Advanced Nuclear Fuel Cycles and Nuclear Wastes

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Advanced Reactors - Background

The earliest development of civilian nuclear power was based on an expectation that oil reserves were being exhausted, with Texas reserves decreasing beyond 1970. The environmental damage caused by coal was already evident. Nuclear power was viewed as an essential complement to, and an ultimate replacement for fossil fuels. It was recognized that thermal spectrum reactors (e.g., LWRs) were extremely inefficient in using the energy content of uranium. LWRs were projected to consume the world's supply of economically recoverable uranium by the end of the 20^{th} century. But the process also produced plutonium that could be used as fuel for fast spectrum reactors. By recycling plutonium in fast reactors (breeders), available supplies of uranium could provide essentially unlimited, inexhaustible energy for the entire world.

While fracking has extended the oil prospects, the environmental damage of all fossil fuel burning is now a matter of concern. Uranium has proven to be more common than originally thought, and world-wide deployment of the current type of LWR reactors continues, supported by perhaps another 50 years of economically recoverable uranium. While these changes have bought time, recycle nuclear power remains the only non-carbon energy source that can provide a long term, reliable base load energy supply. If environmental concerns lead to an early termination of much industrial use of natural gas and solar and wind prove inadequate to support industrial needs, supplies of economically recoverable uranium could be consumed very quickly.

Various new concepts are being explored under the heading "advanced reactors," but in policy discussions, the term generally refers to the recycle/breeder concept and associated recycle technologies. In 1970, a decision was made to focus research on the reactor portion of this fuel cycle. The technology used to extract plutonium from reactor fuel for weapons could be used to provide initial plutonium fuel for the fast reactors. The technology for recycling the fast reactor fuel was left for future development. Modest efforts at developing an effective recycle technology have been undertaken, most notably the ANL Integral Fast Reactor (IFR) Project. This program and all other work on processing the used nuclear power plant fuel were terminated by act of Congress in 1996 based on concerns that spread of plutonium extraction technologies would increase the threat of proliferation of nuclear weapons.

Advanced (recycle) Nuclear Fuel Cycles - Prospects

There are two issues with the breeder/recycle fuel cycle. The first is that the recycle technology has not been developed beyond the concept verification phase. There is no reason to believe that feasible technologies cannot be developed; economic feasibility still needs to be established.

The second issue is: Would the commercialization of a recycle technology present a risk of proliferation of nuclear weapons that outweighs the benefit of an assured, inexhaustible energy supply? This is more a political than a technical question. The technical component is the need for a safeguards program would ensure that any unauthorized program to develop nuclear weapons using the recycle technology would be exposed in time to permit diplomatic or other means of response.

What is the additional proliferation risk implied by recycle nuclear power? It seems reasonable to postulate that any technology that can extract transuranic elements from used nuclear fuel could be adapted to extract weapons usable plutonium from specially selected, or purposefully irradiated nuclear fuel. It should be noted that with the wide-spread access to the high efficiency centrifuge technology for enriching uranium, proliferation based on uranium weapons is simpler, far more accessible, and far less susceptible to (radiation detection and monitoring) safeguarding and inspection than a program based on plutonium extracted from used nuclear fuel. A robust safeguards program is required, whether a recycle technology is or is not developed and deployed. It should also be noted that the complexity of plutonium extraction, coupled with the complexity of plutonium weapons makes this proliferation track far more complex than the uranium track, and well beyond the capability of all but a highly developed industrial establishment.

The technical aspects of a credible safeguards program for a recycle fuel cycle are straightforward. Fuel discharges from nuclear power plants are monitored. Low burn-up discharges, whether from LWRs or from recycle power plants, would need to be specifically tagged and controlled. Facilities for recovery of fissionable material from LWRs, if needed, would require careful monitoring, and could be restricted to the use of a technology that extracts all transuranics rather than selectively extracting plutonium. Storage and transportation monitoring is straightforward due to the accessible radiation signature that would characterize every batch. Recycling facilities also would be subject to inspection and inventory controls, with special attention and priority reactor deployment of any incidental high grade stocks of plutonium. Again, radiation signature tracking simplifies this process. Co-location of breeder reactors and recycling facilities would simplify transportation monitoring, as transportation could be prohibited except for special purposes, such as starting a new facility.

<u>Advanced Nuclear Fuel Cycles - The Path Forward</u>

The first requirement for accessing the unlimited energy resource available with (recycle) advanced reactors would be to distinguish between the technologies for plutonium recovery from LWRs, and technologies that would be appropriate for recycle. Both are carelessly referred to as “reprocessing.” The latter, recycle, has the distinguishing characteristic of recovering essentially all transuranic, thus minimizing the potential for diversion to weapons use and greatly simplifying the waste disposal task.

The second requirement is to explore various technologies such as the electrochemical recycle process to determine both feasibility and economic viability. Since there is large scale deployment of LWRs, that fuel should not be wasted. It would be useful to develop alternative technologies for recovery of all transuranics from LWR fuel for recycle. There is no reason to ease the restriction on processes that selectively recover plutonium and not higher actinides, such as PUREX.

The third requirement is to define the incremental safeguards technologies associated with recycle, and determine their robustness and political feasibility.

Nuclear Wastes - Background

During the wartime and early post-war development of nuclear weapons, as a practical necessity, wastes were considered to be a problem to be dealt with later. This included handling of mining tailing, manufacturing scrap, weapons testing debris, plutonium extraction wastes, research bi-products and wastes, etc. Many of the disposal actions were not adequate for the long term, and in many cases, no provision was made for maintenance of disposal sites. Many deposits of such wastes have now been dealt with, frequently in response to public pressure.

