The ARC-100 Reactor: An Effective Answer to Nuclear Proliferation Concerns

I. Introduction

Advanced Reactor Concepts, LLC (ARC) is engaged in the development and commercialization of a small, modular reactor (SMR) to be called the ARC-100. This reactor will provide 100 megawatts of electric power (260 megawatts of heat energy) and is designed to be factory produced and installed in a 20 foot diameter silo underground. The ARC-100 is a fast reactor, sodium-cooled, with uranium metal-alloy fuel rods, and operates on a closed 20 year refueling cycle; whereas today most power reactors worldwide use uranium oxide fuel (in rods), are water-cooled, and are refueled by replacing about 1/4 of these rods every 12 to 18 months so that a total refueling of the core occurs every 4 to 6 years. The ARC-100 is based upon well-proven technology that originated from 30 years of successful operation of the Experimental Breeder Reactor II (EBR-II) by the US Department of Energy at the Argonne National Laboratory facilities in Idaho. From this experience confidence was gained that a 20 year operating life of the ARC-100 core is achievable.

II. The ARC-100's Unique Features

The ARC-100's unique features described below allow the reactor to offer considerable advances over the technology used in existing light water reactors (LWRs) that are now installed worldwide.

A. Most of the ARC hardware components are built as modules in factories and are much cheaper to manufacture and quicker to install than LWRs. The ARC-100 can be transported to a site and become operational in 18-24 months, versus the 10-12 year construction period for the traditional LWR.

B. The ARC-100's 20 year refueling cycle simplifies operational complexity and reduces operating costs. LWRs require partial refueling every 12-18 months, which is a complex operation and leads to the storage of spent fuel rods on site in cooling ponds and dry casks. Note that the ARC-100 reactor through its internal physics continually replaces its fuel as it operates.

C. The ARC-100 offers passive safety features that make its operation so effectively failsafe as to be described as "walk-away safe." It will not suffer a core meltdown. Unlike all LWRs, the ARC reactor does not depend on extra pumps, external water reserves, operator intervention or any external system to protect is fuel rods and nuclear core from overheating in a complete loss of electric power due to natural or man-made events impacting the reactor. Its fail safe features derive from the manner that the laws of physics and negative feedback cause the heat generated in the reactor core to moderate and stabilize the rate of fission and prevent overheating. This behavior was convincingly demonstrated and documented by the EBR-II.

D. The ARC-100 directly addresses the LWR's problem of creating toxic amounts of nuclear waste first by self-consuming much of its own waste. And, second, the ARC reactor can be fueled with its own and LWR waste, and irradiation of this waste in the ARC-100 reduces its lifetime toxicity. This in turn greatly reduces the time that the waste will be considered harmful and require secure geologic burial. Further discussion of the ARC-100's solution for nuclear waste is provided in **section IX** below.

E. Unique features of the ARC-100 reactor technology and its fuel cycle make it arguably the most proliferation-resistant reactor design ever devised.

The remainder of this paper focuses on the proliferation resistant features of the ARC-100 and its fuel cycle. It also provides information about the nuclear materials required to create a nuclear bomb and the nuclear level reactions that occur in all nuclear reactors in order to give a fuller understanding of the nature of the proliferation problem and how the ARC reactor addresses it.

III. Executive Summary of the ARC-100's Non-Proliferation Features

In essence the ARC-100 never provides a source of (nor a means for producing) weapons usable material. This is achieved first by the nature of the ARC fuel from its initial loading until its removal from the reactor after 20 years and second by the protective containment of the fuel. In summary, the reactor's primary non-proliferation features are:

A. To date, all atomic bombs have always required that the bomb maker create a critical mass of (either) almost-pure uranium 235 (U235) or almost pure plutonium 239 (Pu239). The ARC-100 reactor and its fuel cycle never use or produce pure compositions of U235 or Pu239.

B. The ARC-100 fuel never contains uranium enriched above an average level of 15% U-235. It is impossible to fabricate a nuclear bomb at such low enrichment levels.

