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TITLE SELF LIMITING FEATURES OF ACCIDENTAL CRITICALITY IN A SOLUTION SYSTEM

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SELF LIMITING FEATURES OF ACCIDENTAL CRITICALITY IN A SOLUTION SYSTEM

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ABSTRACT

Experience with the SHEBA solution critical assembly during validation testing of accidental criticality alarm detectors provided several insights into the character of potential accidental excursions. Two observations were of particular interest. First, it is nearly impossible to maintain a solution system, particularly one employing low-enrichment material, in a constant state. If super-critical, the system will heat up, expand (or form bubbles), return to a sub-critical state, and shut down of its own accord without going into short period oscillations. Second, a very slow change in the system could produce a long "pulse" resulting in lengthy exposures, a high dose, but a low dose rate. The experiments dramatically contradicted the popular contention that accidental criticality is characterized by a blue flash, a clap of thunder, and violent expulsion of material.

INTRODUCTION

The purpose of a criticality accident alarm system is, or should be, to reduce the risk associated with fissile material operations [1]. In order to fulfill this purpose, the accident alarm system must be carefully designed to promptly and accurately respond to the class of likely accidents while minimizing false alarms. The class of potential accidents will be addressed, and then the possible characteristics of such accidents will be described.

MAJOR RADIATION ACCIDENTS WORLDWIDE

The Radiation Emergency Assistance Center/Training Site (REAC/TS) at Oak Ridge Associated Universities [2] maintains a complete data base on serious radiation accidents throughout the world. "Major" radiation accidents include those which deliver 25 rads whole body to at least one of those exposed. The tabulation from the 1987 report is indicated on Table I. Of the 290 accidents included for the 43 year period, only 19 are defined as accidental "criticalities." These are further divided into 5 critical assemblies, 9 reactors, and 5 chemical operations. Results for all major radiation accidents are plotted as a histogram function of time in Fig. 1. As a first observation, the incidence of accidental criticalities is dwarfed by the other serious accidents.

TABLE I

MAJOR RADIATION ACCIDENTS: WORLDWIDE
1944-1987

CLASSIFICATION	NUMBER
CRITICALITIES	
Critical Assemblies	5
Reactors	9
Chemical Operations	5
RADIATION DEVICES	
Sealed Sources	128
X-Ray Devices	63
Accelerators	14
Radars	1
RADIOISOTOPES	
Transuranics	22
Tritium	3
Fission Products	15
Radium Spills	2
Diagnosis/Therapy	19
Other	4
TOTAL	290

