Nuclear Criticality Safety Controls for Uranium Deposits During D&D at the Oak Ridge Gaseous Diffusion Plant

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INTRODUCTION

The U.S. Department of Energy (DOE) Deputy Assistant Secretary of Energy for Environmental Management has issued a challenge to complete DOE environmental cleanup within a decade. The response for Oak Ridge facilities is in accordance with the DOE ten-year plan which calls for completion of >95% of environmental management work by the year 2006. This will result in a 99% risk reduction and in a significant savings in baseline costs in waste management (legacy waste); remedial action (groundwater, soil, etc.); and decontamination and decommissioning (D&D). It is assumed that there will be long-term institutional control of cascade equipment, i.e., there will be no walk away from sites, and that there will be firm radioactivity release limits by 1999 for recycle metals. An integral part of these plans is the removal of uranium deposits which pose nuclear criticality safety concerns in the shut down of the Oak Ridge Gaseous Diffusion Plant.

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The Oak Ridge Gaseous Diffusion Plant, now known as the K-25 Site, began construction during World War II. The plant took natural (0.711% $^{235}\text{U}$) uranium hexafluoride ($\text{UF}_6$) gas as feed and processed it into both low-enriched uranium (LEU) and high-enriched uranium (HEU) with enrichments up to $-93%$ $^{235}\text{U}$. HEU production was discontinued in 1964 when the K-25 building was shutdown. LEU operations in other buildings ended in 1985. During operation, in-leakage of humid air into process piping and equipment caused reactions with $\text{UF}_6$ gas that produced nonvolatile uranyl fluoride ($\text{UO}_2\text{F}_2$) deposits. After shutdown, the volatile $\text{UF}_6$ was evacuated but the $\text{UO}_2\text{F}_2$ deposits remained.

DOE has initiated the Nuclear Criticality Stabilization Program to improve nuclear criticality safety by removing the larger uranium deposits from unfavorable geometry equipment. Nondestructive assay (NDA) measurements have identified the location of these deposits. Figure 1 shows the relationship of these larger deposits at two levels of hydrogen moderation, optimum mass moderation, and at moderation conditions corresponding to equilibrium exposure to air, an $\text{H}/\text{U} = 4$. Some deposits contain several minimum critical masses, even at dry (i.e., at $\text{H}/\text{U} = 4$) conditions (Ref. 1). The curves in Fig. 1 were calculated at optimum geometry (sphere) and fully water reflection conditions.

**DESCRIPTION OF THE INCENTIVE TASK ORDER (ITO) PROCESS**

An ITO is the contractual authorization basis for the Nuclear Criticality Stabilization Program with deposits being removed either by the prime contractor, Lockheed Martin Energy Systems, or by subcontractors using a bidding process. DOE, as part of contract reform, has implemented a task order contract for the Nuclear Criticality Stabilization Program. ITOs enable profit to be based on incentives instead of award fees. The contractor, Lockheed Martin Energy Systems, takes increased risk and accountability, but not more liability. There is a definitive structure for earning the fee. The ITO bounds scope and work requirements. The ITO concept was developed to improve task execution through better scope definition, task-specific requirements identification, thorough cost estimating, elimination of management/oversight duplication, and using incentives to motivate the team to achieve cost/schedule savings throughout the life of the ITO.