C. While all nuclear reactors create plutonium during operation and are therefore a potential source of material for building a nuclear weapon, and weapons grade plutonium (almost pure Pu-239) can be created by short irradiations of U-238 in a nuclear reactor, the long-duration irradiations in the ARC-100 degrade the purity of Pu239 and its potential for use in bombs. This occurs because extended nuclear irradiation creates a continuing family of heavy-mass plutonium isotopes and other transuranics. As a result, after a reasonable period of irradiation, the ARC-100's nuclear fuel is not suitable for making a bomb. Any subsequent attempt to chemically separate out the plutonium for bomb making would result in a mixture of multiple plutonium isotopes (and other highly radioactive isotopes) that do not yield material suitable for a nuclear weapon. Further, if LWR waste with its mix of plutonium isotopes and transuranics can be included in the initial ARC fuel loading, the ARC fuel and waste become from day one near impossible to use for bomb making. (See **section- VIII A** below for more detail on ARC's patented process for the introduction of LWR waste.)

D. The above features provide innate proliferation resistance by never using or producing fuel material of sufficient purity for weapons use. Beyond that, physical access to the fuel is precluded by the secure underground placement of the reactor and its 20 year refueling cycle.

E. The presence of Zirconium (Zr) in the ARC-100's fuel provides an additional proliferation barrier. The Zirconium makes it impossible for a bomb maker to use the established PUREX chemical separation process for separation of plutonium from reactor spent fuel since the Zirconium will react with the chemicals and cause an explosion in the plant.

F. The ARC reactor's physical layout, which prevents external access to the neutron emitting reactor core, prevents a bomb making neutron diverter from "stealing" neutrons, a vulnerability inherent in many other reactor designs (LWR's for example). The stolen neutrons allow weapons-grade plutonium to be surreptitiously produced by neutron irradiation of U238 "targets".

G. Unlike LWRs which are partially refueled every 12-18 months and store spent fuel rods onsite, the ARC-100 is refueled completely every 20 years. All the ARC's spent fuel rods remain in a fuel cartridge and are removed intact to a central, internationally-monitored plant for processing. The ARC fuel cycle thus greatly reduces the opportunity for a third party to remove surreptitiously a spent fuel rod and attempt to obtain plutonium for use in making nuclear weapons.

The above proliferation arguments are presented in more detail in **section VIII** below. **Sections IV – V** below describe the basics of nuclear bomb making and some nuclear physics concerning the atomic level changes that occur to nuclear materials in reactors. This information creates a context for understanding how proliferation issues arise from nuclear power reactors.

IV. The Essential Ingredients for a Nuclear Weapon

A critical mass quantity of the correct isotopes of uranium or plutonium, in a sufficiently pure form, is the essential ingredient for creating a nuclear chain reaction that can become a bomb. The mass required for a single bomb is not large (a few 10s of Kg), but the purity requirement is challenging.

Uranium is a naturally-occurring element with two isotopes: U-238, which makes up 99.3% of naturally occurring uranium, and U-235 which has an atomic weight of 235 and constitutes only 0.7% of naturally occurring uranium. Only the U-235 component is useful for making nuclear weapons, and the isotopic purity must be quite high before it can be successfully made into a nuclear weapon.

Plutonium 239 occurs with rare traces in nature, but is primarily created when U-238 captures a neutron while being irradiated in a nuclear reactor. Plutonium also has one rare, but also naturally-occurring isotope, Pu-244. The most common man-made forms of plutonium are Pu-239, Pu-240 and Pu-241, but to date only the Pu-239 has been used for making nuclear weapons with plutonium.

After significant irradiation times within power reactors, sufficient Pu-240 builds up to contaminate the Pu-239 and render it effectively useless for bomb making. The Pu-240 has a radioactive decay process in which it fissions spontaneously, emitting neutrons, creating a heat source and a serious radioactivity hazard. Pu-240 has thus gained the reputation as "*a bomb maker's nightmare.*" There are very serious dangers in even the assemblage of a critical mass of plutonium in a nuclear weapon with the presence of significant quantities of Pu-240. In addition, the radioactivity would make such a weapon virtually impossible to conceal.

The bottom line is: in order to create a nuclear bomb, a proliferator (nation or terrorist) must obtain suitably-pure quantities of either U-235 or Pu-239. Unless a bomb maker can gain access to the required quantities of isotropically-pure materials, he or she will not have the means for making a bomb. The ARC-100 has been designed to present one of the least effective avenues to the attainment of such material.

