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Moderation Control in Low Enriched ^{235}U Uranium Hexafluoride

Packaging Operations and Transportation

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* Managed by Martin Marietta Energy Systems, Inc. for the U.S. Department of Energy under contract DE-AC05-84OR21400.

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ABSTRACT

Moderation control is the basic parameter for ensuring nuclear criticality safety during the packaging and transport of low ^{235}U enriched uranium hexafluoride before its conversion to nuclear power reactor fuel. Moderation control has permitted the shipment of bulk quantities in large cylinders instead of in many smaller cylinders and, therefore, has resulted in economics without compromising safety. Overall safety and uranium accountability have been enhanced through the use of the moderation control. This paper discusses moderation control and the operating procedures to ensure that moderation control is maintained during packaging operations and transportation.

INTRODUCTION

"Moderation is the slowing down of neutrons from the high velocities and correspondingly high energies . . . to low velocities (and energies) at which the capture probability in the fissile ^{235}U atom is relatively large. Hydrogen moderation is thus perhaps the most important factor affecting the neutron economy of a chain reaction uranium system other than the actual enrichment of the fissile ^{235}U isotope itself."[1]

Moderation control is defined as "a method of assuring the nuclear safety of a system of fissionable material such that the k_∞ <1 and the $H/^{235}U$ atomic ratio of the hydrogen moderator and fissile material is maintained below a specified safe value . . . . Transport theory calculations indicate a k_∞ of only 0.80 for the moderation controlled, $H/^{235}U$ of 1.9, 30-inch-diameter $U(4.5)F_6$ cylinder with 0.4-inch steel wall. Since the infinite medium multiplication factor, k_∞, must be greater than unity for criticality, a value of 0.80 is considered adequate, in establishing nuclear safety . . . ."[2]

"The moderation control method is based on the production of high purity UF_6 (99.5 wt %). The 0.5 % impurity . . . is conservatively assumed (as being) hydrogen fluoride. The H/U atomic ratio will, therefore not exceed a value of 0.88 which indicates that the uranium is essentially unmoderated."[3]

Nuclear criticality safety control is defined as "a quantity of fissionable materials contained in such conditions that a self-sustaining chain reaction is impossible under specified conditions or that criticality cannot occur even though no limitation is placed upon possible values of other variables."[4]

The concept of limiting moderation for nuclear criticality safety control was first used in the 1950s to permit bulk shipments of low enriched uranium hexafluoride (LEU) from the Paducah Gaseous Diffusion Plant (PGDP) to the Oak Ridge Gaseous Diffusion Plant (ORGDP) and later to the Portsmouth Gaseous Diffusion Plant (PORTS). Shipments of moderation controlled LEU consisted of four "1-ton chlorine cylinders" which were transported by contract carriers on specially designed trailers. Each cylinder had a nominal capacity of 2.5 tons of UF_6 with a ^{235}U enrichment limit of 2%.

The use of model 48X cylinders having a nominal 10-ton UF_6 capacity evolved in the 1970s, and this method has been proven to be safe and practical. Overall safety withdrawal, packaging, handling, transporting, and refeeding operations of the gaseous diffusion plants was enhanced since fewer cylinders were needed and the potential exposure of site personnel was minimized. Economics were achieved without compromising safety.[5]

A recent study concluded that "a 10-ton cylinder filled with UF_6 under moderation control at a ^{235}U enrichment of 5.25 percent will be substantially subcritical both as a fully reflected single unit and as an infinite array with optimal interstitial moderation. For single 10-ton cylinders under moderation control, a ^{235}U enrichment of at least 12.7 percent is required for criticality."[6]

Overall safety was extended and improved through the use of the 30-in. cylinders whose UF_6 capacity was about ten times the capacity of smaller 12-in. cylinders that had been previously used. UF_6 releases were minimized because the number of connections and disconnections to the production process equipment were similarly reduced by a factor of 10. This greatly reduced the required number of samples and chemical and physical analyses which concurrently reduced the potential for exposure to the radioactive and chemical hazards associated with UF_6 and other uranium compounds. Improved environmental control was realized by a reduction in the radioactive and chemical effluence from the laboratory analyses.

