ENVIRONMENTAL EFFECTS OF NUCLEAR POWER GENERATION

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Summary

The system of dose limitation to control public exposure to radiation exposure, which is adopted almost universally, is briefly presented and discussed for the case of nuclear power generation. The limits of public exposure recommended by the International Commission on Radiological Protection (ICRP) and those adopted for routine operation of light water reactors (LWRs) are also presented. Criteria for site selection, construction and design of are briefly mentioned, as well as procedures for emergency planning, preparedness and response to nuclear accidents. The basic principles that underline the production of nuclear energy is discussed succinctly. The conditions to achieve a nuclear chain reaction are discussed with a view to its application to nuclear reactors and power generation. The environmental effects of nuclear power generation are examined from the construction of a nuclear power plant and its ancillary operations up to environmental impact assessments concerning the transportation of commercial spent fuel to reprocessing facilities, or to interim repositories, passing through several environmental impacts, for example, thermal discharges. Along the way the ALARA (as low as reasonably achievable) criterion adopted for the releases of radioactive effluents during the routine operation of nuclear power plants is examined. A potential inventory of fission and corrosion products, and actinides in spent nuclear fuel is summarized in three tables to be used as a basis for preliminary estimates in the case of a major nuclear accident.

1. Introduction

The nuclear power generation constitutes the intermediate phase between the front- and back-ends of the nuclear fuel cycle. There are in this intermediate phase routine releases of radionuclides to the surrounding environment in liquid and gaseous forms.

As far as the environmental effects of these routine releases are concerned a system of dose limitation to control public exposure to radiation is adopted in mostly all cases. This system of dose limitation is based in a tripod which includes the justification of a practice, the optimization of protection of public exposure, and dose limits for public exposure. Usually the concept of collective effective dose per unit of practice is used in the justification of a practice and in the optimization of protection. In the case of nuclear power generation the unit of practice is the unit of electrical energy generated, that means MW(e); while the unit of collective effective dose is man.sievert (man.Sv). It should be noted, however, that part of the collective dose may be received somewhere in the future. The concept of effective dose commitment to a critical group of individuals is then introduced to further limit future individual doses (that means, doses to typical members of a critical group). Moreover, in the case of exposures to the members of the public, when dose limits are used as constraints for optimization, one should be aware that some conceptual difficulties will appear. Optimization is a source-related requirement, while a dose limit is essentially an individual-related requirement. To avoid that a single practice be inhibit, for example the construction of a second nuclear power plant in the same site where there is one, even when optimization would allow it, small fractions of the dose limit should be allocated to each practice. Thus, exposures from more than one practice would be allowed to overlap.

Fission and corrosion products are in the primary coolant of nuclear reactors in a variety of concentrations. When one assumes that a fraction of one percent of the fuel fails, and a leak occurs at a small rate across the heat exchanger, trace amounts of fission and corrosion products find their way to the steam generator (or the secondary system). Some of these trace radionuclides present in the primary and/or secondary coolant loops may be released in several ways, including, for example, pressurizers, steam valves, seals, and pipes. The atmosphere of the nuclear reactor containment vessel retains the gaseous and volatile radionuclides, while the liquid ones go to floor drains and retention tanks. A system of radioactive waste treatment and retention, the Radwaste system, is design to work in such a way that most of the radionuclides in the containment vessel and in the retained tanks are not released. However, small amounts are released in accordance with the ALARA principle. This means that releases are to be made in a way “to ensure that the magnitude of the individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received, are all kept as low as reasonably achievable , economic and social factors being taken into account.”

By and large, annual averages of the effective dose equivalent received due to nuclear power generation in the world are of the order of $0.1\mu Sv.y^{-1}$, while the annual dose limits adopted for light water reactors (LWRs) lie between 0.10 and 0.25 $mSv.y^{-1}$. This means that the world annual averages are less that one thousandth the adopted limits for nuclear power generation. Moreover. The International Commission on Radiological Protection (ICRP) recommends that the limit for public exposure should be $1mSv.y^{-1}$. A higher value of annual effective dose can be allowed in one single year, however, provided that the average over 5 years does not exceed $1mSv.y^{-1}$.

One aspect of the routine releases of radionuclides from nuclear power generation deserves further attention. Three radionuclides, ^{3}H, ^{85}Kr and ^{14}C with half-lives 12.3

years, 10.7 years, and 57,300, respectively, are emitted in gaseous or liquid phases. Because their long half-lives these radionuclides accumulate and circulate in the global environment. Studies on the long term environmental effects of nuclear power generation will need to take into account the overall releases of ^{3}H, ^{85}Kr and ^{14}C.

The site of construction of a nuclear power plant should always be chosen to minimize the effects of a potential accident. Before constructing a nuclear power plant in any particular site data are gathered on the local meteorology, population density in the surrounding areas, existing crops, and orography. Such data will be used to make site specific analyses involving real time estimation of accident consequences. Design reactors engineers estimate that a probability of occurring an accident with a nuclear power plant is very low, because they trust the multiple levels of protection against reactor and/or containment failures with significant radionuclide releases. However, models are also selected for calculating doses, health effects, and economic costs due to accidental radionuclide releases from nuclear power plants. Moreover, there are established criteria for preparation and evaluation of radiological emergency response plans and preparedness in support of nuclear power plants.

