Critique of
"The Future of the Nuclear Fuel Cycle:
An Interdisciplinary MIT Study (2011)"

Developed by the Science Council for Global Initiative
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1. The Study recommendations on actions to deal with spent nuclear fuel and waste do not recognize the importance of the technological options to reduce the radiological toxicity, which could have great impact on waste management.

One of the main Study recommendations is: *"Planning for long term interim storage of spent fuel – on the scale of a century – should be an integral part of nuclear fuel cycle design."*

This recommendation is based on an implicit assumption that spent nuclear fuel is a *de-facto* waste form destined for ultimate disposal, and that it would take a long time to develop repositories. The Study ponders whether the spent nuclear fuel is a resource or a waste. Since the Study speculates on a large supply of low-price uranium that will continue to meet rising demand for many decades, the value of spent fuel as a resource is diminished. However, there is another dimension to this equation. The actinides contained in the spent fuel are potentially a valuable resource. They are also a long-term radiological risk, and thus must be managed accordingly. The radiological toxicity of the LWR spent fuel constituents is presented in Figure 1 below.

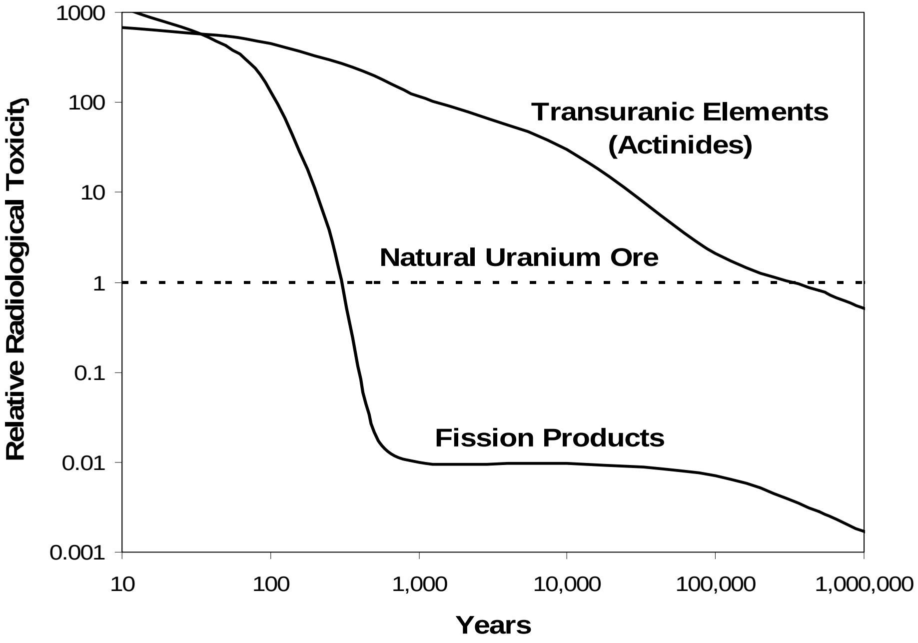

Figure 1. Radiological toxicity of LWR spent fuel constituents as a function of time

Radiological toxicity here is a relative measure of the cancer risk if ingested or inhaled, which we have normalized to that of the original natural uranium ore. As mined, the ore contains uranium along with decay products that have accumulated by its (very slow) decay over millennia. Normalization to the natural uranium ore from which the spent fuel originated is a useful but somewhat arbitrary relative standard. If the radiological toxicity drops below the natural uranium ore level we would be disposing of nuclear wastes that had no greater hazard than the uranium found naturally. The point at which the radiological toxicity curve crosses the natural uranium line then can be defined (at least loosely) as an effective lifetime of the waste components.

For all practical purposes, the radiological toxicity due to the fission product portion of the waste decays with (approximately) a 30 year half-life, due to the dominance of strontium and cesium isotopes. It drops below the natural uranium ore level in about 300 years, and becomes harmless in well under 1,000 years. On the other hand, the radiotoxicity level associated with the actinide portion stays far above that of natural uranium ore for a very long time, and remains at least three orders of magnitude higher than that for the fission products for hundreds of thousands of years. This is why following the National Academy of Sciences Committee recommendation, the EPA standards and NRC regulations for the Yucca Mountain repository extended the regulatory timeframe from the original 10,000 years to one million years.

The important point is this: if 99.9% of actinides could be removed from the waste form, then the radiological toxicity of the remaining 0.1% actinides would stay below the level of natural uranium ore at all times and the effective lifetime of the waste would be dictated by the fission products. If the actinides were mostly removed from the waste stream, the EPA standards and the NRC regulations [whether they cover 10,000 years or millions of years] can be met on an *a priori* basis.

Needless to say, this is an extraordinarily important fact, and the MIT Study ignored it.

2. The role of fast reactors in the analysis of future fuel cycle options is misrepresented and therefore its impact is grossly underestimated.

A system analysis of future fuel cycle options performed by the MIT Study reached the following conclusion:

“A key finding of this analysis is that reactors with conversion ratios much higher than one are not materially advantageous for a sustainable fuel cycle – a conversion ratio near unity is acceptable and has multiple advantages.”

