From:	Afzali, Amir
To:	Reckley, William
Cc:	Segala, John; Valliere, Nanette; Shams, Mohamed; KARL FLEMING; Steven Nesbit; Ed Wallace; Chisholm, Brandon M.
Subject:	[External_Sender] Request for your consideration on QHO estimation methodology
Date:	Tuesday, July 06, 2021 6:37:11 PM
Attachments:	Use of PRA tools to evaluate the QHO risk metrics.pdf

Greetings Bill,

Please find attached a brief essay on methods and tools available for QHO estimation (prepared by Mr. Karl Fleming and reviewed by a number of established experts in the field). I believe it will be helpful if the paper is sent to the ACRS prior to July 21st meeting, where Karl, Ed, and I will be supporting the staff during the LMP training/reintroduction session. Brandon and Steve are included on this email because we may be supporting the staff during its ARCAP/TICAP ACRS presentation in the afternoon of the 21st. The objective of this brief paper is to share our perspective and gain an understanding of the technical challenge(s) which is (are) being articulated to exist for performing analysis in support of quantitatively demonstrating a design meets the QHO performance criteria. I believe developing a shared understanding of this issue will be very helpful for effective exchange of ideas on the solution path for the LMP implementation (within Parts 5o and 52) as well as Part 53.

Best regards,

Amir

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Models and PRA Tools to Evaluate the QHO risk metrics

By Karl Fleming
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The purpose of this note is to describe the models that are used to calculate the risk metrics for comparison against the NRC Safety Goal Quantitative Health Objectives (QHOs). The models used in Level 3 PRAs on LWRs and Non-LWR PRAs to calculate these risk metrics are shown in Equations (1) and (2)[1].

$$Q_{EF} = \frac{\sum_{i=1}^{N} f_i EF_{i,0\to 1}}{P_{0\to 1}} \quad (1)$$

Where:

Q_{EF} = Average Individual risk of early fatality within 1 mile of the site boundary

f_i = Frequency of release category I, among N total release categories
$EF_{i,0\to 1}$ = Total number of early fatalities within 1 mile of the site boundary from accidents in release category i
$P_{0\to 1}$ = Total population within 1 mile of the site boundary

$$Q_{LCF} = \frac{\sum_{i=1}^{N} f_i LCF_{i,0\to 10}}{P_{0\to 10}} \quad (2)$$

Where:

Q_{LCF} = Average Individual risk of latent cancer fatality within 10 miles of the site boundary

f_i = Frequency of release category i, among N total release categories
$LCF_{i,0\to 10}$ = Total number of latent cancer fatalities within 10 miles of the site boundary from accidents in release category i
$P_{0\to 10}$ = Total population within 10 miles of the site boundary

The average individual risk of early fatalities, Q_{EF}, is estimated in terms of the consequence of accidents within 1 mile of the site boundary. In the numerator of Equation 1, the mean risk of early fatalities, is estimated by multiplying the mean frequency of each release category times the total number of early fatalities within 1 mile of the site boundary. By dividing by the total population within 1 mile yields the average individual risk of early fatality.

Consequence models such as MACCS and CRACEZ evaluate consequences by performing a Monte Carlo sampling of weather conditions at the time of the release from a specified source term and for the duration of the release based on meteorological data collected from the site over

[1] See for example Appendix D of NUREG-1860 which documents the basis for using CDF and LERF as surrogates for the QHOs which includes equations equivalent to these.

1 or more years. These codes use a polar coordinate system to divide in the region around the site into small zones or cells. They calculate the doses in the cells and apply health effects models to convert the doses into numbers of health effects based on the population distribution that is input to the code and established health effects models. For early fatalities, there are dose thresholds below which zero early fatalities are recorded. Above those thresholds they apply a probability of death curve to estimate the number of fatalities. For example, if there are 100 people in the cell and the dose calculated in the cell is at the 50% probability of death, 50 early fatalities will be recorded. These codes have the capability to simulate evacuation by moving people from cell to cell during the release and to simulate sheltering by modifying the dose calculation. The different codes have different capabilities to model terrain effects, plume meander during the release, resolution of the evacuation routes, and other factors impacting consequences. The LWR Level 3 PRA standard[2] and the non-LWR PRA standard[3] have requirements that govern these calculations.

