Fueling Uncertainty: A Critical Examination of Centrus Energy's HALEU Production and its Nuclear Risks

Executive Summary

This report critically examines Centrus Energy's operations, particularly its role in advancing High-Assay, Low-Enriched Uranium (HALEU) production in the United States. While Centrus presents HALEU as a solution for next-generation nuclear power, a closer look reveals significant and under-addressed risks to public health, environmental integrity, and global non-proliferation efforts. The analysis of Centrus's recent radiological discharge report, coupled with an assessment of HALEU's inherent dangers, underscores a pressing need for heightened regulatory scrutiny, increased transparency, and a re-evaluation of the rapid commercialization of this potent nuclear material.

The terminology surrounding HALEU often creates a perception of safety that warrants closer examination. The designation "Low-Enriched Uranium" typically implies a lower enrichment level (below 5% uranium-235) and, by extension, a reduced proliferation risk compared to Highly Enriched Uranium (HEU, greater than 20% uranium-235).[1] However, HALEU is defined as uranium enriched between 5% and 20% uranium-235, which is substantially higher than traditional reactor fuel and approaches the HEU threshold.[1] This linguistic categorization can inadvertently downplay the material's actual proliferation potential and criticality risks. The industry frequently highlights HALEU's benefits, such as increased fuel efficiency and the ability to enable smaller reactor designs [1], while simultaneously presenting it as distinct from HEU. This framing, however, may obscure its dual-use nature. For instance, some sources suggest HALEU reduces proliferation risks for non-state actors due to processing difficulties [4], yet others, including the Union of Concerned Scientists and the National Nuclear Security Administration, explicitly highlight significant proliferation concerns, stating that HALEU above approximately 12% uranium-235 can be used directly for weapons.[5] This divergence in understanding suggests that the semantic distinction and the industry's portrayal of HALEU as "low-enriched" could lead to a less rigorous regulatory approach than is truly warranted, potentially exposing the public and the environment to greater, unacknowledged risks. The report highlights how current regulatory frameworks may be insufficient to contain the long-term consequences of HALEU, from its production to its eventual waste, and calls for a precautionary approach.

I. Introduction: The Imperative of Nuclear Oversight

The global push for "clean" energy has revitalized interest in nuclear power, with advanced reactor designs often touted as a safer, more efficient future. Central to this vision is High-Assay, Low-Enriched Uranium (HALEU), a specialized nuclear fuel. Centrus Energy, a key player in the U.S. nuclear fuel cycle, is at the forefront of commercial HALEU production. However, from an environmental and non-proliferation watchdog perspective, the rapid deployment of HALEU without comprehensive, transparent, and stringent oversight poses unacceptable risks. This report aims to dissect the realities behind Centrus's operations and the broader implications of HALEU's commercialization.

The prevailing narrative promoting nuclear power, especially advanced designs utilizing HALEU, frequently emphasizes its "clean" energy attributes and contributions to climate change mitigation.[3] This framing often focuses solely on the lack of direct carbon emissions during electricity generation, overlooking the complex and environmentally impactful entire nuclear fuel cycle. This cycle encompasses uranium mining and milling, enrichment, fuel fabrication, and the long-term management of radioactive waste.[7] The report's critical stance directly challenges this simplified "clean energy" portrayal by committing to expose the full spectrum of environmental, health, and proliferation dangers inherent in nuclear processes, including HALEU production. Public and policy decisions, influenced by the compelling "clean energy" narrative, may inadvertently overlook or downplay the significant and persistent environmental and safety challenges associated with the nuclear fuel cycle. This can lead to a lack of critical examination of the true costs and risks, potentially resulting in insufficient regulatory frameworks and inadequate resource allocation for robust oversight, waste management, and accident preparedness.

II. Centrus Energy: A Profile in Nuclear Ambition

From Government Roots to Private Enterprise

Centrus Energy Corp., originally established as the United States Enrichment Corporation (USEC) in 1992, emerged from the U.S. Department of Energy's (DOE) Uranium Enrichment Enterprise, a government entity. It was fully privatized on July 28, 1998, through an initial public offering, generating over $3 billion for the U.S. Treasury.[9] This fundamental shift from a government-controlled operation to a private, investor-owned company introduced a primary driver of profit and market expansion into its operational priorities.