In assessing the impact of fast reactors on the uranium resource requirements, the above conclusion was reached because of a combination of several incorrect assumptions regarding fast reactor characteristics:

- The analysis used ALMR (PRISM Mod B) as the representative fast breeder reactor design, with a specific inventory (kg fissile material per megawatt electric) about a factor of two too high. The specific actinide inventory is presented here in Figure 2 as a function of the reactor size.

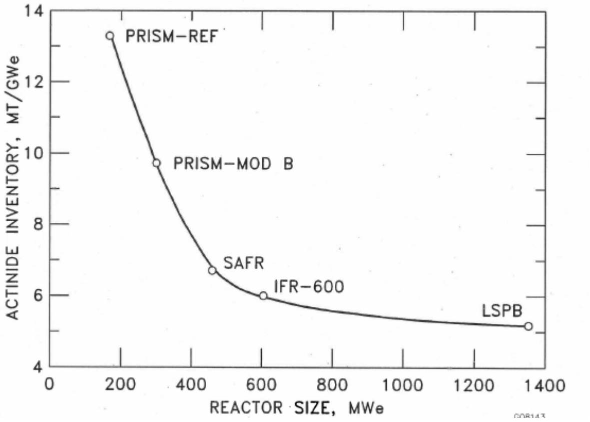

Figure 2. Specific Inventory vs. Reactor Size (MWe)

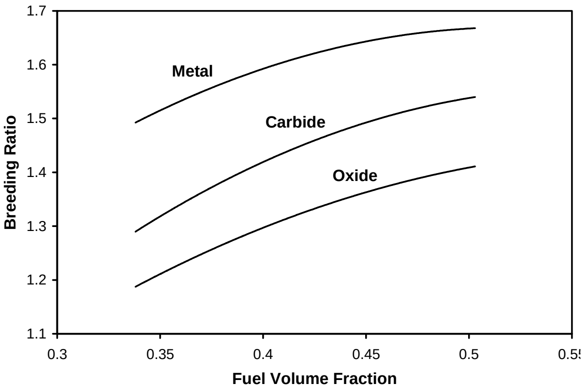

Figure 3. Range of Breeding Ratios

- A breeding gain of 0.23 was assumed, which is too low by a factor of two or three. The breeding ratio potential for what we'll call "advanced" fast reactors is presented in Figure 3 for various fuel types. Here, breeding ratio is the net gain in fissile material over some period of time, compared to the fissile loss from power generation. The metal fuel developed during the Integral Fast Reactor (IFR) program has become the reference fuel in the U.S. It has a breeding ratio potential in the range of 1.50–1.65. In the early years of deployment, the high breeding gain is not needed, but it is there from the start, and it can be used by simply deploying more U^{238} "blankets"—reflector regions actually—to capture a higher fraction of the neutrons leaving the core. If you don't need the plutonium early in fast reactor deployment, you would not load full blankets. A key advantage of the fast reactor design is that the plutonium production rate can be easily tailored to plutonium demand.

- The Study states that breeders require a higher fissile inventory than fast burners, to compensate for a higher neutron absorption rate in the blanket. This statement is flatly wrong, indicative of inadequate knowledge of fast reactors.

- When there is a sufficient fissile inventory coming from LWRs, the initial fast reactors do not need to breed, and the blankets can be replaced with reflectors. As the demand for breeding plutonium grows over time, the "burner reactors" can be converted back to breeders. However, continuing to build burners when the fast reactor introduction is constrained by fissile availability is not a viable strategy, which was the focus of the Study.

- The Study assumes that “All spent fuel is cooled for 5 years before it is reprocessed and recycled as fuel." That is perhaps realistic for LWR fuel, but pyroprocessing of fast-reactor fuel can be done while the fuel is still hot, typically after one year cooling for handling purposes. Application of five-year cooling to fast reactors results in a serious overestimate of the ex-core fissile requirement, with a consequent underestimate of the fast reactor's potential market penetration.

- In the Study, fast reactors are deployed in large numbers only after ~2065 and hence have limited influence on the uranium consumption through 2100. In this case, the uranium requirements are dominated by the large number of LWRs built continuously through this century. If the time horizon is extended, the difference between *with* and *without* breeder reactors becomes much more pronounced.

An example of nuclear fuel cycle system analysis more properly done is illustrated in Figures 4 and 5. These figures depict a scenario for world-wide nuclear energy growth, and the impact of fast reactors on the cumulative uranium requirement is very clear. The introduction of breeders can cap the LWR capacity (Figure 4) and hence also cap the ultimate uranium requirements (Figure 5). The divergence of the cumulative uranium requirements (Figure 5) will continue to widen if the plot is extended beyond 2100.

