Nuclear Criticality Accidents in the Workplace

Introduction

A self-sustaining nuclear reaction with fissionable material can occur in a nuclear reactor, an experimental laboratory, or in a nuclear fuel processing setting. The reactor has shielding and reactivity control mechanisms. A critical mass laboratory anticipates a self-sustaining reaction and has safety features. A self-sustaining nuclear reaction in the fuel processing cycle is unintended and is referred to as a nuclear criticality accident.

Background

Fissionable elements, primarily uranium and plutonium, are handled and processed, frequently on an industrial scale. This includes the manufacture of nuclear reactor fuel, chemical processing to concentrate, purify, or change their form for various industrial applications, and various defense-related activities. A prime consideration in the design, construction, and operation of industrial facilities to process these materials is the prevention of a nuclear criticality accident. However, accidents have happened.

Thirty-eight (38) nuclear criticality accidents have been reported in experiments that were intended to achieve nuclear criticality but behaved unexpectedly or involved human error. Twenty-two (22) nuclear criticality accidents have been documented which involved process operations in the workplace where there were no design features present to either decrease the likelihood of an accident or to protect people from the radiation produced. The number of fission events from these accidents has ranged from about 10^{15} to about 10^{19}.

All of the process related nuclear criticality accidents involved unintended accumulation of an excessive amount of special nuclear material. Of these accidents, 21 involved solutions or mixtures of enriched uranium or plutonium compounds with water or organic chemicals and one involved plutonium metal. That the majority of the process accidents involved solutions or mixtures of special nuclear materials with water or organic chemicals is not surprising. When fissile material is mixed with a liquid or in solution, the amount necessary for nuclear criticality is substantially reduced. Handling and controlling liquids are relatively more difficult than controlling solid materials because liquids tend to leak, flow, extract or migrate to unexpected locations that could provide an unfavorable geometry that can support a self-sustaining chain reaction.

Discussion

A criticality accident is an uncontrolled, self-sustaining nuclear chain reaction in a fissionable material such as uranium or plutonium. An accident of 10^{17} fissions will result in a large and fatal radiation release of some 20,000 Rads (200 Gray) at one foot away. Harmful radiation effects have been limited to those in the immediate vicinity of the accident. A criticality accident will generally not result in adverse health effects to surrounding buildings or residents.

Since the first reported industrial nuclear criticality accident in 1953, the consequences to people have included 9 reported fatalities and significant radiation exposure to at least 36 people. The fatalities occurred to personnel who were located within about a meter of the accidents. Significant but not fatal radiation exposures affected personnel located within about 5 meters from the accident.

Physical damage to property and processing/manufacturing equipment from nuclear criticality accidents has been negligible. In most cases, equipment in which an accident has occurred has been reusable after modest or no radioactive material cleanup. Business and mission interruption from such nuclear criticality accidents has varied depending upon the site and the date of occurrence. In the early days, facilities were restarted after minimal interruption for investigation and cleanup activities. In later times facilities were completely replaced with new ones that incorporated design features to decrease the likelihood of having a nuclear criticality accident. Since the mid-1970's, the occurrence of a nuclear criticality accident has caused long shutdowns of industrial facilities for investigation and remediation. In some instances, affected facilities have been permanently shut down.

The last nuclear criticality accident in the U.S. occurred in 1978 and globally the last reported accident was in 1999. A number of actions contributed to the dramatic reduction in frequency of such accidents. These include the use of the ANS-8 series of nuclear criticality safety standards, the use of more rigorous hazard assessment methods, more robust design features, the community sharing of lessons learned and good practices, enhanced oversight, promoting a healthy questioning attitude and more formal documented conduct of operations programs.

Conclusion

Descriptions of the known nuclear criticality accidents appear in publicly available literature. A useful report is LA-13638, “A Review of Criticality Accidents - 2000 Revision” by a team of United States and Russian Federation authors. Section IC discusses lessons learned.
https://ncsp.llnl.gov/LA13638/reports/000.la-13638.pdf.