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Nuclear energy is unaffordable AND even an impossibly vast expansion of nuclear energy by 2050 will not put a dent in carbon emissions

Cost overruns began almost immediately and the two Westinghouse AP1000 reactors built at the Vogtle site in Georgia cost over $36.85 billion and took 15 years to construct. [1] The nuclear power plants at Vogtle are the most expensive power plants ever built. And these costs don't include the cost of long-term management or disposal of the spent nuclear fuel.

The rapid ramp up of costs of the NuScale small modular reactor slated to be built in Idaho occurred before ever beginning to construct the reactor. The estimated construction cost of NuScale would have exceeded the cost of the large AP1000 reactors at Vogtle, on an energy equivalent basis.

Small and microreactors cannot be expected to cost less than large nuclear power plants on an energy equivalent basis, yet it seems that the claims that they will be less expensive will continue to be made until repeatedly proven to not be true.

With regard to reduced carbon emissions, it is true that nuclear fission does not create carbon emissions. However, mining, milling, conversion, fuel enrichment, fuel fabrication, nuclear plant construction, transportation of spent nuclear fuel all do involve carbon emissions.

Arnie Gunderson writes in 2024 that "We would have to build 1,400 more [1000 MWe plants] within ten years to noticeably impact the pace of climate change. Developing untested technologies such as 'Small Modular Nuclear Reactors' will take decades longer." [2]

Gunderson wrote in 2016 that existing nuclear power plants only made a 3 percent reduction in annual CO2 emissions, and if a huge investment of $8.2 trillion was made in building 1000 large nuclear plants, it would only displace 6.1 percent of the total CO2 released. [3] With 64 gigatons of CO2, 1000 new (1000 MWe) nuclear reactors would only displace 3.9 gigatons of CO2.

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[1] A Mycle Schneider Consulting Project, Paris, *The World Nuclear Industry Status Report 2024*, September 2024. WNISR Project website www.WorldNuclearReport.org

[2] Arnie Gundersen, article for Truthout, "Welcome to Planet Vogtle! The Lessons of Georgia's Nuclear Boondoggle, July 1, 2024. https://www.fairewinds.org/nuclear-energy-education/truthout-nuclear-power-is-not-green-energy-it-is-a-fount-of-atomic-waste-arnie-gundersen

[3] Arnie Gundersen, *Truthout*, "Nuclear Power Is Not 'Green': It is a fount of Atomic Waste," November 14, 2016. Truthout: Nuclear Power Is Not "Green Energy": It Is a Fount of Atomic Waste - Arnie Gundersen #GND

To recap: Gunderson and the World Nuclear Association's own calculations show that a thousand new 1000 MWe (or 1000 gigawatts of electricity), new nuclear power plants would offset only 3.9 gigatons of CO_2 in 2050; 3.9 gigatons out of 64 gigatons is only 6.1 percent of the total CO_2 released to the atmosphere in 2050. [4]

Tim Judson of the Nuclear Information and Resource Service sums it up: "Nuclear power is not a climate solution: It is too dirty, too dangerous, too expensive and too slow." [5] [6]

The facts are not causing the U.S. Congress to question the myths they've been fed and the new house bill H.R. 9710, the "Small Modular Reactor Demonstration Act," throws more taxpayer money into an endless money pit. [7] The collection of ratepayer fees ceased a decade ago in 2014 because DOE has no repository program.

The ADVANCE Act of 2024 passed by Congress conveniently ignores the spent nuclear fuel from new reactors that the DOE is promoting and DOE has no plan for even assessing those costs and tax payer liabilities.

Never-economical and highly polluting spent fuel reprocessing – Looking at the lessons not learned

The nuclear industry promotors keep saying that spent nuclear fuel reprocessing or "recycling" is the answer to the problems of spent nuclear fuel. And yet, these nuclear promotors never discuss the cost of reprocessing or who will pay for it. They also never discuss how environmentally polluting reprocessing, or "recycling" is.

The nuclear promotors are seeking to create the illusion of a solution and before any reprocessing facility is sited, they seem to want to ensure that they further gut the National Environmental Protection Act (NEPA) process.

The Department of Energy tries to make its failure to clean up its mess from spent fuel reprocessing seem unrelated to the commercial nuclear industry, but Robert Alvarez wrote, DOE has not even cleaned up its mess from spent fuel reprocessing from the nuclear weapons program:

> "Nuclear recycling in the U.S. has created one of the largest environmental legacies in the world…According to the DOE, treatment and disposal will cost more than $100 billion; and

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[4] World Nuclear Association, January 31, 2016. https://world-nuclear.org/news-and-media/press-statements/1000-gigawatts-of-new-nuclear-capacity-will-suppor

[5] Editorial Team: Lucia Amorelli, Dylan Gibson, and Tamra Gilbertson, *Hoodwinked in the Hothouse: Resist False Solutions to Climate Change*, Third Edition, 2021. Climatefalsesolution.org https://drive.google.com/file/d/1VQR_AOsVWn0xoFXCODB7sBKLu4IXTTzx/view?pli=1

[6] Karl Grossman, Counterpunch, Hoodwinked in the Hothouse (article), September 24, 2024. https://www.counterpunch.org/2024/09/24/hoodwinked-in-the-hothouse/?fbclid=IwZXh0bgNhZW0CMTEAAR3Lotn_dAndPNNi5kC0ta3Dx-TL8GG1uj48FEWZE3cWY6oOsBWwuBSZfk0_aem_wYO38HCeymSXy7YSLttjCw

[7] Jonathan Miller, E&EDaily, "House committee sets markup of DOE, advanced nuclear bills," September 23, 2024. https://www.eenews.net/articles/house-committee-sets-markup-of-doe-advanced-nuclear-bills/

> after 26 years of trying, the Energy Department has processed less than one percent of the radioactivity in the wastes for disposal. By comparison, the amount of wastes from spent power reactor fuel recycling in the U.S. would dwarf that of the nuclear weapons program…" [8]

The Department of Energy and nuclear promotors avoid any discussion of the cost of recycling or reprocessing spent nuclear fuel. But as Robert Alvarez wrote, reprocessing the nation's spent nuclear fuel is too expensive:

> "As a senior energy adviser in the Clinton administration, I recall attending a briefing in 1996 by the National Academy of Sciences on the feasibility of recycling nuclear fuel…But then came the Academy's unequivocal conclusion: the idea was supremely impractical. It would cost up to $500 billion in 1996 dollars and take 150 years to accomplish the transmutation of plutonium and other dangerous long-lived radioactive toxins. Ten years later the idea remains as costly and technologically unfeasible as it was in the 1990s." [9]

Never mentioned by nuclear promotors is that reprocessing is extensively polluting to the environment (air, water, land) and thus to people and other living things. [10] But Alvarez points out, the radiological contamination due to spent nuclear fuel reprocessing is extensive:

> "In Europe reprocessing has created higher risks and has spread radioactive wastes across international borders. Radiation doses to people living near the Sellafield reprocessing facility in England were found to be 10 times higher than for the general population….Health studies indicate that significant excess childhood cancers have occurred near French and English reprocessing plants…" [11]

Reprocessing increases the volume of radioactive wastes many-fold. World-wide, spent fuel reprocessing has been costly, highly polluting, and has resulted in vast stocks of plutonium that are a liability to store or dispose of.

All nuclear reactors create plutonium-239; spent fuel storage and reprocessing to recover plutonium increases weapons material proliferation concerns.

In the UK, France, and other countries that reprocess their spent fuel, they still need but do not have needed permanent repositories for their spent fuel or high-level waste from

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[8] Robert Alvarez and Miriam Pemberton, *Foreign Policy in Focus*, "Nuclear Recycling Fails the Test,' July 2, 2008. https://fpif.org/nuclear_recycling_fails_the_test/

[9] Robert Alvarez and Miriam Pemberton, *Foreign Policy in Focus*, "Nuclear Recycling Fails the Test,' July 2, 2008. https://fpif.org/nuclear_recycling_fails_the_test/

[10] Pete Roche et al., Greenpeace France, *The Global Crisis of Nuclear Waste – A Report Commissioned by GP France*, November 2018. "In addition to direct discharges of nuclear waste via pipelines, and atmospheric releases of radioactivity, reprocessing produces multiple other waste streams, the most hazardous of which are liquid high level wastes." Difficulties with designing permanent disposal facilities are also described.

