REFLECTIONS ON THE 1978 ICPP CRITICALITY ACCIDENT

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Abstract

The criticality accident on October 17, 1978 is described, including the contributing events and issues. The location of the event was a solvent extraction process and the system is described along with the prior safety analysis. The operational situation at the time of the event is discussed as well as the progression of the accident. The plant evacuation is described and the reentry and recovery issues are provided. The major contributors to the event occurring and the principles learned are recounted. Subsequent plant operations are discussed.

Introduction

On October 17, 1978, the last criticality excursion in a U. S. fuel cycle facility occurred in a 2-foot diameter lower disengaging head of a scrub column which was part of the Idaho Chemical Processing Plant (ICPP) tributyl phosphate (TBP) first cycle uranium extraction system[1]. The ICPP was located within the Idaho National Energy Laboratory near Idaho Falls, Idaho.

First Cycle Process and Safety Analysis

The feed to the first cycle system is from several nuclear fuel head end dissolution systems in the form of an aqueous uranyl nitrate solution and is processed in four counter current pulse columns. In the first or extraction column, the uranyl nitrate is contacted with TBP in a kerosene diluent and the uranium passes from the aqueous to the organic phase. The organic stream proceeds to the bottom of scrub column (H-100) where the uranium laden organic is scrubbed of nitric acid and more fission products, which are removed, by the aqueous stream. The uranium largely stays in the organic stream because the aqueous phase is salted with aluminum nitrate. As some uranium is inevitably removed, the relatively low flow rate of the aqueous stream is recycled and combined with the feed to the first column. The uranium rich organic stream is then fed to the strip column where the uranium is stripped into a non salted weak nitric acid stream. The aqueous stream is then washed of remaining organic in the fourth column.

The equipment diameter of the four columns was ten, eight, nine and four inches respectively, with lower disengaging heads of twenty-four, twenty-four, nine and nine inches respectively, and upper disengaging heads of twenty-four, twenty-four, twenty-four and eight inches respectively. While separation columns were designed to be geometrically favorable, the disengaging heads for the first three columns were not geometrically favorable, therefore relying on concentration control for criticality safety. If uranium is inadvertently removed in the scrub column raffinate, concentrations of uranium in the first and second columns will increase due to the recycle of scrub column raffinate to the first column feed. If the columns are not returned to the proper operating points, eventually the concentration will increase until the most geometrically unfavorable part of the system becomes critical.

The safety analysis of record for the first cycle noted the vulnerability to the salting level of the aqueous scrub stream and a requirement of two engineered safety features, and two administrative controls was affirmed to assure an adequate aluminum nitrate concentration. The engineered features were chemical industry standard density recorders and alarms on the scrub solution makeup tank (PM-106) and downstream feed tank (PM-107). The administrative controls were requirements for the solution makeup and sampling before transfer from the makeup to the feed tank. There were no particularly rigorous design or configuration management standards applied at the time to these instruments.

Description of Incident

The scrub solution makeup tank had several inlet lines, including a demineralized water source and a line for process chemicals such as aluminum nitrate. For a month before the October 17 incident, the demineralized water line isolation valve had been leaking. On September 15, the aluminum nitrate concentration had been 0.7 Molar, within the controlled range of 0.75 ± 0.05 M. On September 27 the concentration was 0.47 M and by October 17 was 0.08 M. With this ten-fold decrease in salting strength, the uranium increased from 0.32 g/liter to over 21 g/liter in the scrub column raffinate. At this concentration, the bottom head concentration was high enough to support criticality. The concentration had been increasing gradually for weeks and by the time the plant radiation monitors detected the fission

[1]"ICPP Criticality Event of October 17, 1978", <u>NUCLEAR SAFETY, Vol. 21, no. 5</u>, September-October 1980

product gases from the critical system, the system was on a stable increasing period of 0.6 hours. This is the equivalent of 0.6 cents excess reactivity or a k_{eff} of 1.00004. Additional uranium stripped into the aqueous phase of the scrub column adding to the reactivity of the system which offset negative reactivity resulting from temperature, fission product poisons, and small bubbles.

The operator noticed the pressure buildup in the system and reduced the pressure on the aqueous outlet leg. A quantity (some 10 to 20 liters) of solution exited the outlet leg and uranium rich material in the column entered the lower disengaging head of the scrub column increasing the uranium concentration in a near step change of one to two grams per liter. If the additional solution entered the head as a ten-liter cylinder with one g/l more uranium than the displaced solution, then the system would have been just supercritical with a very short period. Although the specific numbers are conjecture, the radiation detectors which recorded the fission product gases traveling the system off-gas lines recorded a sharp spike which could have been from a fission energy spike of a fraction of a second to several seconds. The increased energy release in the spike would have generated gas and a resulting pressure surge ejecting uranium solution out the raffinate recycle line of the lower disengaging head. The additional mixing with the lower concentration solution from the upper part of the central column may have caused the system to become subcritical. The first cycle feed had been turned off before the personnel evacuation so the situation did not get worse, but the "shutdown margin" would have been small.

Situation Prior to Incident

The facility operated in a campaign mode and was in the midst of a program to reprocess 500 kgs of high enriched uranium in zirconium based fuel. On September 14, 1978, the eighth batch of scrub solution was prepared. The aluminum nitrate makeup tank level and density recorders showed a continuous liquid level rise of some 1% per day and a corresponding density decrease. The chart paper for this tank ran out on September 19 (and was not replaced) and indicated at that time that 80% of the content had been used to refill the feed tank.