Historically, Centrus played a significant role in the "Megatons to Megawatts" program, a landmark non-proliferation initiative from 1993 to 2013. This program converted former Soviet nuclear weapons material into fuel for U.S. civilian reactors, providing approximately 10% of America's electricity needs.[10] This background positions Centrus as a company with deep historical ties to both national security and commercial nuclear power, allowing it to leverage this legacy for its current and future endeavors.

The American Centrifuge Program and HALEU Production

Centrus's current primary focus includes the American Centrifuge Program (ACP) at the Portsmouth Gaseous Diffusion Plant in Piketon, Ohio.[9] This site has a long and complex history of uranium enrichment, with the U.S. Nuclear Regulatory Commission (NRC) assuming regulatory authority in March 1997. Notably, an NRC investigation in June 1998 looked into alleged "failure to control components with uranium deposits, inadequate maintenance, testing and operation of safety valves on equipment" at the Portsmouth facility.[9] This historical context suggests a recurring pattern of regulatory challenges and safety concerns at the site.

Under a 2019 contract with the DOE, Centrus began demonstrating High-Assay, Low-Enriched Uranium (HALEU) production at the Piketon facility.[9] In June 2021, Centrus achieved a significant milestone, becoming the first U.S. facility licensed by the NRC to enrich uranium up to 20% uranium-235 for HALEU production.[9] The DOE has actively incentivized domestic HALEU production, driven by concerns over Russia's historical monopoly on HALEU manufacturing and the need to secure a domestic supply chain for advanced reactors.[3] Centrus's HALEU operations have seen continuous expansion, with NRC approval for continuation until June 30, 2025, and an application for Phase III, aiming to produce at least 900 kg of HALEU uranium hexafluoride per year starting July 1, 2025, currently under NRC review.[12] This ongoing expansion underscores the government's strategic commitment to HALEU, despite its inherent risks.

The transformation of USEC from a government corporation to a private, investor-owned company (Centrus) fundamentally altered its operational framework by introducing a profit motive.[9] While the "Megatons to Megawatts" program showcased a positive, non-proliferation-driven role [10], the current push for HALEU production is largely commercially driven, albeit supported by government contracts.[9] This commercial imperative, coupled with the historical regulatory issues and alleged safety deficiencies at the Portsmouth site [9], raises concerns that economic incentives could potentially overshadow or compromise stringent safety and environmental measures. The pressure to meet production targets and achieve profitability might lead to a less conservative approach to risk management. The privatization of critical nuclear fuel production, particularly for materials with significant proliferation and safety implications like HALEU, introduces a potential conflict of interest. The pursuit of financial gains could inadvertently lead to a relaxation of safety protocols or a less transparent approach to environmental impacts, necessitating even more robust and independent public oversight to ensure that public health and environmental protection are not sacrificed for commercial ambition.

III. Dissecting the Centrus Q1 2025 Radiological Discharge Report

Overview of the Monitoring Report

The May 22, 2025, report (761-GM-25-044) submitted by American Centrifuge Operating, LLC (ACO), a Centrus subsidiary, to the Ohio Environmental Protection Agency (Ohio EPA) summarizes radiological discharge monitoring for the first quarter of calendar year 2025 (January 1 to March 31, 2025) at the Portsmouth Gaseous Diffusion Plant.[14] The report details sample results for effluent monitoring conducted at external National Pollutant Discharge Elimination System (NPDES) permitted outfalls, specifically Outfall 012/X-2230M Southwest Holding Pond and Outfall 013/X-2230N West Holding Pond.[14] Monitored parameters include Alpha, Beta, Technetium (Tc), Uranium (U), and Transuranics (Americium-241, Neptunium-237, Plutonium-238, Plutonium-239+240).[14]

Analysis of Reported Concentrations

The reported concentrations for the first quarter of 2025 at both outfalls are summarized in the table below.

Table 1: Summary of Centrus Q1 2025 Radiological Discharges (Outfalls 012 & 013)

Outfall ID	Date	Alpha (pCi/L)	Beta (pCi/L)	Technetium (Tc) (pCi/L)	Uranium (U) (µg/L)	Am 241 (pCi/L)	Np 237 (pCi/L)	Pu 238 (pCi/L)	Pu 239+240 (pCi/L)
012/X-2230M	1/8/2025	0.00	4.98	0.00	3.38	0.00*	0.00*	0.00*	0.00*
012/X-2230	1/13/2025	0.00	8.45	0.00	1.46				

