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EVOLVING AN ACCEPTABLE NUCLEAR POWER FUEL CYCLE

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Chairman, Panel Discussion
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Opening Presentation

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AIChE PANEL DISCUSSION - August 25, 1986

This panel subject grew out of some reflection and discussion among a minor group of technical people, that perhaps there may be a better way to run the nuclear fuel cycle than has developed from its military roots. The nuclear age was initiated by the Manhattan Project, the objective of which was to produce weapons materials for the first atomic bombs.

I am a believer in nuclear energy. I believe that we will eventually need it in a big way. However, even from recent experience, I should say especially from recent experience, it is obvious to me that some significant improvements are needed in the nuclear technology so that it will become more pallatable and acceptable not only to technical people but to the entire public at large. As long as it is unacceptable to a large contingent of the public it becomes too costly to apply and highly uneconomical to deploy.

Let us examine the issues.

The first concern is the establishment of long-term safe nuclear power plant operation.

We have accumulated quite a lot of experience with light water reactors (LWRs) since Three Mile Island (TMI), safety systems have been improved, so as to avoid loss of coolant, avoid melt-down, and avoid positive void coefficient, which may have caused the trigger for the Chernobyl accident. It is interesting to note that this very day, the Russians are reporting at the IAEA in Vienna on all they know about the accident.

There is one area which I believe needs further examination and must be improved and that is to make reactors chemically inert.

A melt-down of fuel may be bad enough but it can be contained. An explosion, however, is intolerable, since this causes the spread of fission product activity far afield of the immediate vicinity of the reactor. The real cause of both the potential spread of reactivity at the TMI accident, and that which actually occurred at the Chernobyl accident, was that the generation of hydrogen gas took place by the heated zircaloy fuel element cladding reacting with the surrounding cooling water and steam. Zirconium reacted with water forming hydrogen gas and zirconium oxide solid. At Chernobyl, there may have been an additional reaction of steam with graphite forming both hydrogen and carbon dioxide. Hydrogen and carbon monoxide mixing with air outside the reactor in the building caused explosions at Chernobyl. An article in the New York Times, reviewing the Russian report, stated that the initial act was a steam explosion followed by a volumetric or hydrogen explosion. A steam explosion could sometimes be taken care of with fast acting pressure relief valves, and the expanding steam would cool down. A hydrogen explosion cannot be easily contained and releases a great deal of energy to cause a very high increase in pressure and temperature.

My solution to this materials problem is to attempt to eliminate the reduced metal in water-cooled reactors and make the reactor cores chemically inert. Why not develop an oxide coated or uranium oxide alloyed ceramic fuel element? We know that the thermal, mechanical, and radiation stresses are very high in fuel elements, however, ceramic materials development has progressed rapidly in the last decade, and at least attempts should be made to research the possibilities of inerting the fuel with respect to the coolant, so that we will not have to deal with the potential of blowing up a reactor and spreading radioactivity far and wide. We were very lucky at TMI because, as I understand it, the nuclear LWR pressure vessel filled up with 300 psig of hydrogen due to the Zr-water reaction. Remember all the reports and discussions about a gas bubble. This was hydrogen and it was finally leaked into the containment vessel where it either caught fire or was purposely burned inside the containment. Luckily the containment did not rupture. Insulation inside the containment and other equipment, however, burned. This prompted EPRI to run a full scale experiment for burning off hydrogen in containment vessels to test safety procedures. Why not attempt to avoid generation of hydrogen in the first place? If water reactors cannot be made inert, then helium-graphite gas cooled reactors, or other compatible coolant-fuel-moderator materials should be strongly considered for inerting the reactor.

The second issue is acceptable nuclear waste management and, mainly, high level waste management.

At present, we have the Waste Management Act of 1982, which is based on the geological-age disposal and storage of high level waste. The problem here is that the high level waste requires storage for tens of thousands of years, if not for hundred of thousands of years. And, of course, the objection by the public is "do not bury it in my backyard". These arguments and debates are going on very much now and the DOE is being given a very rough time concerning the process of selection of specific geological-age waste storage and disposal sites. In fact, the AAAS journal Science (August 22, 1986 issue) had a headline on a commenting article which stated "Nuclear Waste Program Faces Political Burial".

The problem with high-level nuclear waste derives from losses built into the Purex spent nuclear fuel reprocessing process. The Purex process was essentially developed to recover fully-enriched uranium-235 greater than 93% U-235 and 99 + % Pu-239, mainly required for weapons production. Because of these specifications, that is the necessity to produce high-purity plutonium (Pu), some plutonium in the extraction process of necessity spills over into the waste, which become very difficult to recover because of its dilute condition. The Pu contaminated waste requires geological-age storage since the Pu has a 26,000 year half life and, as a rule of thumb, requires at least 10 half lives or a quarter of a million years to decay to background. The civilian power reactor fuel does not need this fully enriched or concentrated high-purity fissile material. Reactor fuels need only 3 or 4% fossile fuel concentration when used in light water thermal reactors. The two categories of long-lived nuclear waste are the transuranics or TRUs and the intermediate 30-year half-life radioactive fission products, LLFPs, Cs, and Sr. Most of the other radioactive fission products have half-lives that are short, less than 2 years. The bulk of the fission products, especially after 20 years of storage, are non-radioactive and stable and can be readily disposed of. People forget that from a mass concentration, the long-lived isotopes are a small fraction of the total fission product waste.

