The Use of a Frequency-Consequence Curve for the Licensing of Future NPPs

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1. Introduction

A probabilistic safety assessment (PSA) provides a systematic analysis to identify and quantify all risks that a plant imposes to the operators, general public and the environment. Also, a PSA is used as part of the licensing of plants to generate a sufficiently complete set of accident scenarios whose frequencies and consequences, individually and cumulatively, provide an estimate of the overall risk profile of a plant. For current LWRs, the risk examined is almost always expressed in terms of the surrogate risk objectives: core damage frequency (CDF) and large early release frequency (LERF), because they can be used as surrogate metrics for the NRC's safety goal QHOs. For new, non-LWR types of reactors, however, not only will the quantitative values for CDF and LERF be no longer applicable, CDF itself may be no longer be a useful risk metric.

Therefore, a comprehensive set of technology-neutral safety requirements are being developed by the IAEA[1] and USNRC[2]. They developed and suggested risk metrics applicable to a variety of different reactor designs, which are either ones that express consequences directly or that can be linked to consequences without technology-specific metrics. Also, they developed a criterion that specifies limiting frequencies for a spectrum of consequences, from none to very severe, needs to be established. A frequency-consequence (F-C) curve, that relates allowable consequences to their allowable frequencies, provides such a criterion. On the F-C plane, the F-C curve provides an acceptable limit in terms of the frequency of potential accidents and their associated consequences. The objective of the F-C curve is to establish the licensing basis, i.e., identify the event sequences that the design and operation of the plant need to be able to mitigate. And the objective involves establishing criteria that define the acceptable frequencies for different levels of consequences.

In this study, we introduced an illustrative F-C acceptance curve, and investigated its application by plotting the consequences expressed as exposure doses at the exclusion area boundary resulting from the hypothetical accidents during the operation of the APR1400 reactor.

2. Frequency-Consequence Curve

A typical F-C curve is plotted in Figure 1. The range of the frequencies that need to be considered in establishing the F-C curve encompasses a wide range that includes frequent events (AOOs), infrequent events, and rare events. The consequences can be expressed in several units of measure which include released activity in terms of curies (or becquerels) of various radionuclides, health effects like early fatalities and latent cancers, and radiation doses (rems or siverts). However, the radiation dose is a convenient measure because a body of rules and guidance already exists for its use while the use of other measure could result in confusion.

The sequences of the PSA will populate the space under the F-C curve. Some sequences will have little or no consequences, primarily because of the inherent characteristics and design features of the plant. Others are likely to approach the F-C curve and thus make up the important contributors to the plant risk profile. To be acceptable, the frequency and consequences of all the accident sequences examined need to lie in the acceptable region (i.e., below) of the F-C curve by meeting the dose criteria.

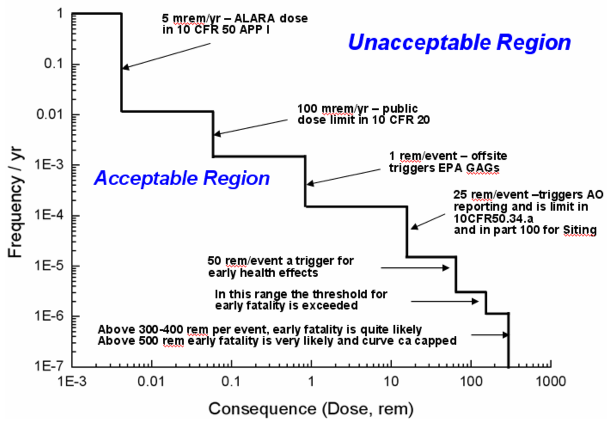

Fig. 1. A typical Frequency-Consequence (F-C) Curve.

In order to investigate the application of the F-C curve, we consider the postulated accidents resulting from the operation of the APR1400 reactor. The accidents with their frequency and consequences considered in this study are summarized in Table 1. The exposure doses are derived from the results of the preliminary safety analysis report[3].

Also, we considered the results of the severe accident analysis[4]. The characteristics of each source term categories resulting from the probabilistic safety assessment of severe accidents are summarized in Table 2. We estimated the exposure dose at the exclusion area boundary by using the MACCS2 code[5].