**CONTROLS DURING PLANT OPERATION**

The double contingency principle is the primary methodology used to accomplish nuclear criticality safety. This principle requires that at least two independent, unlikely, and concurrent changes in process conditions occur before nuclear criticality is possible. In an operating gaseous diffusion cascade, the two
independent controls are maintaining the UF₆ in the gas phase and moderation control. Mass, although not directly controlled, was limited by maintaining the UF₆ in a gas phase. Although the cascade equipment is not geometrically safe, as long as the UF₆ was in the gas phase, the equipment was adequately subcritical due to the low uranium density. When there was moist air in-leakage into the system, the gaseous UF₆ reacted with the moisture and the nonvolatile uranium reaction products compounds deposited onto surfaces near the leak. Therefore, even in the early days of gaseous diffusion plant operation, there were cascade equipment monitoring programs for indications of deposits in equipment. When significant deposits were detected, they were removed. Moderation control was achieved using both passive engineered features and administrative controls. At least two boundaries were required between liquid moderators and the process gas system; system integrity was the only barrier to wet air in-leakage. As long as UF₆ gas was present at a deposit location, any moisture present in wet air in-leakage reacted with the UF₆ instead of moderating the deposit. The gas phase hydrogen fluoride (HF) generated from the reaction was swept away with the process gas. When equipment suspected of containing a deposit was removed from service, the openings were covered and a nitrogen or dry air buffer was provided to prevent absorption of water from the air.

Mass considerations and moderation control are now used for the double contingency evaluation of the shutdown K-25 gaseous diffusion plant. For most of the equipment, NDA estimates of the mass have indicated that it can be considered unlikely that sufficient mass is present for nuclear criticality in individual equipment items. When NDA estimates indicate that there is a deposit greater than a safe mass, mass control is considered to have been lost. In these cases, moderation control and random factors such as the actual geometry of the deposit inside the unsafe geometry equipment are preventing nuclear criticality. Moderation control has been lost, at least to the extent that the deposits have been exposed for long periods of time to humid air. The assumption is made that deposits in the equipment have been moderated to an H/U = 4. Moderation control for shut down equipment is based on preventing additional moderation to the deposits by covering openings and controlling known sources of water and oil.

The deposits, as they presently exist, are the result of ongoing, abnormal conditions of operation and do not meet a strict interpretation of the double contingency principle. Many uranium deposits at the K-25 Site exceed a minimum critical mass and are contained in unfavorable geometry. The deposits are not characterized for shape, chemical composition, hydrogen content, etc. Random factors of safety deter a nuclear criticality safety event. A change in moderation or geometric configuration, for example, could result in criticality in their present condition. Administrative controls are present to prevent changes in moderation and geometry (i.e., masses of uranium coming together to form a larger volume) to maintain an acceptable level of nuclear safety.
CONTROLS WHILE AWAITING DEPOSIT REMOVAL

Several interim measures have been taken to lessen the likelihood of nuclear criticality while deposits are waiting to be removed. These include using administrative controls to limit building access, closing process equipment openings, isolating deposits by closing valves or installing welded partitions, NDA monitoring of the deposits to assure that the deposit configuration has not changed (i.e., the deposits have not moved or combined), and inspecting the roof for leaks and inspecting for other sources of liquid. There is a range of risk of nuclear criticality for the deposits, as shown in Fig. 1—LEU deposits whose exposure to air (H/U = 4) might result in criticality are a higher risk than those deposits which must be in solution. The high enriched uranium (HEU) deposits must have enough moderation to form a solution to achieve nuclear critical conditions at the masses and geometry present in the cascade equipment. Thus, considerable effort has been directed at assuring that the equipment in the K-25 Building, where the HEU deposits are located, is closed and isolated from sources of liquid. Deposits readily go into solution when mixed with water. Also, deposits can become liquid, through a process known as deliquescence, when exposed to moist air flow (Ref. 2). Thus, it is also important to keep equipment closed to air flow. Calculations have shown (Ref. 3) that some dry LEU deposits could become critical if they completely fill the equipment they occupy. As noted in the introduction, deposits are hygroscopic and absorb moisture from air. The equilibrium level of hydration (H/U = 4) is near optimum mass moderation conditions for LEU. Thus, it is important to prevent access to air for some of the largest LEU deposits.