[11] Robert Alvarez and Miriam Pemberton, *Foreign Policy in Focus*, "Nuclear Recycling Fails the Test,' July 2, 2008. https://fpif.org/nuclear_recycling_fails_the_test/

reprocessing. In addition, the product of reprocessing is the recovery of plutonium. And hundreds of metric tons of separated plutonium are a liability to store or dispose of. [12]

In France, despite its reprocessing, their spent fuel pools are filling up with mixed-oxide (MOX) fuel that they don't reprocess and now requires about 30 years of pool cooling, rather than the typical five years, prior to dry storage. [13] They are now facing an emergency in the need to build another refrigerated pool for storage of spent MOX fuel as they continue to struggle to obtain a disposal repository. [14] [15] The short-sightedness of the nuclear industry is not limited to the U.S. [16] [17] In the U.S., the Department of Energy pursued MOX fuel for years, culminating in the cancelled MOX plant at the DOE's Savannah River Site. The cancelled MOX plant was to use surplus plutonium from weapons programs, rather than from recovering the plutonium from c;mercial nuclear spent fuel.

In the 1970s in the U.S., the problem of running out of space to store spent nuclear fuel was becoming a serious pinch point. [18] The reprocessing plant at West Valley in New York state was causing radiological pollution of groundwater and air and the giving high radiation doses to workers. It was not economical to operate or to upgrade. A different reprocessing facility was built in Morris, Illinois, but it could not function reliability or be upgraded affordably. [19] [20]

The never-used reprocessing facility designed and built by General Electric was called the Midwest Fuel Recovery facility in Morris, Illinois. It was not shut down due to policy or environmental concerns; it was built and subsequent testing of the facility indicated that the through-put would be too small to be profitable. It became apparent during the testing that the plant would never be reliable and that frequent repairs would be needed. Those repairs would

[12] Frank N. von Hippel and Masafumi Takubo, International Panel on Fissile Materials (IPFM), *Banning Plutonium Separation*, 2022.

[13] Institut de Reioprotection et de Surete Nucleaire, IRSN, Assessment of dry storage possibilities for MOX or ERU spent fuels, IRSN Report No. 2019-00903, French Issue April 2019, English translation of 2019-00265 also issued April 2019.

[14] Benjamin Mallet, LA HAGUE, France (Reuters), Syndicated Content, wtaq.com, "France seeks strategy as nuclear waste site risks saturation points," February 2, 2023. https://wtaq.com/2023/02/02/france-seeks-strategy-as-nuclear-waste-site-risks-saturation-point/

[15] Reuters.com, "French nuclear waste agency applies for new storage site," January 17, 2023. https://www.reuters.com/business/energy/french-nuclear-waste-agency-applies-new-storage-site-2023-01-17/

[16] Department of Energy, Disposition of Surplus Plutonium, Appendix J, Evaluation of Select Reactor Accidents With Mixed Oxide Fuel Use at the Browns Ferry [Alabama, BWR] and Sequoyah [Tennessee, PWR] Nuclear Plants, 2015. This appendix gives a history of MOX fuel testing in the US up to 2015.

[17] *Friends of the Earth*, "Duke Energy Abandons Plutonium Fuel (MOX) Testing Program in South Carolina Reactor," circa 2008, https://foe.org/news/2009-11-duke-energy-abandons-plutonium-fuel-mox-testing-prog/ [accessed February 27, 2023]

[18] See https://www.nrg.gov/docs/ML1928/ML19281B029.pdf, 1979, where a document for Zion describes the problem of inadequate capacity of spent nuclear fuel pools and the re-racking of storage in SNF pools of the era.

[19] U.S. Nuclear Regulatory Commission, Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors, NUREG-0002, August 1976, GEMAR, (Volume 5 ML071000192). See the comments of J. Gustave Speth, Arthur R. Tamplin, Thomas B. Cochran and others in Volume 5 of the EIS.

[20] National Academies Press, *Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report*, 2006. https://nap.nationalacademies.org/read/11263/chapter/50

involve costly delays and would entail high worker radiation exposure. Spent nuclear fuel shipped to the Morris facility was never reprocessed and has been stored for years in a spent fuel pool at the facility.

A side note — The tracking of spent nuclear fuel shipped to the Morris Operation is a bit hard to follow because some of the fuel shipped there was returned to the utility that shipped it. [21] [22] A small amount of SNF was shipped from Lacrosse BWR to the Morris Operation in 1980 and then returned, as planned in 1981. Point Beach spent nuclear fuel was shipped to the Morris Operation before 1979 and later returned, apparently to Point Beach, between 1979 and 2007. [23] [24] A 1994 Energy Information Administration report, Spent Nuclear Fuel Discharges from U.S. Reactors 1992, is consistent with recent reporting and lists the 674 MT of SNF at Morris.

Chemical reprocessing of spent nuclear fuel, like the reprocessing conducted to obtain plutonium for nuclear weapons at the Department of Energy's Hanford facility, creates vast amounts of radioactive and chemically toxic liquid waste. It is a challenge the Department of Energy continues to struggle with as tanks of liquid waste continue to leak at Hanford and DOE fails to be able to build a vitrification plant. The recovery of plutonium from the spent fuel entails extensive processing and creates vast stores of weapons-usable plutonium.

Another nuclear weapons material is uranium-235. Uranium enrichment plants are used to separate uranium-238 from the lighter uranium-235. Uranium-235 could also be recovered in reprocessing of enriched fuel. However, the reprocessing to recover U-235 is costly and results in too many radioactive contaminants, as was learned with the reprocessing of highly enriched spent fuel at the Idaho National Laboratory from the naval nuclear programs and DOE research programs. The recovered uranium-235 at the INL was only usable for a plutonium production reactor at the Savannah River site that is no longer used.

Robert Alvarez also wrote about the problems with recovered uranium:

> "Reprocessed uranium also contains undesirable elements that make it highly radioactive and reduces the efficiency of the fuel. For instance, the build up of uranium-232 and uranium-234 in spent fuel creates a hazard requiring extraordinary measures to protect workers. Levels of uranium-236 in used fuel impede atom splitting; and to compensate for this 'poison,'

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[21] K. J. Eger, *Morris Operation, Morris, Illinois*, NEDO-20969B2, January 1979. ML19305A290, 166 page report covering January 1972 to December 1978.

[22] DOE-funded Spent Fuel and Waste Disposition program, Spent Nuclear Fuel and Reprocessing Waste Inventory, FCRD-NFST-2013-000263, Rev. 9, PNNL-33938, November 2022. Table 2-3 lists spent fuel stored at Morris at 674.29 metric tons and coming from Cooper, Dresden 2, Monticello, Haddam Neck and San Onofre.

[23] Office of Nuclear Security and Incident Response, *Public Information Circular for Shipments of Irradiated Reactor Fuel*, NUREG-0725, Rev. 15, ML101390089. See Table 3-1 for shipments of commercial nuclear spent fuel between 1979 and 2007.

[24] The LaCrosse Boiling Water Reactor, in Genoa, Wisconsin, requested that the Morris Operation temporarily take some spent fuel as their pool is filling and the pool reracking effort won't be done in time to avert a reactor shutdown. (ML20147B712). Morris Operation does accept shipments of spent fuel from the LaCrosse BWR in 1980 and then returns the SNF in 1981. Significant shipping cask contamination problems occur and are reported in 1981 when the SNF is returned to the LaCrosse BWR facility. (ML20009G683)

recycled uranium has to undergo costly 'over-enrichment.' Contaminants in reprocessed uranium also foul up enrichment and processing facilities, as well as new fuel. Once it is recycled in a reactor, larger amounts of undesirable elements build up – increasing the expense of reuse, storage and disposal. Given these problems, it's no surprise that DOE plans include disposal of future reprocessed uranium in landfills, instead of recycling." [25]

Any fuel enriched in U-235 much above about 10 percent a weapons material proliferation threat. As little as 1000 kg (or 1 metric ton) of HALEU can be used to make a nuclear weapon. [26] The use of high-assay low-enriched uranium (HALEU) fuel is being promoted and the enrichment is up to 20 percent, making HALEU fuel.

Pyroprocessing, a different type of reprocessing that does not use chemicals, was developed for the sodium-cooled fast reactor the Experimental Breeder Reactor, EBR-II. Pyroprocessing releases volatile radioactive gases to the environment but does not require storage of tanks of chemically-laden liquid radioactive waste. Recycling by pyroprocessing is expensive and radiologically polluting, however, and it may be a necessary step for the storage or disposal of sodium-bonded reactor fuels. Yet, no one is talking about who will pay for the pyroprocessing or where it will be conducted.