V. The Basics of Nuclear Reactions in all Nuclear Reactors

Some basic nuclear physics will provide a useful context for better understanding proliferation issues and the related issue of nuclear waste. To begin, consider the process of nuclear "fission" in a reactor which occurs when the nucleus of an atom of U-235 absorbs a neutron. The neutron absorption turns the U-235 nucleus briefly into an excited uranium 236 nucleus. The uranium 236 nucleus then splits into typically two fast-moving lighter elements (called "fission products") and releases free neutrons, which in turn can cause more fissions.

Since the nuclei that can readily undergo fission (U-235 or Pu-239) are particularly neutron-rich (e.g. 61% of the nucleons in U-235 are neutrons while 39% are protons), the initial fission products are almost always more neutron-rich than stable nuclei of the same mass. The initial fission products therefore may be unstable and typically undergo what is called beta decay towards stable nuclei by converting a neutron to a proton. The following elements are typical fission products: strontium, ruthenium, caesium, and tin.

Most fission products are highly radioactive, but have half-lives that range from seconds to decades, not thousands of years. A radioactive element's half-life is the time period for one-half of the element to undergo radioactive decay to a more stable state and lose its radioactivity. Thus, the fission products lose most of their toxic radioactivity and do not present serious health hazards in geologic storage after about 200-300 years of burial.

Alternatively, when an atom of U-238 is subjected to neutron bombardment in a reactor, instead of absorbing a neutron and fissioning, the atom may absorb a neutron and "transmute" (through one or multiple atomic reactions) into a heavier element. U-238 can transmute into plutonium 239 (Pu-239). Pu-239 can transmute into americium 241 and curium 242. Curium 242 can transmute into californium 245, and americium 241 into berkelium 243, etc. Each of these elements is heavier than uranium, and all are referred to as "transuranics" or "transuranium" elements. All of the transuranics are highly radioactive and dangerous, and many have very long half-lives (thousands of years). Thus, their presence in nuclear waste creates the requirement that a geologic repository be safe and stable for hundreds of thousands of years.

These transuranics mixed with uranium can be fissioned or burned in a fast reactor like the ARC-100, but cannot be totally fissioned, or burned to extinction, in a thermal reactor (such as the typical LWR). The ability of the ARC-100 to utilize such mixed fuels is at the heart of its proliferation advantage as well as its advantage in addressing the nuclear waste issue.

VI. Obtaining U-235 for a Bomb

States seeking nuclear weapons have sought to increase or "enrich" the ratio of U-235 to U-238 found in natural uranium. This ratio in natural uranium is 99.3% U-238. Enrichment to significantly greater than 20% U-235 is required for weapons use. This enrichment has normally been achieved by very extensive industrial-scale enrichment processes based on gaseous diffusion or centrifuge separators. In the future, these are likely to be replaced by the more efficient successor process of laser enrichment, currently being piloted.

The initial fuel loading for the ARC-100 will utilize fuel rods which contain an average enrichment of 15% U-235. The ARC fuel is thus not suitable for making a nuclear weapon, nor does the ARC-100 provide any shortcuts to obtaining the required purity of U-235.

VII. Obtaining Pu-239 for a Bomb

States have also created nuclear weapons by accumulating sufficient quantities of nearly pure Pu-239. The original nuclear weapons states (US, UK, France, Russia, and China) all had used dedicated reactors (so-called "defense reactors") to produce Pu-239 for use in their weapons, and have pledged to never "intermix" civilian power production reactors or fuel cycles to obtain plutonium. It is certainly possible that some newly-emerging nuclear weapons states might try to admix these, i.e. by obtaining nuclear reactors that generate civilian power and also create plutonium from U-238. The state could then try to separate out plutonium from the nuclear waste. However, the ARC-100's design and fuel cycle offer arguably a much lower risk of proliferation occurring from its use than any other reactor design that is either operating today or has been proposed. An analysis of the ARC-100's plutonium-based proliferation risk follows in **section VIII** below.

VIII. Why The ARC-100 Does Not Present a Plutonium Based Proliferation Risk

If the ARC-100 is deployed in a nuclear weapons state (US, UK, France, Russia, or China), further nuclear weapons proliferation will not be an issue. Similarly, if the ARC-100 is deployed in stable state that has no nuclear weapons, but is a responsible signatory of the Non-Proliferation Treaty (NPT), the proliferation risk in principle is constrained by that treaty. However, it is useful to examine whether incremental proliferation risks would be presented if the ARC-100 were to be deployed in an NPT signatory state that chose to ignore the NPT. For example, consider if a regime change were to occur resulting in a government that overtly or covertly ignored its treaty obligations. In such a case, it will be argued here that the ARC-100 and its fuel cycle offer strong features to prevent the reactor from ever being used as a path to proliferate nuclear weapons, and relative to other reactors that are now in operation or proposed for the future, it is the least likely design to allow proliferation.