Codes such as MACCS and CRACEZ[4] provide estimates of the QHO risk metrics as a standard output option and have been used extensively for many years to confirm that the NRC safety goals have been met for specific reactors and specific reactor applications. As part of the effort to resolve emergency planning issues for Seabrook Station in 1986 the Level 3 PRA for that plant and the CRACEZ code was used to demonstrate that the QHOs would be satisfied with reductions in Emergency Planning Zones to 1 mile[5]. More recent studies where these QHO metrics have been calculated and applied using MACCS include:

- EPRI's Report: Technical Basis for Severe Accident Mitigating Strategies[6]
- NUREG-2206: Technical Basis for Containment Protection and Release Reduction Rulemaking for Boiling Water Reactors with Mark I and Mark II Containments[7]
- NUREG-1935: State-of-the-Art Reactor Consequence Analyses (SOARCA) Report[8]

Note that the calculation of risks of health effects and other radiological consequences is well established and is essentially unchanged all the way back to WASH-1400, however the capabilities of the tools have been enhanced. The only new "wrinkles" introduced by the QHO metrics is the conversion from calculating the risks to the total population to that of individuals within fixed distances from the site. This changes the arithmetic but not the underlying risk models. It is important to note that calculating the QHO metrics does not require any additional information beyond that needed to perform a Level 3 PRA for LWRs or a Non-LWR PRA that addresses the requirements in the supporting ASME/ANS PRA standards.

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[2] ASME/ANS RA-S-1.3-2017, Standard for Radiological Accident Offsite Consequence Analysis (Level 3 PRA) to Support Nuclear Installation Applications, 2017

[3] ASME/ANS RA-S-1.4-2021, Standard for Probabilistic Risk Assessment for Advanced non-LWR PRA Plants, 2021

[4] These codes were derived from the CRAC code that was used in the Reactor Safety Study and employ essentially the same methodology.

[5] PLG Inc., Seabrook Station Risk Management and Emergency Planning Study, Prepared for Public Service New Hampshire, PLG-0432, 1986

[6] EPRI 3002003301, Technical Basis for Severe Accident Mitigating Strategies, 2015

[7] NUREG-2206, Technical Basis for Containment Protection and Release Reduction Rulemaking for Boiling Water Reactors with Mark I and Mark II Containments, 2018.

[8] U.S. Nuclear Regulatory Commission, "State-of-the-Art Reactor Consequence Analyses (SOARCA) Report, NUREG-1935" Part 1, November 2012

For latent cancer fatalities, the model for Q_{LCF} is similar except that there is a different dose response model (the so-called linear dose response model) and the fatalities and population are extended to 10 miles for estimating the average individual risk in that zone. Since there are no dose thresholds for this health effect, there are always at least fractions of a latent cancer fatality calculated in each cell. The non-LWR standard includes reporting thresholds that eliminate reporting requirements if the latent cancer fatalities are below that which would result from background radiation during the release.

Acknowledgment
The author greatly appreciates the review and comments by my colleagues who are leading industry experts in severe accident analysis and Level 3 PRA. These include Jeff Gabor, Don Vanover, and Grant Teagarden at Jensen-Hughes and Keith Woodard, retired from PLG, who provided useful assistance and references for calculating QHO risk metrics. Grant and Keith are the current and former Chair of the ASME/ANS JCNRM Working Group responsible for the Level 3 PRA standard, respectively. The technical requirements in the non-LWR PRA standard for radiological consequence analysis are taken from and are in alignment with those in the Level 3 PRA standard.