A COMPARATIVE PROBABILISTIC RISK ASSESSMENT OF NUCLEAR AND FOSSIL FUEL POWER PLANTS

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ABSTRACT

A methodology for comparing the adverse health effects of nuclear and fossil fuel power plants was developed. The methodology consists of: (a) Probabilistic Risk Assessments (PRA) of accidents and routine operation for both nuclear and fossil fuel power plants, resulting in CCDF(*) risk curves. (b) Analysis and consideration of uncertainties in risk curves, and (c) Methods, based on Utility Theory principles, for comparing risk curves and for safety oriented decision-making. Thus, the health effects of both types of power plants are presented on an equal basis.

The proposed methodology makes possible safety-oriented intercomparisons of power plants (nuclear vs. fossil) or different technologies of the same type of power plant located at any site. The methods developed in this study are not limited only to power plants, and can be implemented in any safety-oriented process of decision-making under conditions of uncertainty.

A. INTRODUCTION

Routine operational risks of nuclear power plants are extremely low (1,2). The risks of potential accidents in nuclear power plants have been extensively investigated but only lately using probabilistic methods (e.g. Refs. 3,4). The results of the probabilistic risk assessments (PRA), i.e. the magnitude of the various health effects (early fatalities, late cancer fatalities, thyroid nodules, etc.) have been presented by CCDF.

Unlike the risks of nuclear power plants, the risks of fossil fuel power plants were, in most cases, calculated using deterministic methods. To our knowledge, only in one study (5) were the health effects of routine emissions from fossil fuel power plants assessed by applying probabilistic methods in the consequence modelling. Moreover, in all the risk studies, only routine operational releases, and not possible accidents in the fossil fuel plants, were considered. Such accidents may arise either from fires (6) (mainly in the storage tanks of oil plants, or in the coal piles of coal plants), or from meteorological episodes that prevent the dilution of the pollutants. Such episodes have occurred, e.g. in London in 1952, where about 4000 fatalities were reported, due to a significant increase in the air concentrations of pollutants. In the present study, probabilistic methods are used (7) to assess the routine operational and accidental risks from both nuclear and fossil fuel power plants.

B. REQUIREMENTS FOR COMPARATIVE RISK ASSESSMENT OF NUCLEAR AND FOSSIL FUEL POWER PLANTS

A full safety-oriented comparison of nuclear and fossil fuel power plants requires that the risks of both types of power plants be presented on an equal basis (7). This requirement is fulfilled in the present study, by performing for both types of power plants, (a) an evaluation of both routine operational and accidental risks, (b) probabilistic calculations of early and late fatalities(**)

(*) CCDF - Complementary Cumulative Distribution Function.

(**) Early fatalities are defined as those occurring within months after exposure to a pollutant, while late fatalities are those occurring within years after exposure.

presented in the form of CCDF risk curves.

Figure 1 shows an arbitrarily chosen example of early and late fatalities CCDF risk curves obtained in a study (7) on a 1000 MWe coal power plant (Fig. 1a) and a nuclear power plant (Fig. 1b) located at the same site in a densely populated area. In Fig. 1a the early fatalities result from possible meteorological episodes, whereas the late fatalities are caused by routine emissions. In Fig. 1b, both early and late fatalities are caused by severe accidents of low probability-high consequences.

C. COMPARISON OF THE RISK CURVES (7)

In order to compare CCDF risk curves, three main problems remain to be solved: (a) the uncertainties in the CCDF risk curves, (b) comparison of intersecting curves and (c) the different attitudes of the public towards various risk categories. The first two subjects are discussed below while all of them are discussed in detail in Ref. 7.

C1. The Uncertainties in the CCDF Risk Curves

The uncertainties in the risk curves are caused by uncertainties in almost all the submodels and parameters comprised in the PRA (7). Due to these uncertainties, a PRA performed for any plant-site combination (PSC) (*) results in a family of risk curves forming an "uncertainty band", rather than in a simple curve (7,8). The "width" of the uncertainty band may be defined as the difference or the ratio of the expectation values (μ values) of the upper (e.g. 95%) and the lower (e.g. 5%) CCDF risk curves. (Note: These expectation values can easily be obtained by integration of the CCDF risk curves over their whole range of consequences.) It has been shown (7) that, depending mainly on the specific population distribution patterns, the width of the uncertainty bands may vary from site to site for a given power plant and even from plant to plant for the same site. Figure 2 shows hypothetical risk uncertainty bands of 2 PSC: P_1SC-A (plant 1 at site A) and P_1SC-B (plant 1 at site B). Figure 2a shows a straightforward situation: for both the 95% and the 50% curves, site B is preferable to site A from the risk standpoint. However, Fig. 2b shows a more complicated situation: P_1SC-A seems to be preferable to P_1SC-B when comparing the 95% curves, but worse than P_1SC-B when comparing, say, the 50% curves. Such a situation must be considered in risk comparisons. It was suggested (7) that if the ratio $\mu_{B1}95\%:\mu_{A1}95\%/\mu_{A1}50\%:\mu_{B1}50\%$ is greater than 0.5, PSC-B will be preferred. If the ratio is less than 0.5, PSC-A will be preferred.