A. The ARC Fuel Strategy Minimizes Proliferation Risk: ARC envisions two fuel mixtures for its reactor. For the initial loadings of ARC reactors, the fuel rods will consist of an average enrichment of

15% U-235 and 85% U-238, plus a non-fissionable metal, Zirconium (Zr). This fuel is identical to the driver fuel used in and fully proven during the 30 year operation of EBR-II. Again, it is important to note that nuclear fuel containing the ARC's percentage of U-235 can never be used for making a nuclear weapon under any conditions. While all nuclear reactors create plutonium (including Pu-239) during operation and are therefore a potential source of material for building a nuclear weapon, the plutonium produced by the ARC-100 reactor is never during its fuel cycle separated from the uranium and transuranics. And, most importantly, after a period of operation, the ARC initial fuel loading contains fission products plus a plethora of isotopes of plutonium and higher-mass transuranics in a highly-radioactive mixture. This resultant mix is not suitable for making a nuclear bomb, and weapons grade pure Pu-239 cannot be separated out from this mix using any currently available industrial process.

Then, in successive 20 year recycled refuel loadings of the ARC reactor, a mixture of 85% U-238 and 15% recycled transuranic (with multiple isotopes of plutonium) plus unburned U-235 material is recycled back for use as new fuel, after the removal of most of the fission products. It is important to note that this is a proven process. Metal alloy fuel with additions of plutonium and recycled transuranics was successfully irradiated in the EBR-II. The purpose of adding the U-238 is only to provide the raw material for continuing to produce additional fissionable isotopes of plutonium and other transuranic isotopes for use as "new fuel" during the subsequent 20-year reactor operation, in order to: (1) thereby mirror at every step the original fuel loading, (2) maintain the fission fuel breeding characteristics of the original fuel, and (3) match exactly (or improve on) the very attractive nonproliferation characteristics inherent in the ARC fuel.

It is also envisioned that eventually the bulk of the makeup U-238 plus some of that 15% component can be supplied from the used fuel discharged from LWRs. ARC has studied and applied for patents on a methodology for this process that blunts the ambitions of a bomb maker, while at the same time addressing the current problem of disposal of LWR spent fuel. ARC's patent proposes a simple cost effective process for the incorporation of LWR waste into ARC fuel rods: crushing of the LWR spent nuclear fuel and mixing it directly into ARC's traditional U-235/U-238/Zr metallic fuel to form a cermet fuel. Used LWR fuel rods contain mostly U-238, but also small amounts of U-235, multiple isotopes of plutonium, as well as other transuranics such as, americium, neptunium, and curium. These latter materials are highly radioactive and so difficult and dangerous to handle that they are very unsuitable bomb making materials.

ARC's patented process will be a cost effective way to introduce substantial Pu-240 and other transuranic and fission product isotopes into the initial ARC fuel charge. The ARC team believes (although not yet fully proven by experiment) that during irradiation of the new cermet fuel, significant migration of isotopes will take place across the oxide/metal interface between the oxide particles in the LWR fuel and the metal matrix. In that way the Pu-240 from the oxide will mix with the Pu-239 from the metal phase during irradiation. The result would be that at all times (from initial fuel loading, during reactor operation, and during and after pyro reprocessing), the plutonium in the ARC core will never contain the high quality Pu-239-rich material required for making nuclear weapons. And, at the same time, this process would allow a significant quantity of current (and future) LWR spent fuel (and wastes)

—the U-238 as well as the U-235 -- to be eventually utilized for generating power. Later ARC replacement cores will already enjoy this feature without the new use of cermet fuel, due to the recycled transuranics returned from used ARC metal alloy fuel.

B. The Physical Design of ARC Reactor Protects its Fuel from Unauthorized Diversion: Protection for unauthorized access to the ARC-100 fuel is effectively provided by the physical design of the ARC reactor. The reactor's core is contained inside an underground armored-containment vessel with all components sealed within an inert gas at atmospheric pressure. The core is fully submerged in a pool of liquid sodium. Further, there is no machinery available onsite capable of removing any of the reactor fuel rods. The fuel handling must be done remotely and bulky clusters of fuel assemblies must be removed together using the equipment brought from off-site. Thus individual fuel pins cannot be surreptitiously removed and diverted for covert reprocessing. And, the diversion of bulky clusters of fuel assemblies (even if possible) would be detectable because the reactor would cease to produce power. Finally, the reactor vessel is equipped with internationally monitored alarms that would be tripped by any breach, signaling worldwide through communication networks that an attempt to either steal the fuel, or the neutrons, was being made.