The Experimental Breeder Reactor – II (EBR-II) operated from 1965 to 1994 could provide about 19 megawatts-electric (MWe) to be utilized by the INL. [27] Some of the waste from EBR-II is being treated at INTEC, while EBR-II driver fuel is being pyroprocessed to make HALEU at INL's Materials and Fuels Complex. **Spent fuel reprocessing with pyroprocessing increases the radiological airborne emissions from the INL 170-fold based on DOE/EA-2063.** DOE plans to treat at least 165 pounds of sodium-bonded EBR II driver fuel pins into material for high assay low enriched uranium fuel production (HALEU) each year until all pins have been treated, no later than the end of 2028. Expansion of salt-cooled reactors would mean many metric tons of spent fuel to be treated. **Pyroprocessing is highly polluting, despite the small amount of spent fuel being treated and the long time that pyroprocessing requires to treat just a small amount of spent fuel.**

High-temperature gas-cooled reactors in China continue to suffer from poor reliability

While there are few details about the reasons for continued difficulty in operating China's new high-temperature gas-cooled reactors, little power is being generated from them. Difficulties

[25] Robert Alvarez and Miriam Pemberton, *Foreign Policy in Focus*, "Nuclear Recycling Fails the Test,' July 2, 2008. https://fpif.org/nuclear_recycling_fails_the_test/

[26] R. Scott Kemp, Edwin S. Lyman, Mark R. Deinert, Richard L. Garwin, and Frank N. Von Hippel, *Science*, "The weapons potential of high-assay low-enriched uranium," June 6, 2024. https://www.science.org/doi/10.1126/science.ado8693

[27] Susan M. Stacy, *Proving the Principle – A History of The Idaho National Engineering and Environmental Laboratory 1949-1999*, Idaho Operations Office of the Department of Energy, DOE/ID-10799, 2000. p. 165 describes the EBR-II reactor but incorrectly overstates its electrical generation capacity as 62.5 megawatts. The EBR-II was a 62.6 megawatt (thermal) reactor with a 19 megawatt electrical generation capacity.

had caused years of delays in operation of the new reactors, and now it appears that it remains challenging to keep them operating.

The World Nuclear Industry Status Report 2024 tracks how much power is being generated by nuclear energy worldwide and much more about the nuclear industry. [28] China's high-temperature gas-cooled reactor design is called the HTR-PM and consists of two 100 MWe reactors connected to a single turbine. The design uses TRISO fuel. The construction time had been estimated to take "50 months" but it took 11 years to reach full power operations and be declared as commercially operating. But apparently the operating power level has also been derated, reducing the power output. **And the HTR-PM's load factor for 2023 was just 8.5 percent. That means the pair of high-temperature gas-cooled reactors produced power only for about one month out of the entire year. The experience with China's gas-cooled reactors appears to mirror the lousy experience with the gas-cooled reactors at Fort St. Vrain.** The cost for China's HTR-PM reactor pair was estimated to be about $2,000/kWe, but by 2017 had roughly increased to around $6000 to $8000/kWe. See *The World Nuclear Industry Status Report 2024.* [29] **And remember that the U.S. taxpayer is paying millions annually for continued storage of the Fort St. Vrain spent nuclear fuel stored in Colorado and Idaho.**

No design under review by the NRC, yet Aurora Oklo hype is glowing with "getting the green light"

Newsweek reported in September the great enthusiasm about the proposed Aurora Oklo reactor "getting the green light" — even though there is no license application under review by the U.S. Nuclear Regulatory Commission and the agreement with the Department of Energy was made back in 2019. [30]

Aurora Oklo has made two applications to engage with the NRC, one for a 1.5 megawatt-electric MWe compact fast micro-reactor, and more recently, an application to engage with the NRC for a larger 15 MWe reactor.

The first license application of Aurora Oklo to the Nuclear Regulatory Commission for a 1.5 MWe compact fast micro-reactor was denied by the NRC on January 6, 2022. The Nuclear Regulatory Commission rejected the Oklo application. for the novel heat pipe 1.5 MWe reactor because of significant information gaps in its description of Aurora's potential accidents as well as its classification of safety systems and components. [31] Oklo can submit a revised

[28] A Mycle Schneider Consulting Project, Paris, *The World Nuclear Industry Status Report 2024*, September 2024. WNISR Project website www.WorldNuclearReport.org

[29] A Mycle Schneider Consulting Project, Paris, *The World Nuclear Industry Status Report 2024*, September 2024. WNISR Project website www.WorldNuclearReport.org

[30] Monica Sager, *Newsweek*, "Sam Altman – Backed Nuclear Startup Gets Greenlight for First Microreactor," September 25, 2024. https://www.newsweek.com/oklo-artificial-intelligence-sam-altman-nuclear-energy-1959180

[31] NRC Press Release, NRC denies Oklo Combined License Application for Lack of Information; Company May Reapply in the Future, No.: 22-002, January 6, 2022. https://www.nrc.gov/docs/ML2200/ML22006A267.pdf and letter to Oklo at https://www.nrc.gov/docs/ML2135/ML21357A034.pdf

application but had not done so as of September 2024. In 2019, Oklo signed a Department of Energy site use permit to build the reactor at the Idaho National Laboratory site, so this is old news.

Now Aurora Oklo has submitted paperwork to engage with the Nuclear Regulatory Commission to build a much larger reactor, a 15 MWe, Aurora Powerhouse.[32]

Neither Oklo Aurora nuclear reactor proposals have been accepted for review by the NRC, as of September 2024. The communications between Aurora Oko and the NRC reveal only the transmittal letters and little information about the proposed reactor.

Small modular reactor and microreactor accident consequences can cause catastrophic public radiation doses

Small modular reactors are generally loosely defined as being less than 300 mega-watts-electric (MWe) and microreactors have generally been expected to be transportable via a conventional shipping container fit for highway transport and probably be less than 10 MWe. While a large conventional commercial nuclear power reactor may be about 1000 MWe, the public is often led to expect that the radiological consequences of small and micro- reactors will be far less than a large conventional commercial nuclear reactor. But the safety features of various proposed reactors are not necessarily known and many may lack any significant structure containment. Without containing the radiological release from small and micro- nuclear reactors, the small and micro- reactors can release enough radioactive materials for members of the public to receive significant radiation doses. [33] [34]

A perspective on the potential radiological dose consequences from microreactors is provided by two studies prepared by the Idaho National Laboratory. [35] [36] The studies are expressed in terms of the energy produced by the reactor in mega-watts-thermal (MWth) rather than in terms of the expected production of electricity in MWe.

The conversion of thermal energy to electric energy depends on the system design, but the MWe may range from about one-third to about one-fifth of the megawatts-thermal (MWth).

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32 https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/licensing-activities/pre-application-activities/okla-aurora-powerhouse.html

33 M. V. Ramana and Kerrie Blaise, Regulation vs promotion: Small modular nuclear reactors in Canada, Elsevier - Energy Policy, Volume 192, September 2024, 114228. https://www.sciencedirect.com/science/article/pii/S0301421524002489#bib93

34 Troy P. Reiss, Idaho National Laboratory, Prepared for the U.S. Department of Energy, *Evaluation of Microreactor Inhalation Dose Consequences*, INL/EXT-20-58163-Revision-0, April 2020.

35 Troy P. Reiss, Idaho National Laboratory, Prepared for the U.S. Department of Energy, *Evaluation of Microreactor Inhalation Dose Consequences*, INL/EXT-20-58163-Revision-0, April 2020. https://www.osti.gov/biblio/1616677

36 Troy P. Reiss, Idaho National Laboratory, Prepared for the U.S. Department of Energy, *Evaluation of the MARVEL Reactor Inhalation Dose Consequences*, INL/EXT-20-61119-Revision-0, August 2020.

The Experimental Breeder Reactor II (EBR-II), built at the Idaho National Laboratory at what was then the Argonne National Laboratory – Wests, was a sodium-cooled fast neutron spectrum reactor. It was designed for a thermal output of 62.5 MWth and an electrical capacity of about 20 MWe. [37] The electrical output in megawatts is always less than the mega-watts-thermal, and for the sodium-cooled fast-neutron reactor the EBR-II, the electricity generation (MWe) was about one third of the thermal power (MWth).

The small, roughly 85 kWth MARVEL project testing at the Idaho National Laboratory is for the liquid metal sodium-potassium eutectic and will use fuel similar to TRIGA fuel (Type 304 stainless steel cladding and uranium-zirconium-hydride). [38] The fuel for MARVEL is to use high assay low enriched uranium (HALEU) that can be enriched up to almost 20 percent in uranium-235. Conventional light-water reactors in the U.S. use enrichments below 5 percent. TRIGA fuels have been used in research reactors and enrichment of the TRIGA fuel has varied, with some TRIGA fuel far above 20 percent enrichment.