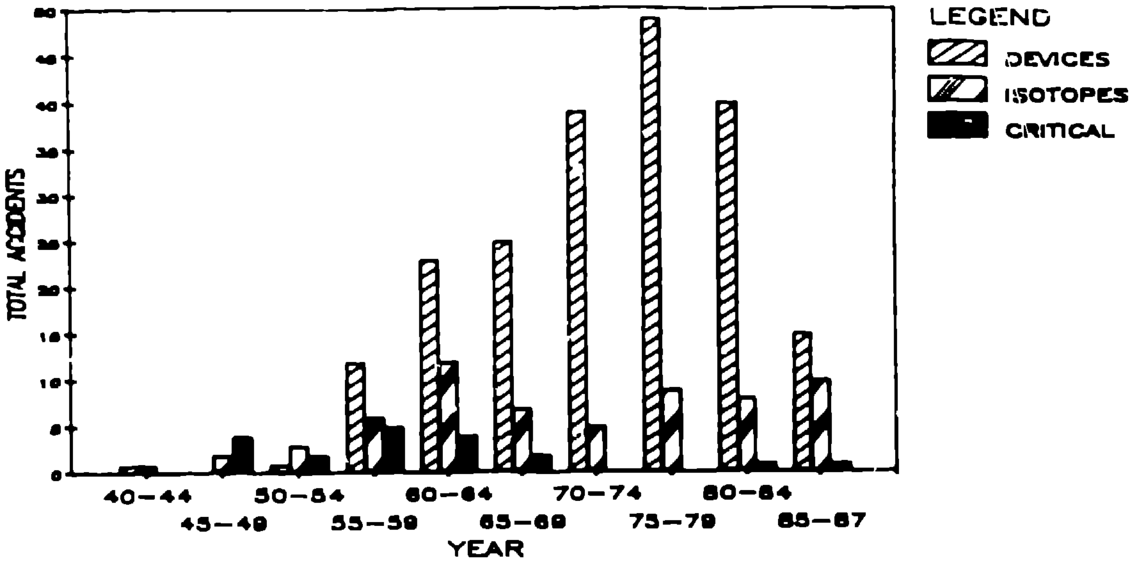

FIGURE 1
FREQUENCY DISTRIBUTION OF
MAJOR RADIATION ACCIDENTS (BY DEVICE)
WORLDWIDE: 1940-1987

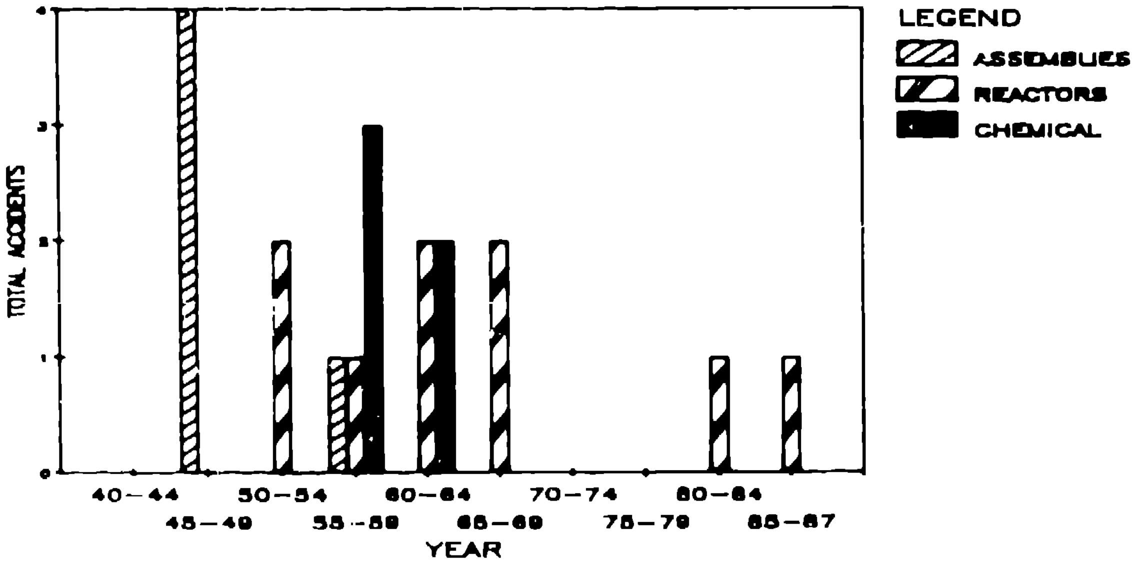

FIGURE 2
FREQUENCY DISTRIBUTION OF
MAJOR CRITICALITY ACCIDENTS (BY TYPE)
WORLDWIDE: 1940-1987

With information provided by Ann Sipe of the DOE/REAC/TS, these accidental criticalities are further broken down by time as indicated in Table 2, and as plotted on Fig. 2. As a second observation, the accidental criticalities are broadly grouped by time and type of accident. In the first 20 years, the dominant type of accident was in a critical assembly. Major accidents in chemical processes dominated the middle years, and major accidents in reactors generally dominate the later years. However, the scale of total accidents is hardly overwhelming:

at most five major accidents in a five year period (1955-1959);
only two major accidents in the last 21 years;
no major accidents in critical assemblies in the last 30 years;
eight of the last 14 major accidents in reactors;
and only one major accident in reactors in each of the last two five year periods.

TABLE 2

CHRONOLOGY OF MAJOR CRITICALITY ACCIDENTS

YEAR	LOCATION	TYPE
1945	*Los Alamos, USA*	*Critical Assembly*
1945	*Los Alamos, USA*	*Critical Assembly*
1945	*Los Alamos, USA*	*Critical Assembly*
1946	*Los Alamos, USA*	*Critical Assembly*
1952	Argonne, USA	Reactor
1953	Russia	Reactor
1958	**Oak Ridge, USA**	**Chemical Operation**
1958	Yugoslavia	Reactor
1958	**Los Alamos, USA**	**Chemical Operation**
1958	*Russia*	*Critical Assembly*
1959	**Idaho, USA**	**Chemical Operation**
1961	Washington, USA	Reactor
1962	**Hanford, USA**	**Chemical Operation**
1962	Puerto Rico	Reactor
1964	**Wood River, USA**	**Chemical Operation**
1965	France	Reactor
1965	Belgium	Reactor
1983	Argentina	Reactor
1986	Russia	Reactor