In addition to the detritus of the wartime program, there are excess and degraded weapons materials and other moderate to high enrichment materials for which there is no further planned use. This includes excess weapons materials purchased from Russia following the collapse of the Soviet Union. Down-blending of high enriched uranium for use in commercial reactors has been used to deal with excess high enriched uranium. Plans were developed to blend weapons-usable plutonium with uranium (MOX) for light water reactor use, but this program has faltered. Russia is planning to use some of its excess plutonium, both reactor grade and weapons grade, as fuel in its fast reactors. The Russians have the only currently operating large-scale fast reactors. Based on laboratory and small scale use of plutonium fuels in experimental and research reactors in the US and elsewhere, this is expected to be an effective use of this material. Except for this Russian repurposing program, there are no current programs for dealing with excess weapons grade or reactor grade plutonium.

Another major category of nuclear wastes associated with the weapons development program are the wastes left from extracting plutonium from production-reactor fuel. Here, a clearly defined plan has been in place from early in the nuclear age. The waste has long been planned to be incorporated into borosilicate glass and cast into stainless steel canisters for disposal. The technology for incorporating plutonium extraction wastes into borosilicate glass is well established. This process has been in routine use in France for over 40 years, and has been successfully used for West Valley wastes. Savannah River is processing accumulated wastes. Processing such wastes at other facilities (Hanford and Idaho) present somewhat different challenges, but plans are underway for incorporating these wastes into borosilicate glass.

The Yucca Mountain repository was designed and developed for disposal of this borosilicate glass waste form. Political considerations, primarily focused on the inclusion of unprocessed spent power reactor fuels in the planned disposals in Yucca Mountain, have blocked proceeding with disposal of processed defense wastes.

Nuclear Wastes - Prospects

For lack of a credible alternative, the nuclear power industry settled on a program of interim storage of used nuclear power plant fuel, with a potential encapsulation of the fuel for disposal without further processing. While analyses show that, with proper encapsulation, Yucca Mountain disposal of unprocessed used nuclear fuel would be safe, this proposed action satisfies no one: pro-nuclear advocates consider it a waste of a valuable resource; anti-nuclear advocates see it as a validation of nuclear power.

Proper handling and disposal of nuclear wastes, whether processed or not, can be very expensive, but is technically straightforward. The technologies for handling and packaging of nuclear wastes are well known. The potential radiation and/or chemical exposure associated with these waste, both before and after disposal, can be realistically evaluated. However, the acceptability of any proposed handling or disposal is judged by the acceptability of the associated risk, and there is no scientifically established basis for determining what level of radiation is biologically harmful.

The current regulations are based on a linear, no threshold (LNT) model. This model is based primarily on data from the Hiroshima and Nagasaki weapons survivors who suffered orders of magnitude greater exposures than those potentially associated with nuclear wastes. This model also assumes that all radiation risk is cumulative over time and over the exposed population, ignoring any biological response other than cancer formation. There is considerable anecdotal data suggesting that a risk determination based on LNT is grossly conservative, but there is no consensus on an alternate model. The actual risk of any disposal alternative is almost certainly much less than currently projected.

Essentially all technical research dealing with nuclear waste has focused exclusively on minimizing the risk associated with disposal. The only materials considered to be recyclable have been plutonium and higher transuranic elements. There has been minimal attention to harvesting usable radio-isotopes, or even rare and unique non-radioactive materials.

With an effective recycle technology, the associated waste disposal is greatly simplified. The most hazardous long lived materials are recycled and consumed. The residual wastes can readily be segregated between the small amount of non-recycled, long-lived wastes and the short lived, high radiation materials. Encapsulation and isolation can be tailored to each particular waste streams.

Since weapons production fuel is relatively low burn-up, the content of transuranics is low. It is unlikely that a transuranic recovery technology would be cost effective for these materials, so it is likely that the borosilicate waste form with disposal in Yucca Mountain or equivalent will be appropriate. However, a technology extracting all transuranics from commercial LWRs would likely be economically viable if there were a market (breeders) for the trasuranics, particularly since this would dramatically reduce the complexity (cost) for waste disposal.

Concluding Remarks

Nuclear power is the only known non-carbon base-load energy supply capable of supporting a modern economy. As with any technology, its benefits are not available without risks. Obtaining the long term benefits of nuclear power will eventually require recycling. This will require addressing the safeguards issue. With recycling, the nuclear waste issue is greatly simplified, and costs (fiscal and sociatal) of nuclear waste disposal are greatly reduced.

Whether there is to be recycling or not, the path forward will need to address at least the following:

> The safeguards issue remains.
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> A more realistic characterization of the risks posed by nuclear wastes. The most promising hypotheses postulate that the body's immune response to radiation resembles the type of response that cancer researchers are trying to stimulate using chemical, biological and genetic methods for treating cancers. Improved communication between these research efforts would be mutually beneficial.
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> A credible program for disposal of suitably processed and packaged wastes, and agreement on a disposal location or locations.

If nuclear power is to have a significant long term future, research will need to resume and accelerate on technologies for recycling used nuclear fuels. In addition to providing a long term, inexhaustible energy supply, recycling will permit innovative uses of radiation and of special radioactive elements isolated in the recycle process.

Clear assignment of accountability for the development and implementation of plans and programs for final disposition of each of the classes of nuclear wastes is needed. A full range of options for dealing with used nuclear power plant fuel should be developed. This will require leadership from DOE that is committed to task completion, with supporting technology development that is not dependant on unrelated academic research programs.