The MARVEL project thermal energy level varies somewhat in the documentation but it was stated that "The MARVEL concept is a 100 kilowatt (kW) thermal (kWth) and approximately 20-kW electric (kWe) generating microreactor." [39] This would indicate that MARVEL would produce approximately 20 kWe from 100 kWth, or only about one-fifth of the thermal power. Note that 100 kWth is only 0.1 MWth.

For the Idaho National Laboratory, and for the purposes of MARVEL testing on the INL site, one study was conducted for MARVEL testing, assuming a 111 kilo-watt-thermal (kWth) reactor and the other study assessed the potential radiological dose consequences of 20 mega-watt-thermal (MWth) for several reactor types. The MARVEL study assumed a 2-year runtime and the 20 MWth microreactor study assumed a 1-year runtime. The longer the runtime, the more fission products that build up and the larger the radiological consequences from an accident. **These assumed runtimes are not bounding of the longer runtimes that would be expected if used for commercial electricity production.**

In addition to fission products that build up in the fuel as the reactor is operated, neutron capture in the reactor creates plutonium and other transuranic radionuclides such as neptunium and americium. For a snapshot perspective of the uranium and transuranic radionuclides for the 20 MWth reactor case at the end of one year of reactor operation, see Table 1.

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[37] C. C. Crothers, Argonne National Laboratory, *EBR-II Primary-Sodium-Storage Facility*, ANL/EBR-003, February 1969. [on osti.gov 4749340.pdf]

[38] A. R. Wagner, J. A. Evans, T. Lange, Idaho National Laboratory, *MARVEL Fuel System and Program Overview*, Undated document, circa 2023, DOE.gov, File: MARVEL-fuel-system-and-program-overview-Adrian-Wagner.pdf

[39] Troy P. Reiss, Idaho National Laboratory, Prepared for the U.S. Department of Energy, *Evaluation of the MARVEL Reactor Inhalation Dose Consequences*, INL/EXT-20-61119-Revision-0, August 2020.

Table 1. Actinide (uranium and transuranics) for 20 MWth reactor at the end of one year.

Isotope	Half-life	Decay Series	Grams
Uranium-234	246,000 year	U-238 series	8.99E+3
Uranium-235	704,000,000 year	U-235 series	2.34E+4
Uranium-236	23,400,000 year	Th-232 series	6.15E+3
Uranium-237	6.75 days	U-233 series	6.52
Uranium-238	4,470,000,000 year	U-238 series	9.51E+5
Neptunium-237	2,140,000 year	U-233 series	2.04E+2
Neptunium-239	2.4 days	U-235 series	3.83E+1
Plutonium-238	87.7 year	U-238 series	1.66E+1
Plutonium-239	24,100 year	U-235 series	2.63E+3
Plutonium-240	6,560 year	Th-232 series	3.55E+2
Plutonium-241	14.3 year	U-233 series	1.08E+2
Plutonium-242	373,000 year	U-238 series	6.93
Americium-241	432 year	U-233 series	1.35

Source: Troy P. Reiss, Idaho National Laboratory, Prepared for the U.S. Department of Energy, *Evaluation of Microreactor Inhalation Dose Consequences*, INL/EXT-20-58163-Revision-0, April 2020. Table notes: The initial enrichment of the fuel in the microreactor analysis was assumed to be only 3 percent and actual microreactor fuel is expected to be closer to 20 percent enriched in uranium-235. Enrichment and burnup will modify the results. In addition, while plutonium-239 has a very long half-life and the grams of Pu-239 remain quite constant, plutonium-241 decay to americium-241 causes a build up of americium-241 over the first few decades. The analysis may be conservative for the short reactor runtimes assumed for testing at the INL but are not conservative for the longer runtimes and increased amount of not only fission products but of the buildup of transuranic radionuclides such as plutonium, neptunium and americium, over the longer runtimes.

I have included the radioactive decay series in Table 1 because this is relevant to understanding the buildup of so-called “naturally occurring” radionuclides in the environment that are actually from reactor operation or accidents. When a radionuclide such as plutonium-238 decays, it decays through the uranium-238 decay series and the decay progeny, although these may be elevated far above natural background levels, they tend to be stated as “naturally occurring.” This is also true for radionluclides such as uranium-236 or plutonium-240 which decay through the thorium-232 series. The U-232 decay series rapidly decays and produces radium-224, and thallium-208, etc. Plutonium-239 decays through the U-235 decay series, albeit very slowly. As some plutonium-239 captures a neutron during reactor operation, it makes plutonium-240. Some plutonium-240 absorbs a neutron and becomes plutonium-241.

Plutonium-241 has often been dismissed because it is only a beta emitter, but Pu-241 decays to americium-241 rather rapidly over the first few decades, whether or not the Pu-241 is contained in the fuel, is released to the environment or is inside the human body, a fact that dose evaluations often miss. Americium-241 is an alpha emitter like plutonium-239, but it is very mobile in water and soil and it is highly retained in the human body and it also has a 59.5 kev gamma adding more damage to tissue. People tend to like the name "Americium" and it has been stupidly used in smoke detector devices. Americium-241 is every bit as bad as plutonium-239 and probably worse but more people don't expect this patriotic sounding radionuclide to be as bad as plutonium. The americium-241 also contributes significantly to the spent nuclear fuel decay heat over time. I point all this out because I want to emphasize that these cited radiological dose studies are not bounding for the longer runtimes (and higher burnup) that may occur in actual operating practice.

Higher enrichment of the nuclear fuel in uranium-235 allows longer runtimes in the reactor before refueling and also means that more fission products build up in the fuel at the end of the fuel's runtime in the reactor.

The release fractions estimated for sodium-cooled fast reactors are compared to a commercial pressurized light-water reactor in Table 2. Release fractions for TRISO-fueled, high-temperature gas-cooled reactors were not included in the INL's study because "Although TRISO fuel was analyzed for inclusion in this document [INL/EXT-20-58163], the complexities of an HTGR analysis are based on particle type, and source terms are based on a functional containment argument for the reactor." The release fractions estimated for molten salt chloride fast reactors were included in INL/EXT-20-58163, as ARF x RF for Kr, Xe, I, Br, Cs, Rb of 1.0 and 1.0E-4 for the remaining elements.

Table 2. Airborne release fractions and respirable fractions.

Reactor release type	**100 percent release, ARF x RF**	**Sodium-cooled fast reactor, ARF x RF**	**Conventional pressurized light-water reactor, ARF x RF**
Noble gases (Xe, Kr)	1.0	0.67	1.0
Halogens (I, Br)	1.0	0.1	0.4
Alkali metals (Cs, Rb)	1.0	0.42	0.3
Tellurium group (Te, Sb, Se)	1.0	6.0E-3	5.0E-2
Barium, strontium	1.0	0.24	2.0E-2
Noble metals (Ru, Rh, Pd, Mo, Tc, Co)	1.0	6.0E-4	2.5E-3
Cerium group (Ce, Pu, Np)	1.0	6.0E-4	5.0E-4
Lanthanides (La, Zr, Nd, Nb, Pm, Pr, Sm, Y, Cm, Am)	1.0	6.0E-5	2.0E-4
Europium	1.0	0.42	2.0E-4
Remaining elements	1.0	2.0E-3	1.0E-4

Source: Troy P. Reiss, Idaho National Laboratory, Prepared for the U.S. Department of Energy, *Evaluation of Microreactor Inhalation Dose Consequences*, INL/EXT-20-58163-Revision-0.

A comparison of radiological doses from a severe radiological release from microreactor is provided in Table 3. Most of the radiological dose is from inhalation and only a small portion is from cloud gamma shine. No ingestion dose is included because the analyses assumed that no one will eat contaminated food or drink contaminated water. Note that doses about 400 rem, the acute radiation whole body dose may be lethal in weeks. [40] **Also note that the radiation doses may far exceed life shortening or lethal doses for a single microreactor at 6000 meters or about 3.7 miles of the accident, with the exception of the 0.111 MWth MARVEL public dose which is below 3 rem.**

Table 3. Microreactor radiological dose comparison.