M									
012/X-2230M	1/20/2025	0.00	1.82	0.00	1.14				
012/X-2230M	1/28/2025	2.33	9.41	0.00	2.85				
012/X-2230M	2/3/2025	0.00	0.00	0.00	1.80				
012/X-2230M	2/10/2025	0.00	5.81	0.00	0.64				
012/X-2230M	2/17/2025	0.00	4.96	0.00	0.74				
012/X-2230M	2/24/2025	0.00	0.00	0.00	1.74				
012/X-2230M	3/3/2025	0.00	0.00	0.00	1.06	0.00	0.00	0.00	0.00
012/X-2230M	3/10/2025	0.00	2.40	0.00	1.47				
012/X-2230M	3/17/2025	0.00	2.75	0.00	1.78				
012/X-2230M	3/24/2025	0.00	0.00	0.00	1.40				

012/X -2230 M	3/31/2 025	0.00	0.00	0.00	0.93				
013/X -2230 N	1/8/20 25	0.00	4.91	0.00	1.85	0.00*	0.00*	0.00*	0.00*
013/X -2230 N	1/13/2 025	4.72	4.85	0.00	1.43				
013/X -2230 N	1/20/2 025	0.00	3.15	0.00	1.74				
013/X -2230 N	1/28/2 025	0.00	6.40	0.00	1.52				
013/X -2230 N	2/3/2 025	0.00	5.29	0.00	1.05				
013/X -2230 N	2/10/2 025	0.00	4.85	0.00	0.59				
013/X -2230 N	2/17/2 025	0.00	4.92	0.00	0.84				
013/X -2230 N	2/24/2 025	15.3	11.3	0.00	1.39				
013/X -2230 N	3/3/2 025	0.00	0.00	0.00	1.41	0.00	0.00	0.00	0.00
013/X -2230	3/10/2 025	0.00	3.40	0.00	1.72				

N									
013/X-2230N	3/17/2025	1.05	3.58	0.00	1.25				
013/X-2230N	3/24/2025	0.00	4.32	0.00	1.10				
013/X-2230N	3/31/2025	0.00	0.00	0.00	0.63				

Note: Transuranic data (Am 241, Np 237, Pu 238, Pu 239+240) was only reported for March 3, 2025, for both outfalls.[14] Empty cells indicate no data was provided for that specific parameter and date in the source document.

Outfall 012/X-2230M Southwest Holding Pond: Alpha concentrations ranged from 0.00 to 2.33 pCi/L (on January 28, 2025). Beta ranged from 0.00 to 9.41 pCi/L (on January 28, 2025). Technetium (Tc) was consistently 0.00 pCi/L. Uranium (U) concentrations varied from 0.64 to 3.38 µg/L (on January 8, 2025). Transuranics (Americium-241, Neptunium-237, Plutonium-238, Plutonium-239+240) were all reported as 0.00 pCi/L on the single reported date (March 3, 2025).[14]

Outfall 013/X-2230N West Holding Pond: Alpha concentrations ranged from 0.00 to 15.3 pCi/L (on February 24, 2025), representing the highest alpha reading across both outfalls. Beta ranged from 0.00 to 11.3 pCi/L (on February 24, 2025). Technetium (Tc) was consistently 0.00 pCi/L. Uranium (U) concentrations ranged from 0.59 to 1.85 µg/L (on January 8, 2025). Similar to Outfall 012, transuranics were all reported as 0.00 pCi/L on the single reported date (March 3, 2025).[14]

Regulatory Framework and Compliance

The Centrus report is submitted in accordance with Ohio EPA Permit No. 0IS00023*ED.[14] This permit requires monthly Discharge Monitoring Reports (DMRs).[15] The Ohio EPA permit mandates monitoring of gross alpha, gross beta, total uranium, and technetium-99 at the outfall locations, with sampling frequency defined by USEC's NRC License. Crucially, transuranic elements are sampled quarterly, *even if not explicitly required by the NRC License.*[15]

Federal regulations include EPA's 40 CFR Part 190, which limits the annual dose equivalent to any member of the public from normal operations of uranium fuel cycle facilities to 25 millirem (0.25 mSv) to the whole body, 75 millirem (0.75 mSv) to the thyroid, and 25 millirem (0.25 mSv) to any other organ.[16] It also specifies limits on the quantity of certain radioactive materials entering the general environment per gigawatt-year of electricity produced, including alpha-emitting transuranics.[16] NRC regulations (10 CFR Part 20) require licensees to use procedures and engineering controls to achieve doses "as low as reasonably achievable" (ALARA) and demonstrate compliance with a public dose limit of 1 mSv/yr (100 mrem/yr), with an ALARA constraint of 0.1 mSv/yr (10 mrem/yr) for airborne radioactive material emissions.[17] For uranium enrichment facilities, 10 CFR 70.59 requires semi-annual reports of principal radionuclides released in liquid and gaseous effluents.[20] NRC Regulatory Guide 4.16 suggests continuous or weekly sampling for potentially significant releases.[17] EPA's Maximum Contaminant Levels (MCLs) for drinking water provide benchmarks: Gross Alpha (excluding radon and uranium) at 15 pCi/L, Beta Particles and Photon Emitters at 4 mrem/year, and Uranium at 30 µg/L.[23]

