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CRITICALITY ACCIDENT ALARM SYSTEM

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ABSTRACT

The American National Standard ANSI/ANS-8.3-1986, Criticality Accident Alarm System [1], provides guidance for the establishment and maintenance of an alarm system to initiate personnel evacuation in the event of inadvertent criticality. In addition to identifying the physical features of the components of the system, the characteristics of accidents of concern are carefully delineated. Unfortunately, this ANSI Standard has led to considerable confusion in interpretation, and there is evidence that the "minimum accident of concern" may not be appropriate. Furthermore, although intended as a guide, the provisions of the standard are being rigorously applied, sometimes with interpretations that are not consistent. Although the standard is clear in the use of absorbed dose in free air of 20 rad, at least one installation has interpreted the requirement to apply to dose in soft tissue. The standard is also clear in specifying the response to both neutrons and gamma rays. An assembly of uranyl fluoride enriched to 5% ^{235}U was operated to simulate a potential accident. The dose, delivered in a free run excursion 2 m from the surface of the vessel, was greater than 500 rad, without ever exceeding a rate of 20 rad/min, which is the set point for activating an alarm that meets the standard. The presence of an alarm system would not have prevented any of the five major accidents [2] in chemical operations nor is it absolutely certain that the alarms were solely responsible for reducing personnel exposures following the accident. Nevertheless, criticality alarm systems are now the subject of great effort and expense.

INTRODUCTION

There are two types of safety-related equipment for use by personnel: the first is effective in preventing injury from occurring; the second is effective in documenting injury to aid in treatment or to mitigate the effects of subsequent litigation.

Safety shoes are effective in reducing injury to the feet. Safety glasses have a demonstrated record of preventing injury to the eyes. Seat belts for automobiles are recognized for saving lives in accidents. Lead aprons and gloves for x-ray technicians have a beneficial impact on health by reducing the exposure to ionizing radiation. Radiation signs in the workplace serve as effective reminders in reducing radiation exposure. Guards on tools, belt protection for rotating machinery, and regulations that require floor-mounted machines be secured from upset contribute to safe operation. The stall-warning in aircraft reduces the possibility of an inadvertent stall. All of these are effective measures in preventing injury from occurring.

By contrast, personnel dosimeters have no impact on radiation exposure — they merely document some measure of that exposure. Material Safety Data Sheets (MSDS) do not prevent exposure to hazardous chemicals — they merely indicate the extent of the hazard. The warning placard for maximum airspeed allowed by structural considerations does not, of itself, prevent the pilot from exceeding that limitation. And unlike a guardrail, a line painted on the floor is merely a guide to assist in preventing incursions into a hazardous situation. These measures are simply tools in documenting injury.

All of the situations indicated above, and many more, are covered by regulations involving safety-related equipment or location and type of warning signs to ensure, to the fullest extent possible, protection of life and limb. However, the situation is considerably different for accidental criticality alarm systems. These systems do not prevent the accident from occurring, and they are generally not effective in documenting the extent of the accident. Nevertheless, they are subject to the same type of regulation and status in law as those things that are directly effective.

What follows is a criticism of several aspects of accidental criticality alarm systems and a suggestion to alleviate the concerns.

MINIMUM ACCIDENT OF CONCERN

Section 3 of ANSI/ANS-8.3-1986 defines the "minimum accident of concern" as "the smallest accident a criticality alarm system is required to detect." It is just a bit amusing that the smallest accident of concern bears no relationship to the potential consequences! Appendix A of the same document (not a part of the Standard by definition) goes on to elaborate on the characteristics of this non-accident. On the basis of "consideration of accident mechanisms," it is stated that the minimum accident is that "which will result in a dose of 20 rad in the first minute at a distance of 2 m from the reacting material." It further goes on to observe that "liberation of little energy over a long time would require control of such delicacy that it is not expected in process accidents."

Consider now the following scenario. A small leak develops in a pipe in a process tank and allows uranyl fluoride enriched to 5% in ^{235}U to collect — a drop of two at a time. By definition, this is not a carefully controlled process. In the absence of any sources except the weak alpha-n on fluorine from decay of uranium and the occasional cosmic ray, the system could become very slightly supercritical at near zero power. Indeed, this is just the scenario that was simulated with SHEBA [3]. The system was allowed to increase in power without human intervention or control. After about an hour, heating from fissions caused sufficient thermal expansion to render the system sub-critical. The peak power was about 1.5 kW (5×10^{13} fissions/s), resulting in a peak dose rate 2 m from the surface of the vessel of about 700 rad/h. However, the delivered dose was about 600 rads in free air! The peak dose rate never exceeded the 20 rads in one minute specified in the standard.