MW-thermal	Release Type	Distance	Collocated worker, rem	Public, rem
0.111 MWth (2 yr runtime)	100 percent release, MARVEL	100 m worker, 6000 m public	296 rem	2.65 rem
20 MWth (2 yr runtime)	100 percent of the MARVEL case, scaled to 20 MW-th	100 m worker, 6000 m public	53,280 rem	477 rem
20 MWth (1 yr runtime)	100 percent release	100 m worker, 4,700 m public	472,000 rem	8,750 rem
20 MWth (1 yr runtime)	Sodium Fast Reactor	100 m worker, 4,700 m public	15,500 rem	254 rem
20 MWth (1 yr runtime)	Molten salt fast reactor	100 m worker, 4,700 m public	34,100 rem	333 rem
20 MWth (1 yr runtime)	Pressurized water reactor Loss-of-coolant-accident release	100 m worker, 4,700 m public	18,500 rem	159 rem

Source: Troy P. Reiss, Idaho National Laboratory, Prepared for the U.S. Department of Energy, *Evaluation of Microreactor Inhalation Dose Consequences*, INL/EXT-20-58163-Revision-0, April 2020, and Troy P. Reiss, Idaho National Laboratory, Prepared for the U.S. Department of Energy, *Evaluation of the MARVEL Reactor Inhalation Dose Consequences*, INL/EXT-20-61119-Revision-0, August 2020 (for the 111 kWth case). Table notes: A collocated worker is one who is able to proceed to evacuate and is not in the immediate vicinity of the accident. The distance of 6000 meters is about 3.7 miles and the distance of 4,700 meters is about 2.9 miles.

The ***likelihood*** of a severe radiological release from the plethora of proposed small modular reactors and microreactors wasn't presented in INL/EXT-20-58163 and while there are vulnerabilities that can be expected from certain types of reactors, there isn't enough information to make much of a comparison of the accident risks. But a cluster of 10 small or micro- reactors

[40] A radiation dose received in an acute dose is known to have an LD50 of 300 to 400 rad, meaning 50 percent of adults receiving this dose would die within 30 days. See many sources, including *Radiobiology for the Radiologist*, by Eric J. Hall, 5th ed., 2000, p. 134.

means that the risk of having an accident would need to be 10 times less than one large reactor, in order to have the same risk of having a reactor accident.

And while some reactor characteristics and features may lower the accident risk, the risk of a terrorist act to destroy and reactor and spread radioactivity is higher than ever, with or without a war taking place. The means of using assault rifles and drones for acts of terrorism are more readily available to the general public than ever before.

It is a fact that shortly after Russia invaded Ukraine in 2022, there were concerns about the potential to damage the largest nuclear power plant in Europe, the Zaporizhzhia plant. [41] There were fears of a nuclear disaster being caused by deliberate attacks or missed targets.

The public and Congress seems to have bought the fiction that small modular reactors and microreactors are safe, all without design details and with increasingly ineffective regulation by the U.S. Nuclear Regulatory Commission (NRC).

The Fukushima accident was around a trillion US dollars and US Price Anderson Act liability is capped at $13.4 billion for large NRC-licensed nuclear reactors. [42] For small NRC-licensed reactors, under 100 MWe and non-reactor operations, Price Anderson liability remains capped at $500 million per accident. Your home, vehicle, your community, may be compensated in pennies on the dollar, not to mention loss of your health and your family's health and will depend on the circumstances and whether Congress calls upon additional payment. Citizens should keep in mind that Price-Anderson Act liability coverage will not necessarily cover damages at all for consolidated spent nuclear fuel storage, transportation or reactors smaller than 100 megawatts-electric. [43] [44] As you can see from the potential radiological consequences in the table, the loss of life and property from even a reactor producing far less than 100 MWe can be devastating.

[41] Ray Hughes, *The Bulletin of the Atomic Scientists*, "Nuclear power: future energy solution or potential war target?" September 16, 2024. https://thebulletin.org/2024/09/nuclear-power-future-energy-solution-or-potential-war-target/

[42] U.S. Nuclear Regulatory Commission, *The Price-Anderson Act: 2021 Report to Congress, Public Liability Insurance and Indemnity Requirements for an Evolving Commercial Nuclear Industry*, NUREG/CR-7293, Published December 2021. (This report does not discuss Department of Energy reactors or operations.)

[43] See the October 2023 Environmental Defense Institute article, "Will the public be compensated for a radiological release from a spent nuclear fuel storage or transportation accident" Liability coverage ranges from about $13 billion to zero dollars."

[44] Michael Franco, *Newatlas*, "Small modular nuclear reactors get a reality check," May 31, 2024. https://newatlas.com/energy/modular-nuclear-reactors/

Newcomer Aalo Atomics adds to the plethora of proposed new nuclear reactors in the U.S.

A newcomer to the list of proposed new nuclear reactors is the Aalo Atomics reactor and *The Idaho Falls Post Register* reported that Idaho Falls Power is negotiating with Aalo Atomics for seven 10 megawatt-electric (MWe) commercial microreactors. [45]

Aalo Atomics has submitted a pre-application plan to engage with the Nuclear Regulatory Commission, a process that does not involve much information about the proposed design.

The company plans to build a non-nuclear prototype of the reactor. The Aalo nuclear reactor is to be factory-fabricated sodium-cooled microreactor that generates 10 MWe and use uranium zirconium hydride (UZrH) fuel. [46] The uranium-235 enrichment of the proposed fuel was not stated but although stated to be "low-enriched uranium fuel," it is likely to be closer to 20 percent enriched than the under 5 percent enrichment of conventional light-water nuclear reactors.

The concept for the MARVEL microreactor design was inspired from the designs of TRIGA Research Reactors and the SNAP-10A experiment. MARVEL will use TRIGA fuel, a uranium-zirconium-hydride fuel clad in Type 304 stainless steel. The uranium-235 enrichment of TRIGA research reactors ranges from 19.75 to 93 percent. MARVEL's enrichment would be about 19.75 percent. While research reactors using TRIGA fuel were in water, the SNAP-10A reactor primary coolant was sodium-potassium (Na-K). [47]

The Department of Energy's MARVEL microreactor is expecting specially procured fuel in the spring of 2024. The nuclear fuel is being fabricated by Framatome-General Atomics in Romans, France. [48] The fuel for MARVEL is similar to the uranium-zirconium hydride fuel used in TRIGA pool-type research reactors that are in operation at various universities around the world.

The Aalo Atomics reactor and the MARVEL reactor that is to be tested at the Idaho National Laboratory are expected to use TRIGA fuel. The uranium-235 enrichment of TRIGA research

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[45] Cody Roberts, *The Idaho Falls Post Register*, "I.F. negotiates for nuclear microreactors," September 17, 2024. Idaho Falls Power is negotiating with Aalo Atomics for seven commercial microreactors.

[46] *World Nuclear News*, "Aalo prepares for US licensing of microreactor," July 10, 2024. https://www.world-nuclear-news.org/articles/aalo-prepares-for-us-licensing-of-microreactor

[47] A. R. Wagner, J. A. Evans, T. Lange, Idaho National Laboratory, *MARVEL Fuel System and Program Overview*, Undated document, circa 2023, DOE.gov, File: MARVEL-fuel-system-and-program-overview-Adrian-Wagner.pdf

[48] *World Nuclear News*, "TRIGA International begins fabricating MARVEL fuel," February 8, 2024. https://www.world-nuclear-news.org/Articles/TRIGA-International-begins-fabricating-MARVEL-fuel

reactors ranges from 19.75 to 93 percent. While research reactors using TRIGA fuel were in water, the SNAP-10A reactor primary coolant was sodium-potassium (Na-K). [49]

The Aalo Atomics nuclear technology has been stated to stem from the 100 kWth MARVEL reactor to be tested at the INL and the SNAP10A reactor. While research reactors using TRIGA fuel used water as coolant, the SNAP-10A reactor primary coolant was sodium-potassium (Na-K). The Type 304 stainless steel cladding of TRIGA fuel has been studied and experiences corrosion in the liquid sodium-potassium coolant and previous cladding tests were for less than 2 years. [50] **It would seem that serious cladding and other materials challenges that limit the lifetime and reliability of the sodium-cooled Aalo Atomics reactor are to be expected for the Aalo Atomics reactors. Leakage of the stainless steel cladding has allowed the release of fission products from TRIGA fuels.**

The fuel proposed for the Aalo rmicroreactor will also pose a nuclear weapons material proliferation threat, during fuel manufacture as well as before and following use in the reactor. Reprocessing to extract uranium-235 or plutonium from spent fuel is highly polluting and creates more nuclear weapons proliferation risks.

The Aalo Atomics was an FY2024 recipient announced for Gateway for Accelerated Innovation in Nuclear (GAIN), a Department of Energy initiative. While the hope is to locate the first Aalo-1 reactor at the Idaho National Laboratory's Central Facilities Area, about 50 miles west of Idaho Falls.