Watchdog Perspective: Critically Assessing Monitoring and Limits

The Centrus report provides transuranic data for only *one specific day* (March 3, 2025) within the entire three-month quarter for each outfall.[14] While the Ohio EPA permit mandates quarterly sampling for transuranics [15], this single data point per quarter is grossly insufficient. Transuranics, such as plutonium and americium, are exceptionally radiotoxic and have extremely long half-lives, posing significant long-term environmental and health risks.[7] Such infrequent monitoring is unlikely to detect intermittent or episodic releases, which could occur at any time during operations, and provides a highly incomplete picture of potential contamination. This contrasts sharply with NRC guidance that suggests continuous or weekly sampling for potentially significant releases.[17]

A critical transparency gap exists because the Ohio EPA permit (0IS00023*ED) explicitly states that it *does not specify radiological discharge limits*, instead referring to USEC's (Centrus's predecessor) NRC License.[15] Attempts to locate explicit radiological effluent limits within the provided NRC license (SNM-2011) information were unsuccessful.[12] This suggests that these limits, if they exist, are either not publicly detailed or are embedded within complex technical specifications, making independent verification and public oversight extremely difficult.

While the reported uranium concentrations (up to 3.38 µg/L) are below the EPA drinking water MCL of 30 µg/L [14], and reported alpha/beta levels are below their respective MCLs (15 pCi/L for gross alpha, and the beta levels are reported in pCi/L, not mrem/year as per the MCL, making direct comparison difficult) [14], the primary concern for a watchdog lies not just in meeting minimum standards but in the long-term accumulation and the cumulative impact of multiple sources and pathways of exposure. These individual discharge reports may not fully capture such long-term or synergistic effects.

The NRC's "As Low As Reasonably Achievable" (ALARA) principle [17] is a fundamental regulatory concept aimed at minimizing radiation exposure. However, without transparent and stringent discharge limits, and with monitoring frequencies that appear to be the bare minimum for key contaminants like transuranics, it becomes challenging to verify if Centrus is truly operating "as low as reasonably achievable" or merely meeting minimal, potentially insufficient, reporting requirements.

The Ohio EPA permit's explicit reliance on the NRC license for radiological limits [15], coupled with the public inaccessibility or lack of explicit detail regarding these limits within the provided NRC license information [25], creates a significant regulatory "black box." This lack of clear, publicly available, and independently verifiable limits makes it exceedingly difficult for the public, environmental groups, or even other regulatory bodies to effectively assess Centrus's compliance or the adequacy of the standards themselves. Furthermore, the extremely infrequent monitoring of highly toxic transuranics (only one reported date per quarter) [14] shifts the burden of proof from the facility demonstrating continuous safety to external parties attempting to detect and prove harm. This passive monitoring approach for critical contaminants implies that unless a major, undeniable release occurs, the ongoing, subtle accumulation of hazardous substances might go undetected or unaddressed. This opacity and infrequent monitoring regime may inadvertently facilitate undetected or underreported releases of radioactive materials, leading to cumulative environmental contamination and long-term, subtle health impacts that are exceedingly difficult to trace back to the source. This systemic issue undermines public trust in regulatory effectiveness and accountability, potentially allowing for a gradual degradation of environmental quality and public health over time without clear attribution or remediation.