C. The 20 Year Closed Refueling Cycle Further Protects the Security of the Fuel: The ARC fuel rods remain inside the sealed reactor core for the full 20 year refueling cycle. The rods are highly radioactive and extremely dangerous to handle without special equipment. They remain so until they are removed by a third party under high security and taken to a fully-secure and safe-guarded facility for reprocessing. The ARC-100 closed fuel cycle technology thus maintains the fuel in a self-protecting radiation field at all times throughout the cycle, and self-consumes some of the plutonium it creates, while creating other plutonium isotopes that render the fuel increasingly unattractive for weapons use, even if the difficult process of chemically separating the plutonium were to later be attempted. Contrast this with the LWR's 12-18 month continuing refueling cycles, where new fuel rods are delivered to the reactor at regular intervals, and spent plutonium-containing fuel rods are accumulated and stored onsite in storage pools and dry casks where, over time, any self-protecting radiation fields will attenuate. Given the likelihood that nuclear power will have to be deployed to generate mankind's ever growing needs for energy, these inherent protections within the ARC system represent a much superior design approach for the long term.

There are significant nuclear policy advantages that could flow from the 20 year refueling cycle. The ARC core design, which allows a non-nuclear weapons nation/customer to be able to rely on an assured, uninterrupted, twenty-year supply of fuel, will in most cases be viewed as a sufficient incentive for the vast majority of customers to be willing to purchase the reactor under conditions that require the use of ARC's proposed fuel cycle, thereby agreeing to forego any attempts to develop their own indigenous fuel cycle, and, in particular, agreeing to never build their own plants for reprocessing nuclear fuel or enriching uranium.

D. The ARC Design Prevents Theft of Neutrons: The ARC-100 design prevents the use of the reactor for the "covert theft" of neutrons, which is the greatest of the threats for gaining plutonium for bomb-making from civilian reactors. In the past, governments like India, Pakistan, and North Korea have acquired nuclear reactors and used the reactors' neutron emissions to produce weapons grade Pu-239. A potential method to produce plutonium from power reactors involves covertly pulling out some fuel rods from the reactor and replacing these with natural uranium fuel rods for short irradiation times. Such a process allows the U-238 to capture a neutron and eventually be transmuted to Pu-239. Controlling the length of time for that radiation exposure means that one can limit the production of the higher plutonium isotopes such as Pu-240, and end the irradiation when a weapons grade mix has been created. Also, a similar variant would be to use covertly-inserted U-238 fueled rods into holes secretly drilled into a reactor's reflectors. This "stealing" of neutrons in order to create weapons-grade plutonium material from a reactor is hard to detect, and therefore should a government entity acquire a typical LWR or heavy water reactor system and covertly use it for this purpose, even international inspectors would be unlikely to know that it had occurred until well afterwards, if ever. The ARC reactor prevents the "theft" of neutrons because its neutron emitting core is inside an underground armored-containment vessel, sealed and alarmed, and under an inert gas atmosphere and submerged in a pool of liquid sodium. Further, the ARC fuel is loaded into the core in 14 canisters each of which contains multiple fuel assemblies, a structure that makes it virtually impossible to substitute individual U-238 pins that could absorb and "steal" neutrons for the production of Pu-239.

E. Zirconium in the Fuel Prevents Plutonium Separation: Additional proliferation protection against the extraction of pure plutonium from the ARC fuel is provided by the presence of zirconium (Zr) alloy metal in its fuel rods. As a result, the ARC fuel cannot be reprocessed to separate out pure plutonium using the conventional chemical separation process known as PUREX. If PUREX is attempted, when the Zr-containing ARC fuel is dissolved in the PUREX process's nitric acid, it tends to explode because the acid dissolves the uranium preferentially, leaving a Zr rich residue behind that oxidizes quickly and explodes. This effect was discovered after a disaster at a chemical plant some years ago. An option to attempt to get around this problem would be to modify the head-end of the PUREX process by substituting hydrofluoric acid to reprocess metal alloy reactor fuel. That change requires the use of special non-metallic lined piping and vessels, and while such an alternative process has been proposed, it has never been carried out and can be considered to be a very serious additional technological hurdle for anyone trying to steal irradiated ARC-100 fuel to extract its plutonium content.