CHARACTERISTICS OF SOLUTION EXCURSIONS

The SHEBA Solution Critical Assembly [3,4] was designed to evaluate accidental criticality alarm detectors. In the experiments in the early 1980's, it became apparent that the behavior of SHEBA in some excursions completely contradicted the common lore of an accidental burst. At Los Alamos, we had accumulated a wealth of experience with bare metal fast burst machines. With initial reactivity of 6¢ ($0.06) above delay critical (DC), rapid expansion of the metal system would produce a "crack" like a rifle shot, the thump of the rugged stand on the concrete floor, and the tremendous stress of thermal expansion that could distort the steel clamps necessary to hold the system together. In a typical Godiva IV burst of 4x10exp16 fissions (~1 lb. of high explosive equivalent), 50 usec (peak width at half maximum), the temperature would increase about 250°C. Complete shutdown was effected by mechanical dissembly of the machine. Dose rates near the device exceeded 10exp8 rads/s, and the integrated dose at 2 m was likely to be 500 rads.

TABLE 3

COMPARISON OF TYPICAL BURSTS*

CHARACTERISTIC	GODIVA IV[a]	SHEBA[b]
Initial Period	0.00001 s	150 s
Peak Width at Half Maximum	0.00005 s	480 s
Typical Time To Peak (sourceless start)	2 s	3000 s
Initial Excess Reactivity (above DC)	$1.06	$0.05
Critical Mass (^{235}U)	65 kg	8.5 kg
Critical Volume	3½ liters	85 liters
Temperature Rise	~250° C	~4° C
Peak Power	100,000,000 kW	1.5 kW
Energy Release	1 MJ	1 MJ
Peak Dose Rate At 2 m	~10^8 rad/s	~800 rad/s
Integrated Dose At 2 m	~500 rad	~500 rad
Total Fissions[c]	~4×10^{16}	~4×10^{16}

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*Figures are given to illustrate differences for a characteristic burst—they are not precise for a specific burst

[a] Fast metal system

[b] Slow solution system

[c] Note that the total number of fissions and delivered dose are nearly equal in spite of several orders of magnitude difference in pertinent parameters.

SHEBA, however, was vastly different (Table 3). In fact, it became a challenge to run the "bursts" so slowly that accidental criticality alarm detectors designed to detect a fast transient could be spoofed into non-response. Control room operations during a typical slow "transient" had all the excitement of glacier watching. Whereas the burst of radiation from Godiva IV would blank part of one line in the raster of the T.V. monitor, the slow burst of SHEBA [5] (Table 4, Fig. 3) gave absolutely no indication that anything at all was happening. The real surprise was that shutdown, or quench of the reaction, resulted from temperature increases of the order of 2-3 degrees C. Expansion - infinitesimal. Although many predicted that the system would oscillate, there was absolutely no tendency to do so. Post analysis indicated that with only 2-3 degrees delta T between the solution and the outside air, coupled with differences of heat capacity between the two media, that the solution would probably evaporate before a recriticality would occur. Indeed, the characteristics of SHEBA were such that most any change to the system (including loss of moderator) would reduce reactivity. The only deviation from this conservatism was that SHEBA was the classical short fat cylinder - that is, free surface expansion would tend to produce a more favorable geometry.

TABLE 4

SLOW BURST CHARACTERISTICS OF SHEBA FOR THREE TYPICAL TRANSIENTS

Solution Volume ~85 liters
Solution Density ~2.16 kg/liter
Initial Temperature ~20°C

Excess Reactivity	\$0.114	\$0.082	\$ 0.066
Initial Period	80 s	122 s	160 s[a]
Peak Power	2.17 kW	1.51 kW	1.46 kW[a]
Peak Width, 1/2 Max	487 s	531 s	511 s[a]
Integrated Energy Release	1.27 MJ	0.98 MJ	0.90 MJ
Integrated Fissions	4×10^{16}	3×10^{16}	3×10^{16}
Peak Dose Rate, 2 m	~800 rad/hr	~550 rad/hr	~550 rad/hr
Integrated Dose, 2 m	~500 rad	~375 rad	375 rad
Temperature Increase	~4.8°C	~4.0°C	3.[illegible]°C

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[a] The long period case was affected by changes in room temperature during the course of the experiment. SHEBA was located in a metal weather enclosure that was not temperature controlled during the experiments.