Table 1. Postulated accidents and their frequency and consequences

Accident	Dose (rem)	Frequency/yr
Steam Line Breaks Outside Containment Upstream of MSIV	0.008	$1.67x10^{-5}$
Feed water Line Break	0.0046	$1.67x10^{-5}$
Single RCP Rotor Seizure with Loss of Offsite Power Resulting from Turbine Trip	0.15	$1.67x10^{-5}$
Postulated CEA Ejection Event	0.0053	$8.33x10^{-5}$
Double-Ended Break of the Letdown line	0.091	$3.33x10^{-3}$
Large Loss Of Coolant Accident	0.006	$1.67x10^{-5}$
Steam Generator Tube Rupture	0.086	$1.67x10^{-5}$
Steam Generator Tube Rupture with a Loss of Offsite Power	0.22	$1.67x10^{-6}$
Postulated Fuel Handling Accident	0.28	$8.33x10^{-5}$

Table 2. Characteristics of Source Term Category of APR1400 Reactor

STC No.	Frequency (/RY)	Dose (rem)
1	1.42x10-6	1.02x10+0
2	7.53x10-7	2.72x10-1
3	4.84x10-12	1.15x10+1
4	1.10x10-11	8.82x10+0
5	1.58x10-8	1.32x10+2
6	6.81x10-9	3.76x10+1
7	1.45x10-8	4.50x10+0
8	3.24x10-8	4.31x 10+0
9	3.12x10-9	9.97x 10-1
10	3.12x10-9	9.91x10-1
11	1.51x10-12	7.31x10+1
12	7.21x10-9	4.50x10+1
13	2.52x10-8	2.15x10+2
14	3.12x10-9	9.97x10-1
15	3.12x10-9	1.08x10+0
16	7.55x10-10	2.15x10+2
17	9.07x10-9	9.43x10-1
18	2.97x10-8	3.71x10+2
19	3.33x10-9	2.60x10+0
20	5.37x10-10	4.11x10+2
21	4.11x10-9	1.40x10+3
22	4.13x10-8	4.47x10+2

The frequency and consequences of all the accident sequences examined in this study for the APR1400 rector are plotted in Figure 2. As can be seen from the figure, all the frequency and consequences of all the accident sequences examined in this study lie within the acceptable region of the F-C curve by meeting the dose criteria. Although the accidents considered in this study do not cover both internal and external events and all modes of operation, we found that the F-C curve can be used as regulatory risk acceptance criteria if we select all the licensing basis events (LBEs) which are chosen from the design specific PSA for use in establishing plant design parameters for a safe operation and an equipment safety classification.

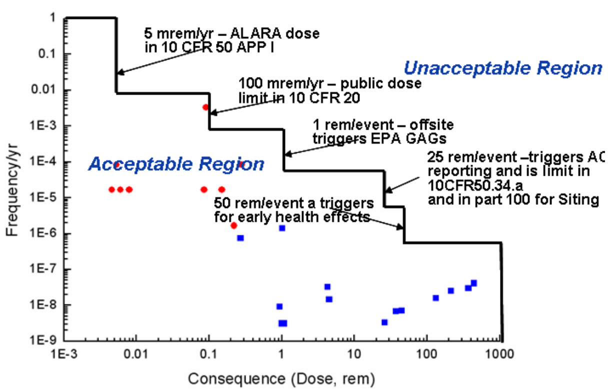

Fig. 2. Plotting of the frequency and consequences on the F-C curve.

3. Conclusions

We estimated the frequency and consequences expressed as doses resulting from accidents during the operation of the APR1400 reactor. Also, we plotted them on the F-C curve in order to investigate the usefulness of the F-C curve as regulatory risk acceptance criteria. We found out that the F-C curve can be used as regulatory risk acceptance criteria for the licensing of future nuclear power plants. However, we have to prepare our own dose and frequency ranges in order to set up an appropriate F-C curve for use in the licensing of future nuclear power plants.

REFERENCES

[1] IAEA-TECDOC-1570, “Proposal for a Technology-Neutral Safety Approach for New Reactor Designs,” 2007.
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[4] APR1400 SSAR, Chapter 19, Probabilistic Safety Assessment and Severe Accident Analysis.
[5] NUREG/CR-4691, “MELCOR Accident Consequence Code System (MACCS) – User’s Guide,” USNRC, 1990.