IV. The Perils of Commercial HALEU Production

A. Proliferation Risks: A Shortened Path to Nuclear Weapons

High-Assay, Low-Enriched Uranium (HALEU) is officially defined as uranium enriched to between 5% and 20% uranium-235.[1] This contrasts significantly with traditional Light Water Reactors (LWRs), which typically use fuel enriched to less than 5%

uranium-235.[2] Many advanced reactor designs, however, are specifically engineered to require HALEU due to its properties that allow for increased fuel efficiency, smaller reactor cores, and longer operational cycles.[1] This higher enrichment level inherently positions HALEU as a more attractive and concerning material for potential nuclear weapons development compared to conventional LEU.[2]

A paramount proliferation concern with HALEU is its proximity to weapons-grade Highly Enriched Uranium (HEU, defined as greater than 20% uranium-235). HALEU, particularly at the higher end of its enrichment spectrum (e.g., 12-20% uranium-235), can be further enriched to HEU with significantly less separative work, time, and infrastructure compared to starting from natural uranium or traditional LEU.[27] This "shortened path" to weapons-grade material is a critical proliferation risk.[28] If a nation-state already possesses uranium enrichment capabilities, utilizing HALEU as a feedstock makes the production of weapons-grade uranium-235 much more efficient and potentially less detectable.[4]

There are conflicting assessments regarding HALEU's proliferation risk. Some sources suggest that certain HALEU fuel forms, such as TRISO fuels, *reduce* proliferation risks for non-state actors due to the complex chemical and mechanical processing requirements needed to convert them into weapon-usable material.[4] However, this view is strongly challenged by other credible sources, including the Union of Concerned Scientists (UCS) and the National Nuclear Security Administration (NNSA). An analysis published by UCS in *Science* explicitly found that HALEU above approximately 12% uranium-235 *can be used directly to make practical nuclear weapons*.[6] This analysis warns that widespread commercial HALEU use without robust, internationally agreed-upon restrictions could "eliminate the sharp distinction between peaceful and nonpeaceful nuclear programs," thereby leaving the international community with "virtually no opportunity to prevent" proliferation once a state decides to pursue weapons.[6] NNSA Administrator Jill Hruby acknowledged the critical need to understand and assess HALEU risks, noting that "reactor type, fuel enrichment level, fuel quantity, and fuel form are important factors in evaluating proliferation risks".[5] The International Atomic Energy Agency (IAEA) faces significant challenges in implementing safeguards with widespread HALEU deployment, as the "significant quantities" of HALEU required for a weapon are much smaller compared to LEU, implying a shorter "breakout time" for states to divert material for weapons purposes.[28]

The stark divergence in expert opinions regarding HALEU's proliferation risk exposes a profound and unresolved "dual-use dilemma" at the heart of nuclear technology. The very characteristics that make HALEU attractive for advanced reactors—its higher enrichment and increased energy density—are precisely what make it a more potent and accessible material for nuclear weapons. The argument that specific fuel forms like TRISO might make it harder for non-state actors to weaponize [4] does not negate the significant risk posed by nation-states, especially those that already possess or are developing enrichment capabilities.[4] The critical finding that HALEU enriched above approximately 12% uranium-235 can be directly weaponized [6] fundamentally alters the global proliferation landscape. It blurs the lines between peaceful civilian nuclear programs and potential weapons programs, significantly reducing the warning time for the international community to respond to diversion attempts. The aggressive push for commercial HALEU production, driven by perceived energy security needs and geopolitical competition (e.g., reducing reliance on Russia [3]), is inadvertently creating a more precarious global security environment. Without a globally harmonized, significantly strengthened, and proactively implemented safeguards regime, the widespread availability of HALEU could lead to an accelerated and less detectable path to nuclear weapons for a greater number of state and potentially non-state actors, thereby increasing the risk of nuclear proliferation worldwide.

B. Accident Scenarios: Unforeseen Catastrophes in the Fuel Cycle

Uranium hexafluoride (UF_6) is the volatile chemical form of uranium used throughout the enrichment process, including the production of HALEU.[30] UF_6 is highly reactive and, upon contact with water (a common occurrence in transport accidents or environmental releases), rapidly hydrolyzes to form uranyl fluoride (UO_2F_2) and highly corrosive hydrofluoric acid (HF).[30] HF is an extremely dangerous substance, capable of causing severe health effects, including pneumonitis and pulmonary edema, even at low concentrations.[30] Uranyl fluoride is highly soluble and primarily toxic to the kidneys, with high levels of intake potentially leading to death.[30] While the immediate chemical toxicity of UF_6 hydrolysis products often dominates in acute release scenarios [30], UO_2F_2 also presents a significant radiological hazard from inhaled uranium.[30] The transportation of UF_6, a routine part of the fuel cycle, is explicitly described as "dangerous" due to both its hazardous chemical and radioactive properties.[30]