The Idaho Falls Power agreement would lease space for seven Aalo-1 reactors and be located in Idaho Falls, next to the city's 17.5-megawatt natural gas power peaking plant currently under construction. Idaho Falls would buy some of the total power produced by the reactors and the remaining power would be available for surrounding municipalities and other commercial applications, according to the Idaho Falls Post Register article. It was acknowledged that the project "probably wouldn't come online before 2030."

The Idaho Falls Post Register article stated that "Eventually sodium reactors will be able to recycle spent nuclear fuel." The was no mention of who would pay for reprocessing the spent fuel, or of the highly polluting nature of pyroprocessing the spent nuclear fuel to recover plutonium to use as fuel. The nuclear industry and Department of Energy know that the cost of reprocessing the nation's spent nuclear fuel is prohibitively expensive, so they don't talk about cost.

The Experimental Breeder Reactor II (EBR-II), built at the Idaho National Laboratory at what was then the Argonne National Laboratory – Wests, was a sodium-cooled fast neutron

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[49] A. R. Wagner, J. A. Evans, T. Lange, Idaho National Laboratory, *MARVEL Fuel System and Program Overview*, Undated document, circa 2023, DOE.gov, File: MARVEL-fuel-system-and-program-overview-Adrian-Wagner.pdf

[50] A. R. Wagner, J. A. Evans, T. Lange, Idaho National Laboratory, *MARVEL Fuel System and Program Overview*, Undated document, circa 2023, DOE.gov, File: MARVEL-fuel-system-and-program-overview-Adrian-Wagner.pdf

spectrum reactor. It was designed for a thermal output of 62.5 MWth and an electrical capacity of about 20 MWe. It used enriched uranium driver fuel and uranium-238 blanket fuel. The primary tank for the EBR-II sodium coolant contained about 86,000 gallons of sodium coolant. [51] **A single proposed Aalo Atomics reactor, slated to produce about 10 MWe is half the size of the EBR-II.** But the EBR-II had a containment and was located away from population centers.

Arguments that MARVEL testing has little environmental impact are based on its extremely small inventory of reactor fuel, not its inherent safety. MARVEL, a proposed microreactor that would use a sodium-potassium-cooled thermal neutron spectrum (not fast neutrons) and generate far less than 1 MWe — it would only generate 0.085 MW-thermal or 85 kW-thermal energy. According to the online document, “Deployment of the MARVEL reactor is expected by late 2024/early 2025.” The MARVEL reactor will be located at the Idaho National Laboratory’s Materials and Fuel Complex (MFC) Transient Reactor Test (TREAT) facility. As small as MARVEL is, delays are still occurring.

The Aalo Atomics communication to the U.S. Nuclear Regulatory Commission states that “This plant is to be operational by 2029, approximately five years from the date of this REP, to support the partner utility’s business needs.” [52] This optimistic statement by Aalo is already expected to not be met. I’m expecting that many other optimistic statements by Aalo, also, will not be met.

The Idaho Nuclear Project involving Idaho Falls Power is to include seven Aalo-1 nuclear microreactors, and steam generators, operated through shared structures like the control room and turbine generators, although the arrangement remains unclear.

The truth about Spent Nuclear Fuel Transportation would scare the public and DOE knows it

The U.S. Department of Energy, Office of Nuclear Energy, is focused on the **Spent Nuclear Fuel (SNF) Package Performance Demonstration (PPD) Request for Information (RFI).** DOE plans to conduct physical demonstrations on a full-sized SNF transportation cask. This initiative, inspired by global testing practices and recommendations in reports from the Blue Ribbon Commission on America’s Nuclear Future and the National Academy of Sciences, aims to address transportation concerns expressed by the public and build trust in transportation safety.

The Department of Energy’s Paul Murray explained that the DOE’s effort to plan a “Package Performance Demonstration” is in order to build public trust and confidence in the safety of SNF transportation casks. Murray stated that the “Package Performance Demonstration” program

[51] C. C. Crothers, Argonne National Laboratory, *EBR-II Primary-Sodium-Storage Facility*, ANL/EBR-003, February 1969. [on osti.gov 4749340.pdf]

[52] Aalo Atomics to the U.S. Nuclear Regulatory Commission, Subject: Regulatory Engagement Plan for Idaho Nuclear Project, Document Number: AA-LIC-LET-0001, July 1, 2024. https://www.nrc.gov/docs/ML2419/ML24193A003.pdf

does not and will not include comprehensive testing or verification of the adequacy of the many cask types.

The effort, Murray explains, **is really just for public trust building and not for assuring the adequacy of the transportation casks and their contents.** The reality is that the "Package Performance Demonstration" program should be renamed the "Package Performance and Propaganda Demonstration." [53]

The U.S. Nuclear Regulatory Commission has refused to conduct more rigorous testing of spent nuclear fuel transportation containers. After a National Academy of Sciences study strongly endorsed full-scale tests be conducted on spent nuclear fuel transportation casks in 2006 [54] and the U.S. Nuclear Regulatory Commission Package Performance Study suggested full-scale transportation accident tests in 2003, [55] so far as of 2018 there has been no testing performed to verify that shipping containers will perform as predicted by computerized analysis.

The NRC decided that full scale testing of severe accident conditions would be expensive and that Yucca Mountain is not happening anytime soon. The Blue Ribbon Commission report told the NRC that the status of the Yucca Mountain repository should not drive NRC's decision to not perform transportation accident testing because of their opinion that an interim storage site needed to be developed. [56]

The 2014 report by Sandia Laboratory for the Department of Energy used a title that implied that testing had been conducted when absolutely no testing has been conducted. **In its report "Full-Scale Accident Testing in Support of Spent Nuclear Fuel Transportation," the Department of Energy spins a gibberish excuse that all they really need to do is convince themselves that the public perception of spent nuclear fuel transportation is satisfactory and therefore no full-scale transportation accident testing is needed.** [57]

Another recent report conducted for the Department of Energy uses biased advertising in the title — *A Historical Review of the* ***Safe*** *Transport of Spent Nuclear Fuel*. Despite the title, the 2023 report documents various accident and contamination problems, although no catastrophic problems. [58] While it is a useful report, it fails to point out many obvious problems the U.S. faces concerning the safe transport of spent nuclear fuel. The elephant in the room is the "size matters"

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[53] See Nuclear Waste Technical Review Board Summer meeting presentations for August 29, 2024 at https://www.nwtrb.gov/meetings/past-meetings/summer-2024-board-meeting---august-29--2024 See Paul Murray, Deputy Assistant Secretary, Spent Fuel & High Level Waste Disposition, U.S. Department of Energy, "Spent Nuclear Fuel and High Level Waste" presentation.

[54] National Academy of Sciences, *Going the Distance: The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States*, National Academies Press, 2006.

[55] U.S. Nuclear Regulatory Commission, *Package Performance Study Test Protocols*, NUREG-1768, 2003.

[56] Blue Ribbon Commission on America's Nuclear Future, Report to the Secretary of Energy, 2012.

[57] U.S. Department of Energy, *Full-Scale Accident Testing in Support of Spent Nuclear Fuel Transportation*, Fuel Cycle Research & Development, Sandia National Laboratories, FCRD-NFST-2014-000375, September 2014. http://large.stanford.edu/courses/2017/ph241/watson2/docs/sand2014-17831r.pdf

[58] Kevin J. Connolly, Oak Ridge National Laboratory, and Ronald B. Pope, Argonne National Laboratory, U.S. Department of Energy, Office of Nuclear Energy, *A Historical Review of the Safe Transport of Spent Nuclear Fuel*, ORNL/SPR-2021/2111, November, 3 2023.

issue. Most of the shipments of spent nuclear fuel discussed in the report are for far smaller and lighter shipments. Now commercial nuclear spent fuel casks have been designed to hold more spent fuel assemblies and the casks are heavier than ever before. A new rail car had to be designed for the heavier casks.

From an older report, the number of spent nuclear fuel shipments in the U.S. for commercial spent nuclear fuel from 1964 to 1989 is 2623 casks shipments. [59] [60] Of these, 223 shipments were between 3.1 and 3.3 metric tons uranium (MTU) of fuel with the remaining 2400 shipments less than 2 MTU of fuel per cask, usually far less.

There have been 850 naval spent fuel shipments, 236 U.S. research fuel shipments and 250 foreign research fuel shipments, totaling 1336 shipments.

Future spent nuclear fuel shipments of perhaps 10 MTU in the fuel loaded into the cask and involve much more fuel per cask and much more weight of the fuel and cask combination.