F. Summary of Proliferation Advantages: Since the ARC-100 fuel rods will contain an average of 15% U-235, its initial fuel loading is incapable of being diverted for proliferation purposes. In the early stages of the operation of a new ARC fuel cartridge, Pu-239 will be generated, but as noted above, the ARC design makes the theft and use of this material by a bomb maker very difficult. After a short period of operation, the plutonium created in the ARC-100's fuel rods could never make a " good" bomb because there are so many different plutonium isotopes bred into it, as well as other highly radioactive transuranic species, which make the material extremely hard to handle and even harder to do precision chemistry on. The resultant fuel, if directly extracted, is also so radioactive, especially with spontaneous neutron emissions constantly taking place within it, that it would be very hard to make it into a nuclear weapon, and certainly not into a useful bomb that could be handled and transported without being easily detected. Notwithstanding these radiation dangers, if such a bomb even could be fabricated, it would be a very inefficient one (coming apart prematurely early in a chain reaction) - what those in the weapons business would describe as a “flash in the pan" scenario.

Even in the regime change scenario, it is almost certain that the barriers to proliferation offered by the ARC-100 would cause any state or individual intent on proliferation to seek an alternative path. ARC believes that the innovations offered by the design and associated technologies unique to the ARC reactor will provide major advances in proliferation protection, making it arguably the most "proliferation-proof" reactor design and fuel cycle ever introduced.

IX. The ARC Proliferation Protections Also Address the Nuclear Waste Issue in Important Ways

The ARC-100 fulfills the maxims expressed by the International Atomic Energy Agency (IAEA) focused on the proliferation problem (*Semenov and Oi, 1993*): "*Closing the nuclear fuel cycle ultimately means developing fast reactors, for only in fast reactors can plutonium be recycled again and again until it is gone. Recycling in LWRs is limited to just a few cycles.*" ARC does not quarrel with the correctness of the IAEA’s first statement, but as discussed above, by the adoption of the fuel design in the ARC-100 system, with the additional option to directly introduce LWR spent fuel into the fuel elements of ARC-100's, eventually substantial amounts of existing and future LWR wastes could enter the same ARC-100 closed-fuel cycle.

Continuous recycling through a fast reactor of the transuranic elements coming from either LWR or ARC reactors results in the plutonium and the other transuranics being burned up (while producing net energy) and the remaining materials emerging as waste streams consisting almost exclusively of fission products, which have much shorter lifetimes required for their geologic repositories. In fact, the resultant waste materials sent to the new geologic repositories will, after only 300 years, have a profile of specific radioactivity that is well-below that of the original uranium ores that were mined from the earth to start the whole nuclear energy generation process.

That IAEA report also included the statement: " *Nuclear power development will likely proceed along at least two separate, independent paths: the once-through nuclear fuel cycle and the closed fuel cycle, depending on the political, economic, and environmental considerations of individual nations*." That statement is only halfway true today, as there is as of yet no closed fast reactor nuclear fuel cycle in commercial operation, or yet offered as a commercial reality. Yet, through the ARC-100 design configuration and its planned fuel handling processes (that have already been demonstrated at laboratory scale), its commercialization will make a reality of the closed fast reactor fuel cycle, as well as eventually unite the two paths into one single closed cycle, as LWR wastes are ported into the ARC-100's, and ultimately, following pyro-processing, the fission product portion of both waste sources will go into the same geologic repositories.

It is thus envisioned that the fuel cycle process to be utilized by ARC will immediately work for solving the nuclear waste isolation problem for ARC-100 reactors. But the extra step, by proving that LWR spent fuel rods can be directly introduced into the future fuel elements pioneered by ARC, will allow the eventual inclusion of substantial portions of current and subsequent LWR spent fuel under the new, much shorter lifetime criteria as for the ARC geologic repositories.

And, the further consequence of the wide spread adoption of the ARC fuel technology with its ability to ultimately convert to energy as much as 90-95% of its uranium fuel load (versus 3-5% for today's LWRs) will be to bring about a huge increase in the efficiency of utilization of the earth's natural uranium.