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Fission Yield and Criticality Excursion Code

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The ANSI/ANS 8.3 standard[1] allows a maximum yield not to exceed 2x 10^{19} fissions to calculate requiring the alarm system to be effective. It is common practice to use this allowance or to develop some other yield based on past criticality accident history or excursion experiments. The literature on the subject of yields discusses maximum yields larger and somewhat smaller than the ANS 8.3 permissive value. The ability to model criticality excursions and vary the various parameters to determine a credible maximum yield for operational specific cases has been available for some time but is not in common use by criticality safety specialists. The topic of yields for various solution, metal, oxide powders, etc. in various geometry's and containers has been published[2,3,4,5,6,7] by laboratory specialists or university staff and students for many decades but have not been available to practitioners.

The need for best-estimate calculations of fission yields with a well-validated criticality excursion code has long been recognized[18]. But no coordinated effort has been made so far to develop a generalized and well-validated excursion code for different types of systems·. In this paper, the current practices to estimate fission yields are summarized along with its shortcomings for the 12-Rad zone (at SRS) and Criticality Alarm System (CAS). calculations. Finally the need for a user-friendly excursion code is reemphasized.

Current Practice

Fission yield data from all of 22 process related criticality accidents (1 from Japan, 1 from UK, 7 from USA and 13 from Russia/USSR)[8,9] are available. In addition thirty-three (33) reactor and critical experiment related accidents were also reported[8]. Every one gives an estimate of total fission yield with varying degrees of uncertainty, whereas data for first fission spike, duration of events exist for most of them, but are less reliable. Most of the process related accidents are from solution systems, systematic excursion data were generated in the KEWB[10], CRAC[11] and SILENE[12] and SHIVA[13] series of experiments. Empirical formulae were developed by Olsen[14], Tuck[15], Barbry[16], and Nomura[17] to estimate bounding fission yields (maximum credible accidents) from the available the accident/experimental data for solution accidents based on system volume and duration of accident. The total number of fissions occurred under different accident conditions ranged from ~ 10^{15} to about $4x10^{19}$. In addition, the time duration for the excursions also varied widely, from seconds to ~ 37 hours.

The fission yield for source term estimation is generally determined by correlating a particular facility scenario with closest available experimental or accident data and then selecting the best possible fission yield value by engineering judgement. Occasionally the solution excursion formulae are used to correlate fission yield with system volume. On many occasions, lower but still conservative fission yields values like $2x10^{18}$, $1x10^{18}$, $5x10^{17}$ were justified and used in many 12-Rad zone estimation.

But the problem comes when the facility demands more realistic best estimate calculations to improve operation flexibility or to minimize cost without jeopardizing safety. They often ask � "could you justify a lower number so that we do not have to put a shield to avoid 12-rad zone and save 1 million dollar, or give us a lower fission yield so that this room or that corridor is beyond the 12-rad zone boundary and this improves operation". There is most likely sufficient conservatism in a gross approximation like 10^{18} in many situations. The same number of experimental and accident data point are used to justify all kinds of accident scenarios. The more conservative yield values are used, because we can not calculate the best estimate fission yield value without a well-validated criticality excursion code. We often extend the areas of applicability to a great length because of lack of suitable accident data. For example, how far you want to go with CRAC data based on highly enriched uranium to justify a low enriched uranium solution excursion, where the Doppler reactivity feedback is quite prominent. The other question is whether to consider the fission yield from the first spike or the total fission yield. It is very conservative to consider the total fission yield in some situation where the pulse duration is quite large. But how far one can extrapolate the CRAC data to use only the first burst yield in calculating the 12-Rad zone based on engineering judgment. The need to develop a capability for determination of yields where the approximate methodology may not be conservative for some system like the damped power excursion is even stronger.

The following example illustrates another need for a better estimation of fission yields.

CAS Placement Calculation

Knowledge of fission yield (indirectly) is needed in the CAS placement calculation. Of course, we all have a methodology to do CAS study where the minimum accident of concern is taken from ANS 8.3, i.e. a dose rate of 20 rad/min at 2 meters from the source. This corresponds roughly to a fission rate of 10^{15} per minute. This dose rate was based on a consensus and derived from the CRAC slow excursion experiment. It is also added in ANS 8.3 that "the basis of a different minimum accident of concern shall be documented. Concern was already documented[19] that this minimum accident dose rate may be too high, because long period excursions may not be covered by the standard. In other cases of large volume, the minimum accident of concern (~ 10^{15} fissions) may be too low. This is a potential area where an excursion code could become handy.

Summary and Conclusion

With the recent event at Tokaimura, the current status of the fission yield estimation has been critically examined. The following key questions should be addressed to reduce the gross approximations in fission yield estimation:

1. Even though the current practice of defining a maximum credible fission yield is sufficient for most occasions, a real need to develop a well-validated excursion code to obtain a best-estimate fission yield is recognized. Evaluations based on engineering judgement (using the accident and experimental data point) have reached their potential limits.
2. A need to compile all Crac, Silene, Shiva and KEWB excursion experiment data as part of the International Handbook of Evaluated Criticality Safety Benchmark has been recognized. New excursion experiments to substantiate the existing data should be identified.
3. The different mechanisms from solids and solution excursions were well understood and well documented. The mechanism for powder excursions was not widely studied.
4. An ever-increasing demand by the facility to reduce the fission yield number for the 12-Rad zone calculation for more flexibility of the facility operation is recognized.
5. In the other case of CAS, a higher fission yield, if justified, will minimize the cost of CAS installation.
6. The maximum fission yield number from the ANS 8.3 standard should be studied to determine if the value is excessive or not sufficient for the general application.
7. The question of using first burst fission yield number or the total yield number should be further evaluated using an analytic method to recommend the best approach to assure safety.

It is important for operators of nuclear facilities to have a good understanding of the hazards of working with fissionable materials, particularly with their application. The possible yield of specific criticality accidents is important in particular. Criticality safety staff at nuclear facilities should be able to advise on design details of equipment which would reduce the yield of a hypothetical criticality accident. They should be able to assure that criticality alarm systems detector and alarm generators are appropriate to assure that those in danger of excessive radiation dose from an accident are warned so they can take appropriate action. They should have the choice of deploying a system that is not excessively conservative or significantly non-conservative. Criticality safety staffs are handicapped by the lack of strong analytical tools, generally available and centrally maintained in order to provide these safety services to nuclear facility operators. Now is the time to start a well-coordinated development of a user-friendly and well-validated criticality excursion code.

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