The reliability of UF_6 accountability improved because multiple sampling and analyses were no longer required and the corresponding accountability losses were reduced. Nuclear fuel processors were also receptive to the concept of moderation control because their operations also reflected similar enhancements. In all cases, economies continue to be realized through the use of moderation control.

Strict moderation control procedures are followed during UF_6 cylinder filling operations. UF_6 is withdrawn as a gas from a cascade unit and condensed for liquid-phase transfer to a shipping cylinder. Since hydrogen fluoride (HF) is the only possible hydrogenous contaminant in the cascade stream, condensing operations are based on equilibrium studies of the UF_6-HF system to ensure that the liquid UF_6 is virtually free of HF. In addition, a nonhydrogenous material is always used as the primary condenser coolant to preclude inadvertent moderation of the UF_6 in the event of equipment failure.

To evacuate large UF_6 cylinders after each use, an allowable cylinder "heel" is established on the conservative premise that any residual material would be water. In the case of the 2.5-ton cylinder, a 25-lb "heel" is specified. This amount of water would not create an unsafe condition if mixed with any amount of UF_6 at ^{235}U enrichments to 5%. A 50-lb "heel" is authorized for 10-ton cylinders enriched up to 4.5% At enrichments above 5%, ^{235}U k_{∞} curves have points of inflection, and criticality is possible.[7]

To ensure that moderation control is achieved during shipping operations and transportation, the following practices help ensure that inleakage of water does not occur into filled UF_6 cylinders:

1. Packagings used for UF_6 must meet the standards of the American National Standards Institute-ANSI N14.1.[8]

2. Operations associated with moderation controlled UF_6 follow the guidance of U.S. Department of Energy Report ORO-651, Uranium Hexafluoride: A Manual Of Good Handling Practices.[9]

3. The internal cylinder pressure is verified before filling to verify that it is subatmospheric. If pressure is atmospheric, a leak may be indicated and the cylinder is removed from service for evaluation.

4. Cylinders are filled with liquid UF_6 at pressures exceeding atmospheric pressure. Any breach in the cylinder wall, plug, or valve assembly will be readily detected by the presence of a white vapor [consisting of uranyl fluoride (UO_2F_2) and hydrogen fluoride (HF), which are products of the water reacting with the UF_6] and the strong odor of hydrogen fluoride. Corrective action would immediately begin to stop the leak. Also, a valve

cap with a Teflon™ seal is installed over the valve opening as a second leakage-containment boundary. Both the valve design and the leak test operations ensure that a single error will not allow water to leak into the cylinder.

5. The cylinder is cooled after filling for at least 5 days in order for the UF_6 to solidify. After 5 days, a pressure test is performed to verify that cylinder pressure is subatmospheric, and the valve cap is secured. This ensures that water inleakage can not occur due to a single error.

6. During cool down and on-site storage, a breach of containment would be indicated by a visible white vapor. Should this occur, corrective actions would be taken to stop the release and before any water could enter the cylinder.

7. A visual inspection of the full cylinder is also made before loading it into an overpack to verify that the containment boundary is maintained.

8. A filled cylinder is placed into a protective overpack, and a numbered tamper indicating device (TID) is placed on the overpack. When the filled cylinder in an overpack is received, the TID is verified by the receiving site.

CONCLUSION

Theoretical studies have shown that moderation control ensures the safety of fissionable materials, and operational practices have implemented procedures to achieve moderation control. In addition, facility personnel who perform shipping and packaging operations are trained and qualified with these minimum qualifications: the use of equipment to load and unload packages; correct loading and unloading procedures; knowledge of radiation, criticality, and contamination safety; understanding of industrial safety and emergency procedures; implementing U.S. Department of Transportations regulations (49 CFR Pt. 173) requirements; and following specific packaging requirements of the U.S. Department of Energy and/or U.S. Nuclear Regulatory Commission Certificates of Compliance and the corresponding Safety Analysis Reports for Packaging.

Over 40 years of packaging operations and transportation of low ^{235}U enriched uranium hexafluoride have been safely performed because of the successful implementation of moderation control practices.

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