In fact, should spent fuel shipping to a repository or consolidated storage commence, with perhaps 35,000 to 100,000 shipments over 25 years, there would be more spent nuclear fuel shipped in a single year than has been shipped in the U.S. since the first nuclear plants began operating. [61]

And in that time, road, bridge, and rail infrastructure has been crumbling and rail accidents from human error and other causes increasing and have continued increasing since the NRC study reexamined accident frequencies in 2000. [62] The severity of transportation accidents in the United States has also has increased due to increased transportation of oil that sustains long burning high temperature fires, as well as due to crumbling roads and bridges. [63] It is hard to keep up with all the trail derailments and accidents.

And the spent nuclear fuel contents of those casks will contain not only more fuel assemblies, but fuel also contains more fission products from the higher and higher runtimes in reactors (high burnup fuel). Some of the fuel relies on "moderator exclusion" to

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[59] Science Applications International Corporation, Oak Ridge, Tennessee, "Historical Overview of Domestic Spent Fuel Shipments Update," ORNL/Sub—88-997962/1, July 1991. https://www.osti.gov/servlets/purl/5430848

[60] NEI webpage Factsheet at https://www.nei.org/resources/fact-sheets/safe-secure-transportation-used-nuclear-fuel says that the NRC says there have been 1300 safe SNF shipments in the U.S. based on NRC document NUREG/BR-0292, Rev. 2 at https://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0292/ It is unclear how the 1300 safe SNF shipments number was determined from the NUREG/BR-0292 document over the past 35 years.

[61] State of Nevada, Nuclear Waste Project Office, "Transportation of Spent Nuclear Fuel and High-Level Radioactive Waste to a Repository," Factsheet, 1999. http://www.state.nv.us/nucwaste/trans/trfact03.htm

[62] U.S. Nuclear Regulatory Commission, "Reexamination of Spent Fuel Shipment Risk Estimates," NUREG/CR-6672, 2000.

[63] Environmental Defense Institute comment submittal by Tami Thatcher, Public Comment Regarding Interim Storage Partners LLC's Consolidated Interim Storage Facility, Docket NRC-2016-0231, November 19, 2018. See more discussion of transportation issues regarding spent nuclear fuel. http://www.environmental-defense-institute.org/publications/CommentNRC2018Texas.pdf

argue that the fuel won't go critical if water enters the cask. In the past, it was not considered safe or acceptable to ship spent nuclear fuel that could go critical if water entered the cask.

There is also the issue of the fuel in the casks not meeting existing shipping requirements and whether or not the U.S. Nuclear Regulatory Commission will grant exemptions to various safety requirements for the acceptable contents of the shipping casks, see more at the Nuclear Waste Technical Review Board's website at NWTRB.gov.

The radiological consequences of transporting thousands of spent fuel shipments were wished away by technically unsupportable assumptions made by the U.S. Nuclear Regulatory Commission when it approved the consolidated spent fuel storage license for Holtec's proposed facility in New Mexico. The NRC assumes that there are no radiological releases resulting from the transportation of 10,000 canisters of spent nuclear fuel to the proposed Holtec facility based on NUREG-2125 because NUREG-2125 deliberately omits realistic accident scenarios such as impact with a surface that isn't flat. NUREG-2125 also fails to address the increased vulnerability and fission product inventory of high burnup fuel. [64]

Many surfaces along the transportation routes are not flat, and this means that accident impacts are greater than assumed in NUREG-2125. Fires involving longer duration fires or hotter temperatures can occur and are more severe that assumed by the NRC for cask design. [65] [66] Wishfully and willfully assuming away the devastating radiological releases that may occur as the result of a severe transportation accident does not make it so. The consequences of a severe transportation accident are not being included in environmental impact statements such as the one for the proposed Holtec consolidated storage facility in New Mexico. Other forever consolidated storage facilities are being sought despite New Mexico and Texas aggressively working to prevent these away-from-reactor facilities being sited in their states.

High temperature fires burning longer than 30-minutes are more severe than spent fuel transportation casks were designed to withstand. **When putting the spent fuel cask on a train, there is currently no way to avoid sending spent fuel casks along with an unlimited number of oil tankers connected in route, according to the Department of Energy.**

Other countries don't just pretend to care about citizen safety — other countries have conducted more rigorous testing of spent nuclear fuel shipping containers and they impose far more restrictive speed limits and so forth for their transportation by truck or rail. See the U.S.

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[64] Office of Nuclear Materials Safety and Safeguards, Nuclear Regulatory Commission, *Spent Fuel Transportation Risk Assessment*, NUREG-2125, May 2012. http://pbadupws.nrc.gov/docs/ML1212/ML12125A218.pdf

[65] Memo from Marvin Resnikoff to Bob Halstead, "NUREG-2125 Review," July 18, 2013, https://sanonofresafety.files.wordpress.com/2013/06/nureg-2125-review.pdf

[66] U.S. Nuclear Waste Technical Review Board (NWTRB) Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel, December 2010

Nuclear Waste Technical Review Board meeting presentation at the June meeting by the nuclear power program in Switzerland. [67]

The consequences of canister failure must adequately address how much of the radionuclide inventory in a canister is released (see Table 4), which will be higher for higher burnup fuels.

Table 4. Spent fuel canister partial radionuclide inventory. (Source: NUREG-1864, 50,008 MWD/MTIHM (10-yr-cooled))

Nuclide	Bq	Ci	Nuclide	Bq	Ci
Co-60	1.61E14	3133	Pu-238	3.98E15	107440
Kr-85	2.77E15	74800	Pu-239	1.87E14	5060
Y-90	3.40E16	918000	Pu-240	3.47E14	9384
Sr-90	3.40E16	918000	Pu-241	5.23E16	1414400
Ru-106	2.72E14	7888	Am-241	1.20E15	32504
Cs-134	5.13E15	138720	Am-242m	1.97E13	532
Cs-137	5.54E16	1496000	Am-243	3.07E13	816
Ce-144	5.08E13	1374	Cm-243	3.02E13	816
Pm-147	3.37E15	91120	Cm-244	5.66E15	153000
Eu-154	4.15E15	112200			

Table notes: MWD is MegaWatt Days of reactor operation; MTIHM is metric tons initial heavy metal (uranium-238 and uranium-235); Bq is becquerel and is disintegration per second; Ci is curie; 1 curie is 3.7E10 bq. This is only a partial list of radionuclides in the spent fuel.

The spent nuclear fuel canisters placed inside transportation casks are stainless steel and are susceptible to chloride-induced stress corrosion cracking and can be expected to have been exposed to chlorides. The NRC knows that the canisters will experience through-wall cracks. The NRC's current approach is to say they will decide what to do when spent fuel canisters are rotted by corrosion.

In the U.S. an increasing number of severe train accidents have occurred. And crumbling road and bridge infrastructure is real. And there is a growing threat of terrorism from the next deranged person with an assault rifle and a drone to commit unpresented acts of terrorism during spent nuclear fuel transportation.

The actual health harm of the unmonitored and unreported radiation dose that citizens will receive from the spent nuclear fuel shipments is likely to be larger than the industry claims with its inadequate radiation health risk modeling.

[67] Mark Whitmill, Kernkraftwerk Gosgen Daniken AG (KKG), Switzerland, U.S. Nuclear Waste Technical Review Board Summer Board Meeting in Idaho Falls, June 13, 2018. See www.nwtrb.gov The government of Switzerland makes exacting requirements for cask design and requires that they "demonstrate that the casks will withstand all static and dynamic loads during normal operation and under hypothetical accident conditions." A double lid system is mandatory. They require sub-criticality for the most unfavorable cask arrangement and complete flooding. They require demonstrating adequate performance including resistance to aging effects during the planned usage period for all materials. They have far fewer cask shipments and far fewer miles to travel across their country than the U.S. Switzerland has voted to phase out nuclear energy.

If the potential transportation accidents are portrayed realistically, the public is not going to feel safe, nor are the emergency responders.

Efforts announced to reopen Three Mile Island Unit 1 (the one that didn't melt down); pollution for local communities but electricity for predicted needs of data centers

Three Mile Island Unit 1 was finally shutdown because it was a money loser, but now its owner Constellation plans to restart the moth-balled reactor and have it back online by 2028. Constellation Energy made a deal with Microsoft and the power would be used for meeting the predicted expanding power needs of artificial intelligence. The power will not go to meeting the needs of Pennsylvania's citizens. [68]

The citizens living near TMI-1 receive airborne radioactive effluents from the operating plant through steam generator tube leaks and other pathways. Radioactive waste water releases are dumped to the nearby river and include what isn't caught by filtering. The accident risks fall on the citizens. The costs of accidents and of this unsafe misadventure and the long-term storage and mismanagement of spent nuclear fuel will fall to the U.S. taxpayer.