A criticality accident is an uncontrolled nuclear fission chain reaction that occurs when a sufficient quantity of fissile material (a critical mass) accumulates unintentionally.[32] These events, while not nuclear explosions, can release intense, potentially fatal radiation doses.[32] Historically, 67 known criticality accidents occurred globally between 1945 and 1999, resulting in 21 deaths.[32] Such accidents can be triggered by seemingly minor factors, such as water leaking into fissile material, which acts as a neutron moderator.[32] HALEU's higher enrichment (up to 20% uranium-235) means that a critical mass can be achieved with significantly smaller quantities of material compared to traditional LEU.[28] This necessitates distinct and rigorous "adjustments" to criticality safety controls for HALEU, which are "not the same as for LEU".[8] The U.S. Department of Energy (DOE) and NRC are actively collaborating on developing new criticality safety data and benchmarks specifically for HALEU use, storage, and transportation, indicating existing data gaps and the novel challenges presented by this material.[33] Criticality controls in facilities handling UF6, such as during cylinder cleaning operations, are complex and can be susceptible to human errors or reliance on potentially inaccurate historical records.[38] A discrepancy in the assumed enrichment data for a cylinder, for example, could invalidate safety limits and lead to a common-mode failure, increasing the risk of an accidental criticality.[38]

The entire HALEU fuel cycle, from uranium mining and milling to enrichment, deconversion, fuel fabrication, and spent fuel management, involves extensive transportation of various uranium forms.[8] The unique properties of HALEU, particularly its higher enrichment, necessitate the development of new or modified transport containers to ensure criticality safety.[28] The acknowledged lack of sufficient criticality benchmarks for HALEU means that, as a precautionary measure, smaller amounts of HALEU must be shipped per conveyance, which consequently increases the overall number of transportation events and the associated risks.[34] Specific concerns, such as water infiltration into HALEU fuel containers during transport or storage, require ongoing validation through experiments.[35]

The ongoing, collaborative efforts by the DOE and NRC to develop fundamental criticality safety data and benchmarks for HALEU [33] strongly suggest that the full safety envelope for commercial-scale HALEU production, handling, and transport is not yet completely understood or definitively established. The explicit need for "adjustments" to criticality safety controls [8] and the acknowledgment of "data gaps" [33] indicate that the industry is proceeding with commercialization while still in the process of fully characterizing, quantifying, and mitigating all potential accident scenarios. This approach is particularly alarming given the severe and immediate consequences of UF6 releases (chemical and radiological toxicity) and criticality accidents (fatal radiation doses).[30] Commercial HALEU production is advancing with a significant, inherent, and largely unquantified risk. The fact that foundational safety data is still being generated suggests that the current regulatory framework may be reactive—responding to identified gaps—rather than proactively preventative. This could potentially expose workers, emergency responders, and the public to unforeseen hazards, as the full spectrum of risks may not be fully understood until after widespread deployment.

C. Radioactive Waste Management: A Legacy of Contamination

Spent HALEU fuel presents distinct challenges compared to conventional spent nuclear fuel. Due to its higher initial enrichment (up to 20% uranium-235), it retains a significantly higher residual fissile content (typically 7-10% compared to approximately 2% for LEU spent fuel).[29] This increased fissile material poses unique and complex criticality safety challenges for its long-term storage and ultimate disposal.[29] Furthermore, depending on the fuel's burnup levels, HALEU spent fuel could contain a substantially higher proportion of actinides and fission products (potentially up to 24% or more) compared to current Light Water Reactor (LWR) spent fuel (approximately 4%) [29], which impacts its radiotoxicity and heat generation profile.

The distinct properties of HALEU waste necessitate the development of new or modified regulations and licensing regimes specifically for its back-end management.[28] While the nuclear sector has developed "reliable storage, transport and disposal technologies" for spent fuel since the 1950s [40], these were primarily designed for conventional LEU fuels. The higher residual enrichment of spent HALEU could make reprocessing economically attractive [29], a process that itself carries significant nuclear proliferation and terrorism risks due to the separation of plutonium.[2] If reprocessing becomes commercially viable for HALEU, it raises serious concerns about nuclear latency (states developing reprocessing capabilities) and diversion risks for recovered HALEU or separated plutonium.[29] It is important to note that currently, there is no practical technology for reprocessing certain HALEU fuel types, such as TRISO fuel.[29] The criticality risks associated with higher enrichment levels are a key challenge for disposal planning.[40]