Atmospheric and terrestrial food-chain transport models are prepared to estimate air concentrations at ground levels and ground contamination concentrations at off-site locations resulting from accidental releases of radionuclides to the atmosphere. An accident may release significant amounts of , for example, $^{131\text{-}135}I$, $^{131m,\ 132}Te$, ^{134}Cs, and ^{88}Kr into the atmosphere. The atmospheric pathway will bring these and other gaseous radionuclides into a radioactive plume to be deposited on the ground and to become available for direct inhalation within a short time after an accident. Dose estimates due to short term inhalation are subject to great uncertainties, because the source term is seldom well known. Emergency planning should also contemplate coordinated actions based on the available information to classify the accident and to evaluate the potential off-site consequences and countermeasures to minimize the theoretically predicted consequences. In addition, both short-term and long-term environmental monitoring are required to provide input for models in which decision-making personal base their actions. Personnel monitoring is also required when there are indications that inhalation or ingestion of radionuclides might have occurred. The overall objective of emergency preparedness and response is to prevent or keep to a minimum the radiation dose to the public and workers.

2. Nuclear Energy

Whenever a reaction occurs in which the atomic number, mass number or radioactivity of the atomic nucleus changes energy is released. This kind of nuclear energy arises from the special forces that hold the positive proton and the neutral neutron within the small volume of the atomic nucleus. These special forces are a million times stronger than the chemical bonds that hold together molecules. The binding energy BE that maintains together the components of a stable nucleus is equivalent to the so called mass defect, expressed as $BE = \Delta m.c^2$, where c is the electromagnetic constant (the speed of light in a vacuum). The BE is equivalent to the work needed to split up the nucleus into separate protons and neutrons, and is always positive. The BE varies with the size of the nucleus, that means with the number of protons and neutrons in its interior. The BE is lower for very lighter elements, increasing steeply as Z increases. Thus, energy can be released by combining two deuterium nuclei to form a helium nucleus. This combination is known as a fusion reaction. The BE curve passes through a maximum at intermediate nuclei, and decreases for heavier nuclei. This means that at some point intermediate nuclei form the most stable elements. For heavier nuclei the BE decreases, indicating that the more positively charged the nucleus becomes, the less stable it is. As a matter of fact, this is why there are not very heavy elements in nature, and all elements heavier than bismuth are naturally unstable (i.e., radioactive). Just before the beginning of WWII it was observed that when the heavy element uranium was bombarded with slow neutrons a violent reaction occurred. This striking phenomenon was correctly interpreted not too much later as the fission of ^{235}U (a less abundant naturally occurring uranium isotope) into two or more lighter elements with release of high amount of energy. One fission is always accompanied by the emission of two or more neutrons, because the neutron-to-proton-ratio of each fission product is lower than that of the that of uranium. The emission of more than two neutrons per fission is the key for the of the energy released by the fission either for military use or power generation. A chain reaction. A nuclear chain reaction is achieved when neutrons released by a preceeding fission are absorbed by surrounding fissile nuclei maintaining an indefinite fission chain. Nuclear energy from fission and fusion have already been used in military weapons, however, only fission has been used as a controlled source for power generation thus far.

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Biographical Sketch

Anselmo Salles Paschoa was born in Rio de Janeiro, Brazil, on December 15, 1937. Mr Paschoa holds a PhD degree from New York University. He is a Full Professor at Pontifícia Universidade Católica do Rio de Janeiro – PUC RJ. He was Visiting Associate Professor at the University of Utah, Guest Scientist at Brookhaven National Laboratory, and Visiting Scientist at Memorial Sloan-Kettering Cancer Center. Dr Paschoa was Guest Lecturer in courses offered by the Pan-American Health Organization, the Universidad de Sevilla, the International Atomic Energy Agency (IAEA), and the International Center for Theoretical Physics. He is member of several scientific and professional societies and associations. He was member of the Board of Directors of the International Union of Radioecologists, and Vice-President of the International Radiation Physics Society for Central and South Americas. Dr Paschoa has published more than 100 scientific articles and papers. He is member of several international scientific committees in the fields of Radiation Physics and Environmental Sciences. Dr Paschoa was Director for Radioprotection, Nuclear Safety and Safeguards in the Brazilian Nuclear Energy Commission (CNEN) from May 1990 to August 1992. In September 1991, he was head of the Brazilian Delegation to the General Conference of IAEA and Alternative Governors of Brazil to the Board of Governors of the IAEA from 1990 to 1992. Recently, Prof. Paschoa was member of the United States National Academy of Sciences Committee on Evaluation of EPA Guidelines for Exposure to Naturally Occurring Radioactive Materials, National Research Council.