CONTROLS DURING DEPOSIT REMOVAL

Since, by definition, the objective of the K-25 Site Nuclear Criticality Stabilization Program is the removal of relatively large masses of $^{235}\text{U}$, fissile mass control must be re-established. Therefore, in addition to the controls identified in the preceding paragraph, the single most important control for deposits in unfavorable geometry equipment is the control of addition of bulk moderators. To accomplish moderation control, prior to deposit removal, the target cascade equipment is tested for any free-standing liquid by drilling holes at the lowest point and seeing if any liquid flows out. When equipment is open during deposit removal, moderation control is maintained by disabling the fire sprinkler system or placing a non-combustible barrier above cascade equipment openings to shed overhead water. Openings are covered, and if necessary, systems are buffered with nitrogen or dry air. Equipment openings are sealed during transport. Physical, dry methods (i.e., wire brushes, scraping) and vacuuming are used to remove deposits. Only a small amount (<4 L) of liquid is permitted for wiping and cleaning. Cascade equipment openings are permanently welded closed at the conclusion of deposit removal activities.
Demonstrated double contingency is re-established by removing the deposit and placing it into safe geometry storage containers. Safe geometry (e.g., deposit collection bottles, HF traps) and interaction control (maintaining prescribed spacing between equipment containing fissile material) are the primary controls during this phase of the project.

CONTROLS WITH CONTRACTORS CONDUCTING DEPOSIT REMOVAL

The Nuclear Criticality Stabilization Program is organized using the ITO concept, as described above. The Program will identify deposits needing to be removed, define the location of the deposits, and may remove in situ easily accessible deposits. Once general deposit characterization is complete, Energy Systems will propose a scope, schedule, and budget for conducting the work. DOE may accept Lockheed Martin Energy Systems Inc.'s proposal or ask that the work be competitively bid. The request for proposals solicitation will define deposit removal requirements, e.g., meet national standards and federal and state laws. If Energy Systems out-sources the work to private companies, the K-25 Site will continue to have overall responsibility for certain technical aspects of the work, e.g., nuclear criticality safety. If a private company contracts directly with DOE, the company will probably have to have an Nuclear Regulatory Commission license for handling highly enriched fissile material and would have total responsibility for nuclear criticality safety.

DEPOSIT REMOVAL TECHNIQUES

A graduated approach is used in removing deposits. Deposits are removed from simple equipment (e.g., tubes, piping) before attempting to remove them from complex geometry equipment (e.g., compressors, pumps). Prototype removals will be conducted for each type of equipment with greater than minimum critical mass present. These practice sessions with equipment with low mass of uranium are used to confirm methods and procedures for safe operations. Lessons learned are incorporated into the methods and procedures prior to removing deposits involving large fissile masses.

Physical, dry methods (e.g., wire brushes, scrapers) are being used to remove deposits. A special facility has been constructed for the physical deposit removal. The Deposit Removal Room, within the K-25 Building, contains a specially designed stainless steel glove box system. Those deposits that can not be removed in situ in the field by vacuuming, are brought to the Deposit Removal Room for equipment scraping and vacuuming inside the glove box. After uranium deposits are removed, contaminated scrap hardware is stored in special locations.
Physical, mechanical methods may not be adequate for large, complex cascade equipment such as converters. Efforts are underway to construct and demonstrate a gas phase (ClF$_3$) process. The fluorination process is a means of converting solid deposits on equipment surfaces to volatile fluoride compounds that can be pumped away to gas treatment systems (Ref. 4). A key advantage of this fluorination technology is that deposits can be removed without disassembly of the process equipment. The Nuclear Criticality Stabilization Program’s charter requires only removing deposits, not decontaminating equipment.

SUMMARY

Removal of large uranium deposits from shutdown gaseous diffusion plants at Oak Ridge, Tennessee, is an integral part of the D&D and reutilization of the K-25 Site. The objective of the K-25 Site Nuclear Criticality Stabilization Program is to remove and place uranium deposits into safe geometry storage containers to meet the double contingency principle. Each step of the removal process brings us to safer conditions where multiple controls are present. Upon completion of the Program, nuclear criticality risks will be greatly reduced.

REFERENCES


Fig. 1. K-25 Site $^{235}U$ deposits vs enrichment.