C2. Comparison of Intersecting Risk Curves

In some instances, the CCDF risk curves intersect each other. The problem is illustrated in Fig. 3. Curves A and B may represent the risk of early or late fatalities obtained in PRA of two PSC. Risk curve A seems to be less severe than risk curve B up to point M, but more severe than risk curve B beyond this point. Can one of the PSC curves be distinctly preferred over the other from a safety point of view, or is it a matter of different individual preferences? A similar issue has been dealt with in the field of economics, concerning portfolio analysis and selection (9). Here, similar curves represented the uncertainties in the returns (profits) of different investment alternatives. The solutions given in portfolio analysis were based on Utility Theory considerations. Applying this methodology to the intersecting PSC risk curves, two criteria have been developed (7): (a) the Risk Aversion Criterion (RAC): According to this criterion, if the integral of curve A is greater than that of curve B for any value of X (that is, subtraction of the cumulative area under curve B from the cumulative area under curve A, for any X, yields a positive number), then curve A is preferred over curve B by all "risk averters"(**), (b) the Mean Variance Criterion (MVC):

(*) Plant Site Combination (PSC) means a combination of a certain plant, located at a given site.

(**) A "risk averter" is a person whose "utility function" is concave. For detailed discussion, see Refs. 7,9.

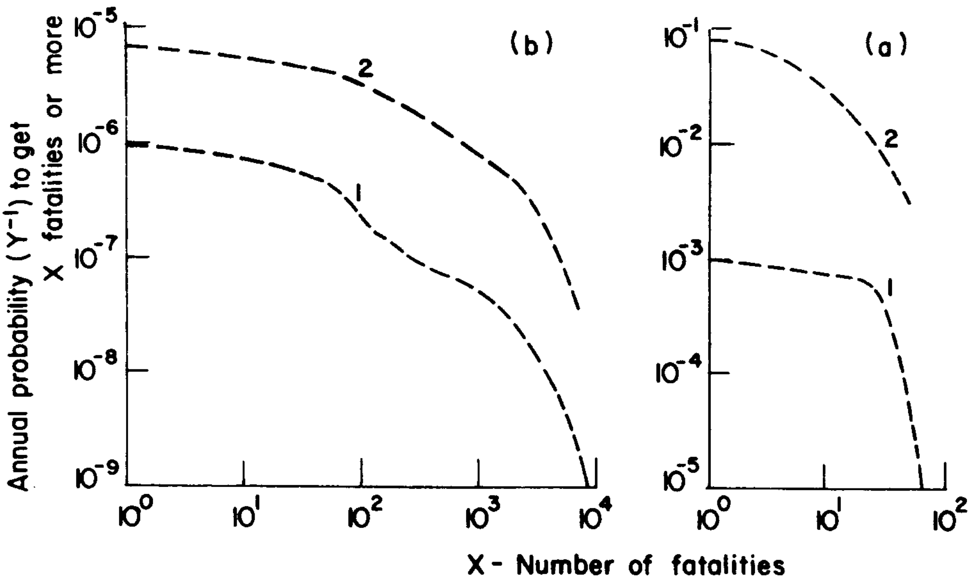

Fig. 1. CCDF risk curves for early and late fatalities caused by a coal-fired power plant (a) and a nuclear power plant (b) located at the same site (7). Curve 1 - early fatalities, Curve (2) - late fatalities.

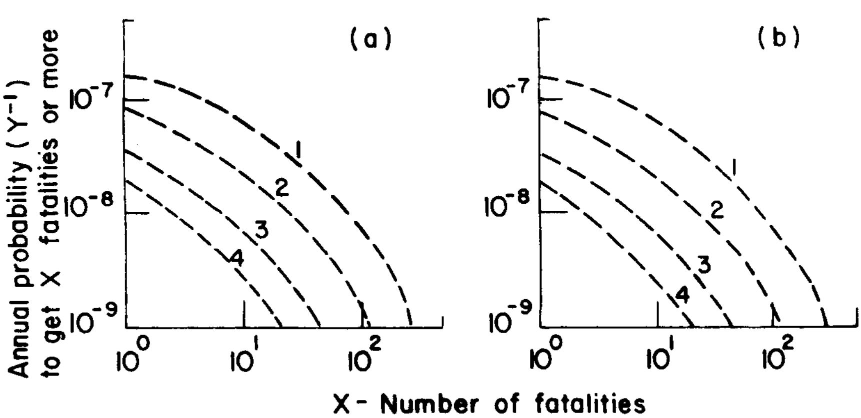

Fig. 2. Uncertainty bands of hypothetical CCDF risk curves for two plant site combinations, P_1SC-A and P_1SC-B (7). a) Straightforward case: 1.P_1SC-A 95%, 2. P_1SC-B 95%, 3. P_1SC-A 50%, 4. P_1SC-B 50%, b) Complicated case: 1. P_1SC-B 95%, 2. P_1SC-A 95%, 3. P_1SC-A 50%, 4. P_1SC-B 50%.

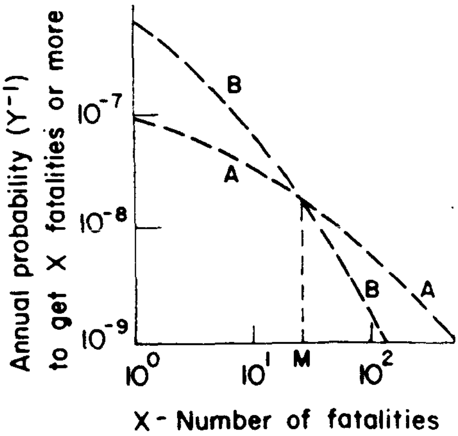

Fig. 3. Hypothetical intersecting CCDF risk curves.

According to this criterion, if both the expectation value and the variance of curve A are smaller than the corresponding values of curve B, then curve A will be preferred over curve B. Again, this holds for all "risk averters". Due to some mathematical weaknesses of the MVC criterion, it is recommended (7) that this criterion be applied only when the RAC criterion cannot be used (e.g. in cases where X values can be found for which the integral of curve A is not greater than the integral of curve B).

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