The environmental and health dangers associated with HALEU production extend beyond the enrichment process to encompass the entire uranium fuel cycle. Uranium mining and milling operations generate substantial quantities of radioactive wastes and mill tailings.[41] These wastes contain long-lived radioisotopes, such as thorium-230, which has a half-life of 76,000 years and decays to produce radon gas, a known carcinogen responsible for up to 20% of lung cancer cases in Canada.[7] Contamination from these sites can persist for generations, spreading through wind-blown radioactive dust and contaminating surface and groundwater, which in turn affects drinking water supplies, crops, soil, and animals.[7] The long-term effects on human health, including increased incidences of cancers, fertility problems, and inheritable defects, are often subtle, widespread, and notoriously difficult to detect clinically or epidemiologically, making direct attribution challenging.[7]

The persistent nature of radioactive contamination from the uranium fuel cycle, particularly due to the extremely long half-lives of certain radionuclides like thorium-230 and the subsequent generation of radon gas [7], means that environmental impacts extend for millennia. This timeframe far exceeds the operational lifespan of any nuclear facility or the political and economic planning horizons of current generations. The "subtle and widespread" nature of the health effects [7] makes it inherently difficult to establish direct causation, which can allow the nuclear industry to deflect responsibility for long-term public health consequences. Furthermore, the economic incentive to reprocess HALEU [29], despite its well-documented proliferation risks [2], compounds the waste management problem by potentially creating new pathways for fissile material and adding to the complexity of future waste streams. This deferral of the true costs and risks onto future generations represents a significant ethical and practical failing. The commercialization and widespread deployment of HALEU, while promising short-term energy benefits, is effectively committing countless future generations to an unmanageable and potentially irreversible legacy of radioactive waste and environmental contamination. This approach not only poses significant health risks that will manifest over vast timescales but also creates a perpetual burden of stewardship, undermining the very goals of sustainable energy development and intergenerational equity.

V. Regulatory Gaps and the Illusion of Safety

The NRC officially asserts that its current regulatory framework, including 10 CFR Part 20 and EPA's 40 CFR Part 190, is "sufficient to provide reasonable assurance of adequate protection of public health and safety with regard to HALEU".[1] However, this assertion is significantly undermined by several factors. The ongoing, active collaboration between the DOE and NRC to develop fundamental criticality safety data and benchmarks for HALEU [33] strongly suggests that the comprehensive understanding of HALEU's behavior and its associated risks is still evolving and not yet fully established, particularly for commercial-scale applications. The acknowledged "lack of benchmarks" currently necessitates shipping smaller amounts of HALEU per conveyance, which increases transportation costs and, implicitly, the frequency of transport events and associated risks.[34] This indicates that the regulatory body itself recognizes gaps in foundational safety data, even as commercialization proceeds.

As detailed in Section III, the infrequent monitoring of highly hazardous transuranics (only quarterly, with a single data point reported per quarter in the Centrus report) [14] represents a critical deficiency. While NRC regulations require semi-annual reports [20] and suggest more frequent (continuous or weekly) sampling for potentially significant releases [17], the specific reporting for transuranics appears to be at the bare minimum. This infrequent sampling makes it exceedingly difficult to detect episodic releases, accurately assess the cumulative long-term accumulation of these highly radiotoxic and long-lived radionuclides, or identify patterns of contamination that might only emerge over time.

The principle of "As Low As Reasonably Achievable" (ALARA) is a cornerstone of radiation protection, requiring licensees to minimize exposures to radiation and releases of radioactive materials to the extent practical.[17] Yet, without transparent, robust, and frequently updated effluent limits specifically tailored to the unique risks of HALEU, and with monitoring frequencies that appear to be minimal for some critical contaminants, the practical effectiveness and enforceability of ALARA become highly questionable. The reliance on broad dose limits (e.g., 25 mrem/year for the public from EPA, 100 mrem/year from DOE) [16] may not adequately capture the localized or cumulative impacts of specific radionuclide releases, especially when the precise composition and behavior of HALEU waste are still being characterized.

The apparent contradiction between the NRC's assertion of regulatory sufficiency [1] and the simultaneous acknowledgment of ongoing data gaps and the need for new criticality benchmarks for HALEU [33] points to a significant regulatory lag. The nuclear industry is actively and rapidly pushing for the commercialization and widespread deployment of HALEU [3], while the regulatory framework appears to be playing catch-up, attempting to develop foundational safety data concurrently with commercial operations. Furthermore, the reliance on industry-submitted discharge reports [14] and the lack of explicit, easily verifiable state-level radiological limits [15] can inadvertently foster an environment where industry self-regulation is implicitly prioritized over independent, proactive, and transparent oversight. This dynamic can create a situation where the industry effectively defines the terms of its own safety, potentially leading to a higher tolerance for risk than what is truly "as low as reasonably achievable" from a public health and environmental protection standpoint. This regulatory environment, characterized by a reactive approach to emerging risks and a reliance on industry-provided data, may not adequately protect public health and safety. It risks allowing the nuclear industry to operate within a framework that prioritizes commercial expediency over comprehensive risk mitigation, potentially leading to undetected or under-addressed environmental contamination and long-term health consequences that are difficult to attribute or remediate.