Also on September 19 the campaign was shutdown due to process upsets. A faulty level instrument for the first cycle evaporator was replaced and the process restarted on October 13. On October 17, the last transfer from the aluminum nitrate makeup tank to feed tank took place.

The density recorder and alarm for the aluminum nitrate feed tank had been determined necessary in studies in support of the Safety Review Document for the first cycle process and a Maintenance Job Release (MJR) had been approved in September of 1976. The MJR had initiated a change in the plant process drawings, but the work itself was still pending in October of 1978. The safety studies for this highly radioactive process were based on plant drawings.

The plant off-gas system collected vessel off gas from a variety of processes and vented through a HEPA filter bank to a tall stack. The atmospheric conditions favored an inversion and the fission gases settled toward the ground. The process makeup area was in a non airtight structure above the process building.

Plant Evacuation

A radiation area alarm sounded in the process makeup area at 8:40 p.m. In short order, other alarms sounded around the plant. Plant staff took portable radiation instruments outside the process building and detected radiation fields up to 100 millirem from the facility to the plant gate. The health physics supervisor and the operations manager agreed on an evacuation of the process facility and at 9:03 p.m. the evacuation alarm was sounded. The plant staff reported to the guardhouse and the construction workers reported to the more distant Central Facility. The source of the radiation was unknown at first. Various

reentry teams collected data such as strip charts and stack filter samples. An analysis of the stack filter showed short lived fission particles, which confirmed a criticality accident.

Recovery Planning

Author Wilson was the ICPP Criticality Safety Manager and was informed of the apparent criticality incident through a late night phone call from the ICPP safety manager. As the current campaign was the first cycle extraction system, he reviewed the safety analysis for this process for clues for what might have happened. At the time, the criticality engineers and the control development process focused largely on the physics of control parameters rather than scenario development, but the array of engineered and administrative controls for the first cycle system appeared robust. When he arrived at the plant the incident command post was in the cafeteria building, several hundred feet from the main process building.

The process had remote sampling capability, so samples of various streams were taken and chart recordings from the operations corridor were evaluated. It was determined that the process parameters were well outside controlled boundaries but the event's specific location was unknown. The criticality safety staff modeled with a three dimensional Monte-Carlo commuter code (KENO) several of the process columns with the sketchy process data to assist the discovery process. A radiation instrument lowered into the cell later confirmed the scrub column as the location of the criticality event. This action had not been well reviewed as the column would have been just slightly subcritical at the time, but the additional reflection did not cause a recriticality.

The recovery plan was to add boric acid solution to the column until the solution could be drained into a down stream large diameter tank without causing another criticality event. The plans were developed using the complete administrative system for documentation, review and approval. The criticality safety staff supported the effort with computer calculations to show the safety margins of the various approaches. A neutron detector was lowered into the process cell to provide quicker indications of a possible additional excursion than stack monitors.

Part of the organic layer in the upper disengaging head was drawn off through sample lines and boric acid solution with a tag of lithium was added through the same path. More boric acid solution with a tag of cadmium nitrate was added to the lower disengaging head through sample lines. The column was mixed by air from bubbler probes associated with the installed column instrumentation. Samples of the resultant aqueous stream later showed good mixing of the tag lithium and cadmium throughout the column, and with assurance of a well poisoned vessel, the column was safely drained.

Observations and Lessons Learned

The significant contributors to the accident are listed below along with an associated lesson in italics.

- The aluminum nitrate feed tank density recorder and alarm were not installed even though it appeared on the plant's controlled drawings.
  Strong configuration control of safety related equipment and consistency between the plant and safety analysis documents is important for a safe plant.
- The operating procedure which required sampling before transfer between the aluminum nitrate makeup and feed tanks was not followed and the procedure actually used in the process makeup area was a much older version without the requirement.
  Procedural compliance and a functioning work control document system are important safety elements.
- Significantly more solution was transferred from the makeup tank to the feed tank than was made up. The chart paper for the safety related density recorder was not replaced.

Inquisitiveness of the plant staff to apparently obvious abnormal conditions is mandatory for safe operations. Clear identification of safety related equipment is essential as is surveillance and maintenance of that equipment.

- In the two years preceding the incident, the experience level of the operators decreased dramatically.
  When operator experience is significantly reduced, training and oversight must increase commensurately.
- The safety analysis prepared in 1974 identified the criticality risk if the aluminum nitrate scrub feed were to become dilute, but incorrectly assumed that stoppage of the scrub feed was also necessary. The Criticality Safety Evaluation process had been excessively focused on the physics of subcriticality and not on risk assessment.
  A comprehensive determination of failure scenarios is necessary to assure development of adequate controls.
- Operator actions to be taken in the event of low scrub flow had not been defined.
  Predetermined operator response to abnormal conditions should be developed.

Aftermath

The plant was shutdown for two years. Before startup, the criticality control system was extensively changed. The formalism of Technical Standards was adopted with the specification for each controlled parameter of Failure Limits, Safety Limits, Limiting Conditions For Operation, and Limiting Control Settings. In this formalism, detailed operational controls were developed along with a QA system to assure continuing effectiveness. An automatically actuated plant protection system was added to the first cycle extraction system. This system employed the concepts of diversity and redundancy to the extent possible. Multiple sensors for pH, conductivity, flow, density, etc. were employed to reduce the possibility of chemical process conditions exceeding analyzed conditions. An increase in operator training and conduct of operations emphasis characterized restart operations. A focus on criticality accident scenario development was institutionalized. These program changes had a dramatic and positive effect on the safety of operations.