Although this example is hypothetical, at least one accidental criticality alarm system that had been actually emplaced failed completely to respond to this "accident" - hardly a consolation for someone receiving a L/D 50! It must also be pointed out that this excursion was far from violent. There was no blue flash; there was no boiling; and, except for the counters, there was no indication that an excursion was taking place.

Can anyone prove that an accident such as this has never taken place?

Can anyone prove that such an accident could not take place? The only consolation is that the consensus standard identifies this as an accident that is below the level of concern!

DETECTION CRITERION

Paragraph 5.6 of the standard states that "(T)he alarm signal shall activate promptly when the dose rate at the detectors equals or exceeds a value equivalent to 20 rad/min at 2 m from the reacting material."[1] Now, the rad is a very convenient and well-defined unit. It is defined as an energy deposition of 100 ergs/g, based on an ionization potential of 34.0 electron volts per ion pair. However, here the simplicity stops. At the distances in question, the fission process is accompanied by both gamma rays and neutrons. Interactions of both gamma rays and neutrons with air are energy dependent. However, the ANSI/ANS-8.3-1986 does not address either the neutron/gamma ratio or the spectra. Relegated to Appendix B (not a part of the Standard) is that a neutron-to-gamma-ray dose ratio of 12 is assumed for an unmoderated metal assembly. By contrast, the ratio for a moderated assembly is 0.3. Throughout the Department of Energy (DOE) complex, contractors have been held to quality control on the instrumentation for detection of accidental criticality. Accurate measurements of neutron and gamma-ray response are made, sometimes at great expense. In fact, on occasion, accurate measurements are required, and instruments are rejected because they fail the 20 rad/min equivalency test by a few percentage points.

COVERAGE

Paragraph 4.2.1 of ANSI/ANS-8.3-1986 states that "(T)he need for criticality alarm systems shall be evaluated for all activities in which the inventory of fissionable materials in individual unrelated areas exceeds 700 g of ^{235}U, 520 g of ^{233}U, or 450 g of ^{239}Pu or 450 g of any combination of these three isotopes."[1] This is both reasonable and proper. The guideline is clear, and the results of the intelligent evaluation determine whether or not an expensive system need be installed. However, the approach of United States Department of Energy Regulators was to paraphrase in DOE Order 5480.5 the statement from the standard as, "Criticality alarm systems shall be required for all activities in which the inventory of fissionable materials in individual unrelated areas exceed 700 g of ^{235}U, 520 g of ^{233}U, or 450 g of ^{239}Pu or 450 g of any combination of these three isotopes." The difference is dramatic! Now the requirement no longer results from an evaluation of reduction of risk, but it is an absolute — and deviation is a violation of the law.

DETECTION

Thermal neutrons are easy to detect, and several accidental criticality alarm systems have been developed to utilize thermal neutrons. However, ANSI/ANS-8.3-1986 requires that the system be able to *infer* the neutron plus gamma-ray energy deposition rate in dry air 2 m from the reaction. For a large facility, the relationship between thermal neutron flux at detector locations and energy deposition in air from mixed neutron and gamma-ray fields may vary highly and may be most difficult to calculate. It may be quite appropriate to use thermal neutron detectors, but it is difficult to impossible to prove that such a system meets the requirements of the standard.

CONCLUSION

To justify the designation as a "standard," ANSI/ANS-8.3-1986 should be re-written to recognize the problems, specifically:

1. The minimum accident of concern should be defined on the basis of total dose delivered to those potentially exposed. One way to measure this total dose is a recording gamma-ray meter.

2. Rather than wrestle with an ill-defined neutron/gamma-ray ratio, the standard could be written about either. Little would be lost in accuracy, and nothing would be lost in safety, to specify the dose rate and delivered dose for gamma rays alone. The flux-to-dose conversions are well defined, and the spectra of gamma rays from fission and fission products really doesn't change that much for various systems. Finally, gamma rays are much easier to calculate in the complex geometries of processing plants.

3. The standard itself should contain a disclaimer to prevent well-intentioned, but poorly-informed, bureaucrats from incorporating changes. Specifically, the requirement for an evaluation of the need for a criticality alarm system is quite appropriate, particularly when coupled with the intelligent approach that systems shall be provided wherever it is deemed that they will result in a reduction in total risk, including the hazards that result from false alarms. It is entirely inappropriate to make the requirement for incorporation of a system an absolute independent of an evaluation of the risks and hazards.

REFERENCES

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