When the Three Mile Island Unit 2 melted about half of the core in 1979 only one year after it came online, citizens were belated warned and a partial evacuation was conducted days after the major airborne radiological releases had already occurred. The elevated cancers in the area were downplayed and then creatively attributed to stress and "radiophobia." Even though epidemiology saw the elevated cancer rates, the elevated cancer rates were said not to be due to TMI-2 accident releases ***because the releases had been too small*** to have caused the cancers. In fact, the monitoring of the releases and the speculated guesses at the quantities released were biased and unreliable. And few noticed that the epidemiology noted and adjusted for the unsurprising rising cancer rates ***due to normal operation*** of the first TMI unit.

Joseph J. Mangano and others published a study, "Infant Death and Childhood Cancer Reductions after Nuclear Plant Closings in the United States. The study found that following nuclear power plant closures, decreases in the radioactivity of milk has been noted and reductions in deaths among infants who had lived downwind and within 64 km of each nuclear plant were noted. Cancer incidence in children younger than 5 years of age were also noted to fall significantly after the shutdowns. [69]

[68] The Lancasteronline Editorial Board, The LNP, "Do benefits of a restarted Three Mile Island Unit 1 outweigh risks to Lancaster County residents who line near it?" September 25, 2024.

[69] Joseph J. Mangano, Jay M. Gould, Ernest J. Sternglass, Janette D. Sherman, Jerry Brown and William McDonnell, Radiation and Public Health Project, "Infant Death and Childhood Cancer Reductions after Nuclear Plant Closings in the United States," *Archives of Environmental Health*, Vol. 57 (No.1), January/February 2002.

Jay M. Gould and Benjamin A. Goldman would write in their book *Deadly Deceit – Low Level Radiation High Level Cover-Up* of excess infant deaths near the Department of Energy's Savannah River Site and near the 1979 Three Mile Island nuclear accident. [70]

More recently, a meta-analysis inadvertently highlighted the Three Mile Island epidemiology problems. [71] A 2020 meta-analysis of low dose and low dose rate epidemiology that included a new 2011 Three Mile Island epidemiology study. [72] The 2020 meta-analysis is a main-stream study conducted with support from the National Cancer Institute, National Institutes of Health and by the Department of Energy.

The results of the 2011 TMI epidemiology cited in the 2020 meta-analysis, when compared to other radiation studies reveals obvious problems, particularly with the leukemia risk. The leukemia rate from TMI-2's meltdown either occurred at doses far below the doses expected to cause leukemia or the releases from the TMI-2 accident were larger than estimated. Recall that elevated rates of leukemia cases that followed the Three Mile Island nuclear reactor accident in March 1979 had been attributed to "stress." [73] [74]

Using an earlier study of TMI epidemiology, some raw figures on the cancer and leukemia rates within a 10-mile radius of the accident are provided in Table 5.

For five years before the March 1979 accident (1975 through March 1979) and for five years after the accident (1981 through 1985), the numbers of cancer and leukemia cases are provided below in Table 5. Just look at how case numbers increased after the TMI accident.

The number of cases in the five years before the accident compared to the number of cases from 1981 through 1985, that included a 2-year lag time, reveal significantly elevated numbers of cancers and leukemias.

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[70] Jay M. Gould and Benjamin A. Goldman, *Deadly Deceit – Low Level Radiation High Level Cover-Up*, Four Walls Eight Windows New York, 1990. ISBN 0-941423-35-2. The finding of excess infant deaths near the Department of Energy Savannah River site around the 1970s and near the 1979 Three Mile Island nuclear accident are described in Jay Gould's book *Deadly Deceit*.

[71] Environmental Defense Institute August 2023 newsletter article, "Three Mile Island, Recent Meta-Analysis Inadvertently Highlights Three Mile Island Epidemiology Problems," and also see May, June and July 2023 newsletter. at http://www.environmental-defense-institute.org/publications/News.23.Aug.pdf

[72] Amy Berrington de Gonzalez et al., *J. Natl Cancer Inst Monogr.*, "Epidemiological Studies of Low-Dose Ionizing Radiation and Cancer: Rationale and Framework for the Monograph and Overview of Eligible Studies," July 2020 (56): 97-113. PMID: 32657348. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7610154/

[73] Maureen C. Hatch, PhD, Sylvan Wallenstein, PhD, Jan Beyea, PhD, Jeri W. Nieves, MS, and Mervyn Susser, MB, BCh, American Journal of Public Health, "Cancer Rates after the Three Mile Island Nuclear Accident and Proximity of Residence to the Plant," June 1991.

[74] Maureen C. Hatch, PhD, Jan Beyea, Jeri W. Neives and Mervyn Susser, MB, BCh, American Journal of Epidemiology, "Cancer Rates after the Three Mile Island Nuclear Accident: Radiation Emissions," September 1990.

Table 5. Selected cancer and leukemia case numbers five years before and five years after the March 1979 Three Mile Island nuclear accident.

Grouping	1 - Lowest fallout	2 - Next to lowest fallout	3 - Next to highest fallout	4 - Highest fallout	
Age, 0-24 years	Childhood Cancers				Total cases
1975-1979	17	1.3	8.7	6	31.83
1981-1985	17	13	12	5	47
Age, 0-24 years	Childhood Leukemia				
1975-1979	1	0	0	0	1
1981-1985	1	0	2	1	4
Age, 25 years or above	Adult Leukemia				
1975-1979	7.8	11.2	6	2	27
1975-1979	14.1	16.3	11.6	7	49
Age, 0-24 years	All Cancers				
1975-1979	538.6	525.5	403.8	254.1	1722
1981-1985	845.9	874.8	707.4	401.8	2829.9
Age, 0-24 years	Lung Cancer				
1975-1979	45.1	63.2	50.7	35	194
1981-1985	88.2	137.4	120.5	93.9	440

Table notes: Data based on Maureen C. Hatch, PhD, Jan Beyea, Jeri W. Neives and Mervyn Susser, MB, BCh, American Journal of Epidemiology, "Cancer Rates after the Three Mile Island Nuclear Accident: Radiation Emissions," September 1990. Fractional case numbers are from splitting a case into different study tracts when the correct tract was not known. Cases in 1975 known to be undercounted in hospital records. The "all cancers" data include the lung cancers presented here.

The 1990 and 1991 study of the Three Mile Island epidemiology studied a 10-mile radius around the reactor. It subdivided regions according the weather patterns, topography and elevation to estimate where the highest radioactive fallout from the accident would be received by wind patterns following the accident. The studies, while acknowledging the lack of reliable monitoring of radioactivity, the authors fully (and wrongly) accepted the statements that the releases had been minimal and that the maximum dose had been below 100 millirem external dose. The stated the average radiation exposure was just 10 millirem (page 403 of Hatch, 1990).

The more recent 2011 TMI epidemiology study has raised the maximum dose to the public to 210 millirem, but retains the 10 millirem mean dose.

The study of Three Mile Island epidemiology funded by the Three Mile Island Public Health Fund, a court-supervised fund, made a number of biased decisions in how it treated the data and arrived at its conclusions. The improperly low 1975 case numbers, from hospital data problems, were improperly utilized to create a rate change that would minimize the effect of the 1979 accident. The study authors in the 1991 TMI study by Hatch [75] noticed the steep rise in cancer cases in 1982 in regions receiving the highest radiation doses from the accident. The study noted that the cancer rates by 1982 were clearly elevated, nearby the plant. But by 1984, the cancer rates had fallen to preaccident levels. The elevated cancers and leukemias were then attributed to "stress" and many statements were made asserting that stress might be a plausible cause of the elevated cancers and leukemias. ***Radiation was soundly, but wrongly, dismissed as a cause of the elevated rates of cancer and leukemia cases.***

Everyone should watch *Radioactive – The Women of Three Mile Island*, by Three Mile Island Productions. See the 2023 trailer at **https://radioactivethefilm.com/** **It Won the Audience Award for Best Feature Documentary at Dances with Films Festival – NYC.**

Articles by Tami Thatcher for October 2024.

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[75] Maureen C. Hatch, PhD, Sylvan Wallenstein, PhD, Jan Beyea, PhD, Jeri W. Nieves, MS, and Mervyn Susser, MB, BCh, American Journal of Public Health, "Cancer Rates after the Three Mile Island Nuclear Accident and Proximity of Residence to the Plant," June 1991.