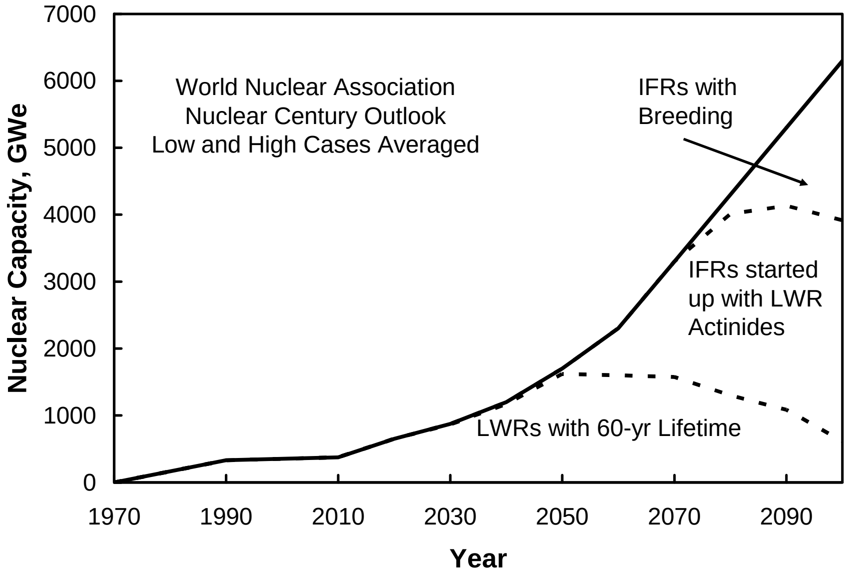

Figure 4. Example scenario for worldwide nuclear energy growth

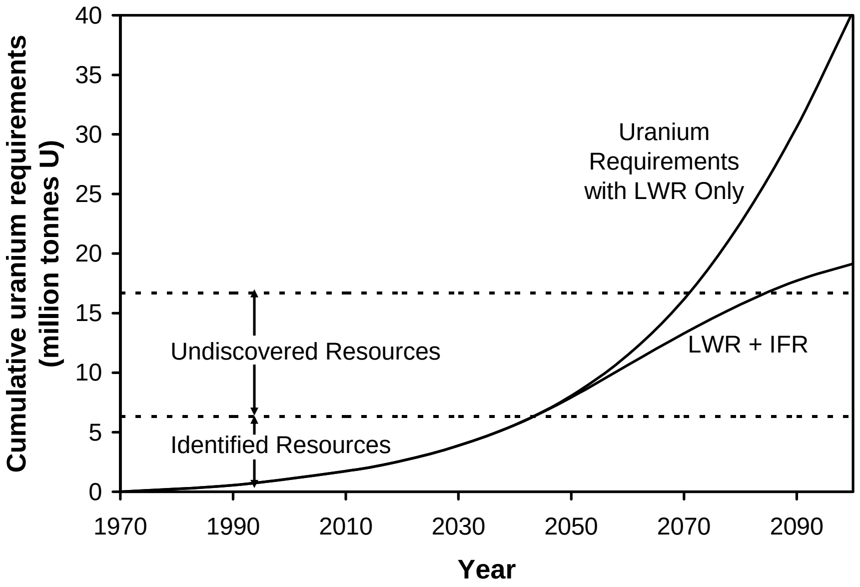

Figure 5. Uranium resource requirements and availability for nuclear growth scenarios with and without fast reactors

3. Fast reactors are critically needed for both limitless energy supply and for waste management.

The public views adequate nuclear waste management as a critical linchpin in further development of nuclear energy. The technical community, therefore, needs to provide a practical approach to deal with the waste issue. The Fukushima accidents call attention to the importance of managing spent fuel safely. It appears the best technical approach is extracting the actinides from spent fuel, which reduces the effective lifetime of nuclear wastes from ~300,000 years to ~300 years. Extracting actinides (and using them to generate power) is by far the best technical approach to dealing with nuclear wastes. The MIT Study fails to mention this important possibility.

If actinide extraction is chosen as a pathway for waste “disposal,” the recovered actinides still must be transmuted to fissile material or fissioned directly. This can be done only in fast reactors. Actinides can be burned in fast reactors, generating energy and at the same time creating more fissile material for the future. A key advantage of fast reactors is that they can be utilized as “burners” when excess plutonium inventories exist, and then converted to “breeders” whenever needed. Only fast reactors can satisfy the waste-disposal mission simply and effectively while extending utilization of the uranium resources by more than two orders of magnitude. Thermal reactors—such as LWRs and high-temperature gas-cooled reactors—utilize less than 1% of uranium resources, even with recycling of plutonium and some of the uranium. Thermalspectrum reactors, even optimized, can extend the resource utilization only marginally, and they cannot burn actinides effectively.

Actinide recycling also requires an efficient processing technology, with improved economics and nonproliferation characteristics. The pyroprocessing technique based on electrorefining, developed in the IFR program, has the potential to recover the actinides from LWR spent fuel as well as to fully recycle fuel in fast reactors. The fundamentals of pyroprocessing have already been demonstrated – this is not new science.

The technology is now ready for pilot-scale demonstration, and it should be given the highest priority. We do not need decades of R&D to pursue all esoteric ideas. We already have in our hands the most advanced technology, technology that no other countries possess.

The MIT Study also talks about the inter-generational equity considerations. We believe that our generation should demonstrate the technologies that will solve the energy supply and waste management problems, rather than proposing a century-long interim storage of the spent nuclear fuel.