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First Responders and Criticality Accidents

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INTRODUCTION

Nuclear criticality accident descriptions typically include, but do not focus on, information useful to first responders. [1] We studied these accidents, noting characteristics to help (1) first responders prepare for such an event and (2) emergency drill planners develop appropriate simulations for training. We also provide recommendations to help people prepare for such events in the future.

ACCIDENT SUMMARY

Table I summarizes accident characteristics based on a 60 accident review that neglects victim-specific information.

In addition to Table I observations, automatic alarms usually provided the first process accident indicator for people who were not very near or watching the source:

- Fourteen accidents occurred in areas covered by a criticality alarm system.
- Three accidents in well shielded areas, and one in a facility for which such accidents were deemed incredible, occurred in areas with radiation, but no criticality, alarm coverage.
- Three process accidents occurred in areas that lacked criticality and radiation alarms, presumably because criticality accidents were deemed incredible.
- One process accident occurred in a critical assembly area for which alarms are not described.

Criticality alarms are not required in reactor and critical assembly facilities because their systems usually achieve the critical state intentionally. These facilities have other instrumentation, but accident descriptions rarely include relevant alarms.

VICTIM SUMMARY

These 60 accidents resulted in 21 fatalities and 29 other people with acute radiation injury. All seriously exposed persons suffered acute radiation sickness. At least seven suffered permanent disabilities, including at least four with limb amputations.

We therefore studied 23 accidents (Table II) in depth, focusing on accidents that resulted in fatalities or significant physical injuries to exposed victims, from shortly before the critical excursion until the victim was taken offsite for treatment. With 11 process and 12 non-process events, the list includes all accidents that resulted in exposures of at least 1 Gy.

Table III summarizes observed characteristics.

RECOMMENDATIONS

- Anticipate the accident, but do not over-predict the scenario.
- Train and drill workers and responders well regarding criticality safety factors and controls, making observations, and executing protective measures.
- Prepare responders to gather and report observations.
- Prepare responders to deal with victims with a wide range of exposures and behaviors.
- Prepare responders to deal with incidental workers and, especially when the public is near facility boundaries, the *worried well*.
- Prepare workers and responders for initial reactions that range from precisely executed tasks to ordered confusion to chaos.
- Do not allow rescue or reconnaissance entries without absolute justification and good planning.
- Do not attempt to terminate or stabilize a critical system until the system is well understood and actions are well planned, staffed, and practiced.
- Implement ANSI/ANS-8.23 where appropriate. [2]

REFERENCES

1. T. P. MCLAUGHLIN, et. al., *A Review of Criticality Accidents*, LA-13638, Los Alamos National Laboratory, Los Alamos, New Mexico (2000). Including its references.
2. ANSI/ANS-8.23, *Nuclear Criticality Accident Emergency Planning and Response*, ANS (1997).

TABLE I. Numbers of Accidents with Observed Characteristics

Characteristic	Process Accidents	Non-Process Accidents	Total
Nuclear criticality accident	22	38	60
Public exposures ≥ 0.01 Sv	0	0	0
Worker exposures ≥ 0.01 Sv	18	17	35
Worker exposures ≥ 0.12 Gy	14	13	27
Worker exposures ~ ≥ 1.00 Gy	11	12	23
One or more fatalities	6	8	14
One-burst power history	5	35	40
Power history ≥ 5 minutes	≥ 15[a]	2 or 3[b]	≥ 17
Terminated by human intervention	≥ 8	≥ 6	≥ 14
Secondary burst due to unplanned response actions	2	0	2
Significant contamination locally/outside building/off-site	5 / 2 / 0	8 / 3 / 0	13 / 5 / 0
Significant industrial injuries incurred during response	0	1	1

(a) The longest history was terminated after about 37 hours in April 1962 in Hanford, WA USA.
(b) The longest history was terminated after about 158 hours in June 1997 in Sarov, Russia.

TABLE II. 23 Accidents Reviewed in Depth

Location and Year(s)	Fatal Exposures	Others ≥ 1 Gy	Others ≥ 0.01 Sv[a]	Location and Year(s)	Fatal Exposures	Others ≥ 1 Gy	Others ≥ 0.01 Sv[a]
Argonne, IL USA 1952	0	2	2	Mol, Belgium 1965	0	1	0
Arzamaz-16 / Sarov, Russia 1963, 1997	1	2	4 or 5	NRTS (SL-1), ID USA 1961	3[b]	0	22
Buenos Aires, Argentina, 1983	1	0	8	Oak Ridge (Y-12), TN USA 1958	0	5	3
Chelyabinsk-70, USSR 1968	2	0	0	Siberian Chem. Comp., USSR 1961, 1978	0	2	7
Hanford, WA USA 1962[b]	0	0	5	Tokaimura, Japan 1999	2	1	0
Kurchatov Institute, USSR 1971a, 1971b	2	4	2 or 3	Vinča, Yugoslavia 1958	1	5	0
Los Alamos, NM USA 1945, 1946, 1958	3	5	15	Wood River Junction, RI USA 1964	1	1	3
Mayak, USSR 1953, 1957, 1958, 1968	5	9	7				

(a) Includes worker exposures received during accident response, investigation, and cleanup.
(b) SL-1 fatalities were due to physical injuries, but radiation doses would have been fatal for all three victims without evacuation.