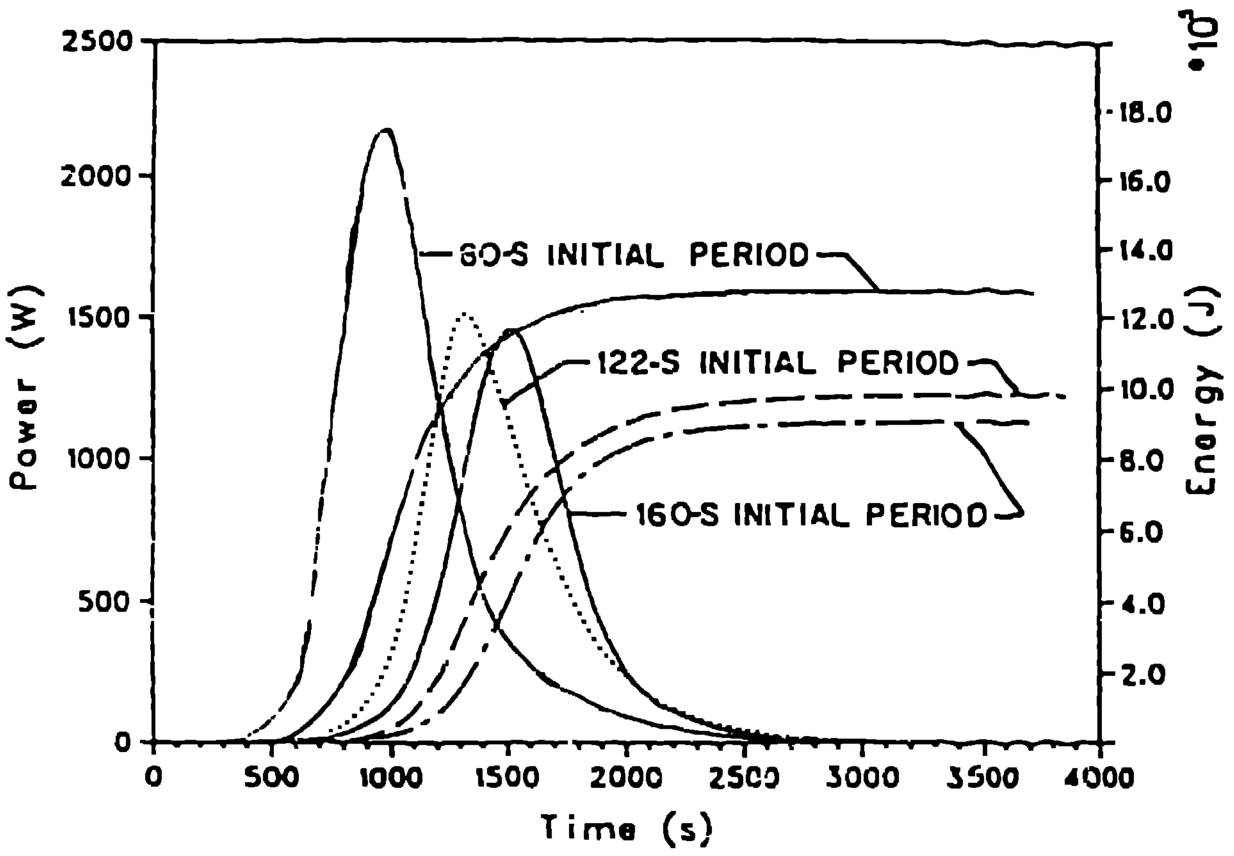

FIGURE 3

TIME VERSUS POWER AND INTEGRATED ENERGY RELEASE FOR THREE TRANSIENTS OF SHEBA

CONCLUSIONS

The conclusions to this discussion are not all new. Some are repeated from [4].

1. Is the general interpretation of the ANSI Standard adequate to ensure the intended response to an accidental criticality?

2. Are the concepts of accident scenarios sufficiently broad to include the class of slightly supercritical systems?

3. Could accidents similar to those simulated occur without detection?

4. Could accidents similar to those simulated occur without detection until routine dosimeter readout, and would the results of the dosimetry be dismissed as unlikely?

5. Does the recent incidence of major criticality accidents indicate too much concern for the problem?

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