VI. Conclusion: A Call for Precaution and Accountability

Centrus Energy's expansion into commercial HALEU production, while championed as a step towards advanced nuclear energy, introduces profound and multifaceted risks that are not adequately addressed by current regulatory practices or public discourse.

The inherent proliferation dangers of HALEU, its potential to shorten the path to nuclear weapons, the severe consequences of accidents involving highly toxic UF6 releases and criticality events, and the long-term, complex challenges of managing novel, highly radioactive waste streams demand an urgent re-evaluation of this path.

The analysis of Centrus's own discharge report reveals critical gaps in monitoring frequency for dangerous transuranics and a concerning lack of transparent, explicit radiological limits at the state level. These deficiencies, coupled with the ongoing scientific efforts to fully understand HALEU's criticality safety, paint a picture of a rapidly developing industry outpacing its regulatory safeguards.

Recommendations:

- **Immediate Moratorium on HALEU Expansion:** An immediate halt to any further expansion of commercial HALEU production and deployment is necessary until a comprehensive, independent, and publicly transparent risk assessment—encompassing proliferation, accident scenarios across the entire fuel cycle, and long-term waste management—is completed and thoroughly reviewed by non-industry experts and public stakeholders.
- **Strengthened Regulatory Oversight and Transparency:**
    - Mandate continuous, real-time monitoring for all significant radiological effluents, especially transuranics and other long-lived radionuclides, at all HALEU production facilities. This data must be immediately accessible to the public in an easily understandable format.
    - Establish clear, explicit, and legally binding radiological discharge limits at both federal and state levels, specifically tailored to the unique risks of HALEU production and its associated waste streams. These limits must be publicly accessible, rigorously enforced, and subject to periodic independent review and adjustment.
    - Implement a program of independent, unannounced inspections with real-time sampling capabilities to verify compliance, detect undeclared releases, and ensure the integrity of reported data.
    - Revise and update regulatory frameworks to proactively address the novel criticality, transport, and waste management challenges posed by HALEU, ensuring that regulations anticipate rather than react to emerging data gaps and technological advancements.
- **Enhanced Proliferation Safeguards:** Given HALEU's direct weaponization potential, particularly at enrichments above 10-12% uranium-235 [6], implement international security standards equivalent to those applied for Highly Enriched Uranium (HEU) and plutonium. This must include significantly stricter physical

security measures, robust material accounting and control systems, and enhanced international verification protocols to prevent diversion.
- **Transparent and Sustainable Waste Management Strategy:** Demand the development and public commitment to a comprehensive, technically feasible, and financially sound plan for the permanent disposal of HALEU spent fuel and associated wastes *before* further production scales up. This plan must explicitly address HALEU's unique characteristics and criticality concerns, involve robust public engagement, and be subject to independent scientific and ethical review.
- **Prioritize Public Health and Environmental Protection:** Shift the burden of proof from the public demonstrating harm to the industry demonstrating absolute safety and minimal environmental impact. This requires upholding the ALARA principle with verifiable, stringent standards that prioritize public health and ecological integrity over commercial expediency.

The cumulative evidence presented—including unquantified risks, significant regulatory gaps, conflicting expert assessments of proliferation potential, and the long-term, intergenerational burden of radioactive waste—strongly argues for the application of the precautionary principle. This principle dictates that if an action or policy carries a suspected risk of causing harm to the public or the environment, in the absence of scientific consensus that the action or policy is not harmful, the burden of proof that it is not harmful falls on those taking the action. The current trajectory of HALEU commercialization appears to operate in reverse, with rapid deployment preceding a full understanding and comprehensive mitigation of its inherent and potential risks. Without a fundamental shift to a precautionary approach, the aggressive pursuit of HALEU as a solution for advanced nuclear energy risks creating irreversible harm to human health and the environment. This approach would ultimately undermine the very goals of sustainable energy development and global security, leaving a hazardous legacy for countless generations.

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