TABLE III. Additional Characteristics Noted in 23 Accidents

# of Accidents	*Initial Indicator of Serious Accident As Observed by Closest Worker(s)*
17 / 3	Reported/assumed to be self evident (light flash, heat, etc.)
2	Onset of illness
3	High radiation field detected (including radiation alarm) without criticality alarm
6	Criticality alarms immediately after (confirmed other indicators)
2	Other (dosimetry evaluation, ozone smell, etc.)
# of Accidents	*Serious-accident-recognition Rapidity by Closest Worker(s)[(a)] -/- Organizations*
17 / 2 -/- 8 / 6	Reported/assumed immediate (≤ 5 minutes after 1st achieving k_{eff} ≥ 1.0 during event)
1 / 0 -/- 2 / 2	Reported/assumed moderate (5 to 15 minutes)
1 / 0 -/- 3 / 1	Reported/assumed slow (> 15 minutes)
2 / 0 -/- 2 / 0	Identified by techniques that were not employed within 30 minutes of critical event
# of Accidents	*Methods initiated within 30 minutes to Quickly Identify Overexposed Workers*
2 / 1	^{24}Na in blood (quick-sort), reported/assumed
10	Behavior, illness, interviews
2	Other
8	Not identified in readily available accident descriptions
# of Accidents	*Consequences for Early Responders, Not Including Victims Acting As Responders*
1 / 0	Rescued victims with fatal/non-fatal exposures at the immediate scene
0 / 1	Received exposures over 0.01 Sv that were more/less than 1.00 Gy
# of Workers	*Exposures Due to 9 Accidents with ≥ 5 Minute Power History*
5 / 1	Fatal exposures among workers on/off-scene during initial critical state
17 / 1	Others, ≥ 1.00 Gy among workers on/off-scene during initial critical state
16 / 2	Others, ≥ 0.01 Sv among workers on or near/off-scene during initial critical state
# of Workers	*Radiation Sickness[(b)] for Fatal[(a)] / Non-fatal, ≥ ~1 Gy / about 0.12 to < ~1 Gy Exposures*
18 / 40 / 42	Relevant exposures (max. # if exposure statistics expressed in ranges)
3 / 0 / 0	Immediate (< 5 minutes) onset of illness
5 / 2 / 0	Rapid (5 to 30 minutes) onset of illness
2 / 1 / 0	Moderate (30 minutes to few hours) onset of illness
0 / 12 / 0	Slow (few hours to one day) onset of illness
0 / 3 / 0	Very slow (>1 day) onset of illness
0 / 0 / 21	No visible symptoms, apparently
8 / 22[(c)] / 21	Onset of illness or lack of symptoms not identified in readily available descriptions
# of Workers	*Behavior of Some Victims with ≥ ~1 Gy Exposure*
1 / 1	Incoherent almost immediately, but left immediate scene with/without assistance
56	Sufficiently coherent and ambulatory to evacuate and, if appropriate, shower
2	Collapsed completely within minutes
2	Denied presence at accident scene (anecdotal information)
≥ 8	Acted as responder or expert (e.g. provided reports, estimated doses, etc.)[(d)]
5	Altered evidence (e.g. attempt stabilization, hide guilt, etc.) before evacuation
1 / 1	Altered evidence during re-entry, leading to fatal / ≥ ~ 1Gy exposure
# of Workers	*Contamination in Addition to Irradiation While On-site*
7 / 2	Reported/assumed significantly contaminated personnel with ≥ ~ 1Gy exposure

(a) SL-1 victims are excluded because they died of physical injuries. By the time rescuers arrived, two victims were dead and the third was unconscious. However, all three had received fatal doses.

(b) It might be difficult to distinguish very mild or early radiation sickness from stress or anxiety because some of their readily observable symptoms (headache, nausea, feeling hot) are the same. In all cases, medical treatment was based on symptoms; dose estimates played little or no role. In the future, early information about relative distances from the source to major body parts might help physicians predict symptoms to assist in identifying and preparing for potentially useful treatments.

(c) No or very mild radiation sickness is specifically identified for five exposures of about 1 to 3 Gy.

(d) Victim actions and decisions were good in some cases, but, even then, a few decisions appear to have been questionable or bad. Victims are very stressed regardless of appearance.