation capability in a relatively wide area around the plant in which, for all practical purposes, any human development is frozen. This could discourage small countries and/or areas with significant growth to invest in the nuclear construction. Finally the fact that the off-site zone around NPP is treated in a special way sends an incorrect message to the public regarding the safety of NPPs and in the unlikely event of an accident could even induce among residents of the affected areas the "paralyzing fatalism" that is recognized to be the largest and long lasting public health problem created by the Chernobyl accident (IAEA, 2005).

The current advanced and safer reactor designs further reduce risk to public, and should therefore offer the possibility to methodologically link the level of safety to the emergency areas and eventually to reduce or to eliminate some of the emergency plan and evacuation requirements. This need was identified by the IAEA INPRO international project (IAEA, 2003) ("*The innovative nuclear reactors and fuel cycle shall not need relocation or evacuation measures outside the plant site, apart from those generic emergency measures developed for any industrial facility*") as well as by the Generation IV International Forum (GIF) (GIF, 2002). It is deemed possible to reduce emergency-related site requirements for advanced plants, while at the same time providing a protection to the general public equal or better than that provided by the current generation of NPPs and current regulations.

Achieving licensing with this new objective could offer societal and economic benefits to member countries, general public and plant owners/operators, including:

* Corresponding author. Tel.: +39 02 23996325; fax: +39 02 23996309.
E-mail address: marco.ricotti@polimi.it (M.E. Ricotti).

0149-1970/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.pnucene.2013.12.002

- enable wider choice of siting locations in countries with relatively high population density;
- increased public acceptance of nuclear power, since they will be treated as any other industrial facility;
- reduced need for infrastructure, thus reducing cost;
- reduced operational costs;
- enabling co-generation, including district heating, desalination and ethanol production, where the plant cannot be located remotely from the intended user;
- enable siting that would reduce transmission costs.

In particular the Small–Medium size Modular Reactors (SMRs) concept (Ingersoll, 2009; Boarin et al., 2012), which is gaining growing interest from several IAEA member countries (IAEA, 2007, 2010b), may effectively and better comply with new safety features required to allow the reduction or even the elimination of the EMR. At the same time SMRs may take advantage from that for their deployment strategy.

In principle EMR criteria could be based on four possible rationales: risk, probability, cost-effectiveness and consequences.

The methodology presented in this paper follows a risk informed approach (ANS, 2011) and links the EMR with the safety level of the nuclear power plant. The methodology is applied to a GenII, large size reactor (LR) and to an enhanced safety GenIII+, SMR.

The purpose of the paper is a preliminary demonstration of the potentialities of the risk-informed methodology in evaluating the EMRs, taking into account the safety improvements obtained in the GenIII+, new reactor designs. The analysis presented in this paper reflects the limited availability of suitable data in the open literature as well as the complexity of a thorough evaluation. Due to the preliminary and demonstrative goal of the analysis, the evaluation does not cover the impact of external events and does not consider the possible post-Fukushima scenarios. The data used for the analysis are the results of level 2-PSAs based only on at-power internal events; for the GenIII+ reactor also the Fuel Handling Accident has been considered.

To obtain a complete analysis, a supplementary evaluation of the impact of the site-dependent external hazards should be performed.

Nevertheless, the above-mentioned limitations do not impair the validity of the risk-informed approach and the test.

The EMR areas estimated with the methodology for both the types of reactor are shown and compared.

2. Current EMR approach and previous studies

The birth of the EMR concept, originally called Emergency Planning Zone (EPZ), was introduced after the construction of the early nuclear power plants. The National Regulators established the EMR following the international advise based on the Design Basis Accidents (DBA), the current EMR are reported in Table 1. Besides, the extension of the EMR for the protection against beyond design basis accidents (BDBA) is site dependent and evaluated according with the NPP safety features. In general, countermeasures for the BDBA can be decided in detail after the accident is occurred, because more time would be available for the emergency response beyond the established distances. After the Fukushima accident, a revision of the actual requirements has been implemented in some countries (NRC, 2011). The increased Emergency Preparedness now has to include emergency plans and sustained assistance for prolonged station blackout and multiunit events. To ensure protection, the station blackout mitigation capability has to be enhanced considering also the design basis and beyond design basis external events.

Table 1
Current EMR in some countries.

USA	10 miles	Plume exposure pathway	Exclusion area	Total radiation dose to whole body in 2 h>25 rem Total radiation dose to the thyroid from iodine exposure in 2 h>300 rem
	50 miles	Ingestion exposure pathway	Low population zone	Total radiation dose to whole body during the entire period of passage>25 rem Total radiation dose to the thyroid from iodine exposure during the entire period of passage>300 rem
France	5 km		Evacuation pre-planned	
	10 km		Sheltering pre-planned Stable iodine tablets distributed	
	>10 km		Possible extension of protective actions	
Spain	10 km		Sheltering, evacuation and stable iodine intake in the preference sector	
	30 km		Food restrictions	
Japan	8–10 km		Lower limit of radiation exposure between $D < 10$ mSv whole body $D < 100$ mSv thyroid	

2.1. Past studies and previous attempts

The analysis of past experiences (Thompson, 1997; EPRI, 1999; NEI, 2002; EUR, 2002; Lee et al., 2004) suggests the adoption of a mixed deterministic and probabilistic approach which still involves a relevant modification in the fundamental EMR defining criteria as currently conceived (i.e., from consequences, as it is currently, to risk).

The proposed methodology is based on accepted concepts such as PRA techniques and deterministic dose evaluation as used in current practice; it suggests a more complete definition of the current and accepted criteria for the EMR by focussing on the frequency of exceeding a given dose at a given distance. The EMR can be redefined while still maintaining the same dose (explicitly defined in the current Protective Action Guides-PAG) and the same frequency (implicitly defined by the choice of a fixed distance) defined by the regulatory body.

The proposed methodology addresses the two conceptual weaknesses highlighted for previous efforts in the redefinition of the EMR defining criteria:

- in the deterministic part of the methodology all the foreseen sequences including severe accidents, are evaluated. Severe accidents are limiting scenarios but cannot be removed from the analysis without infirming the completeness of the methodology. Previous attempts in the EMR redefinition were rejected because lacking a satisfactory account of severe accidents;
- the probabilistic part is shifted from establishing a cut-off frequency. This screening criterion of accident sequences evaluates the frequency to overcome the dose limit at a certain distance. By means of the data provided by PRAs, such a distance can be evaluated rather than pre-set. Arbitrary selection of the cut-off frequency value represented the major objection against the probabilistic approach to EMR redefinition.

The methodology presented here will combine probabilistic, deterministic, and risk management methods that would support licensing with reduced emergency planning requirements. It is articulated over the following steps:

- Review the licensing regulations which specify the emergency response planning for the current Light Water Reactor (LWR) plants.