This being the case then, why don't we design a fuel reprocessing scheme which, instead of extracting plutonium, we extract only the stable fission products and recycle all the TRUs and the LLFPs long-lived radioactive fission products back into the fuel elements? The cycle would go like this. The LWR spent fuel would be stored for, say up to 20 years, to decay out all the very short-life isotopes then the fuel would be reprocessed to extract the stable fission product waste, and all the other radioactive material would be recycled to be incorporated into fresh fuel elements for the power reactors. Thus, I am suggesting that reprocessing be performed primarily for waste treatment and not for plutonium recovery. This was referred to several years ago by some negative term "back door" reprocessing. Today, however, the positive term can be applied to reprocessing for waste management. Maintaining the Pu in dilute form also lessens the fear of promulgating a plutonium economy because the plutonium will always be in dilute form. The emphasis is on recycling waste, just as we speak about recycling industrial and municipal waste, not only to recover the valuable material resources. Recycling of TRUs and fission products leads to the avoidance cost of geological-age disposal and should overcome the objections of the public on nuclear power because it would no longer be necessary to select a site to bury the waste. I might mention here that the AIChE Nuclear Energy Division's Position Paper states that currently there is no alternative to geological-age storage, even though other approaches, such as transmutation, were examined. This is not true since recycling has never been seriously considered. My contention is that examination of new process approaches such as recycling developed and balanced against avoidance costs can lead to more economical nuclear energy.

It is claimed today in the U.S. that reprocessing is uneconomical for recovering of plutonium from spent fuel because of the availability of low-cost uranium. This is true today only because the nuclear industry is declining and there is much less demand for fissile material than was originally forecast a decade ago. Reprocessing for nuclear waste recycling and avoiding geological-age storage may become economical if it allows the nuclear power industry to become acceptable to the public who wil allow the industry to expand.

Of course, there always will be a low-level waste disposal problem from the use of radioactive isotopes for medical and industrial treatment services and from general cleaning operations around the nuclear power industry, however, the problem of low-level waste disposal is much smaller than the disposal of high-level and long-lived waste. High level waste is currently being stored and generated by the military nuclear program.

The third issue is provision for long-term fissile fuel supply in a long-term nuclear fission economy.

The only fissile material existing in nature, U-235, is very limited, projected to last perhaps 3 to 5 decades, depending on the cost of natural uranium and the rate of installation of nuclear thermal reactors around the world. The conventional method of extending the fuel supply is to develop the breeder reactor which would convert the bulk natural fertile U-238 to the fissile Pu-239 or the fertile naturally plentiful Th-232 to the fissile U-233. However, the breeder reactors have yet to be proven safe. One type, which we and many more have advanced, is the liquid metal sodium cooled fast breeder reactor (LMFBR). But we know very well that sodium reacts violently with water producing hydrogen which, as stated previously, can cause dangerous explosions. There are other technical problems such as the rate of plutonium production or the so-called "doubling time" and the nuclear positive reactivity void coefficient problem which may be the basic cause of the Chernobyl accident. Furthermore, there is a need for closing the cycle by reprocessing to recover the fissile material. If this system is applied, in the long run, all power reactors will have to be breeders because we will have run out of reasonable cost U-235 for fueling new reactor capacity. Also, breeders are necessary to convert thorium to U-233 in the thorium-uranium (Th-U) cycle. Therefore, having acquired much experience over many years and NRC licensing of LWR thermal reactors, we will have to discard this experience and adopt a whole new generation of liquid metal fast breeder reactors, and this will take additional decades to prove safe for licensing.

There is, however, another option, and that is to adopt a Spallator (accelerator breeder). The first amount of Pu was made by an accelerator at Berkeley by E. O. Lawrence using spallation neutrons. Modern accelerator technology allows us to design and construct large linear accelerators to efficiently produce high energy protons, which when directed and impacted on a natural U or Th target, produces large amounts of neutrons for converting the fertile material, U-238 and Th-232, to fissile Pu-239 and U-233, respectively. This can be performed in a subcritical target assembly which would be much safer than any breeder reactor. Furthermore, one Spallator fuel producer would provide enough fuel for many conventional light water reactors or other gas-cooled thermal reactors over the entire reactor lifetimes. For example, one 600 MW(e) accelerator breeder or Spallator can produce sufficient Pu-239 from natural U-238 to fuel as many as <u>nine</u> 1000 MW(e) light water power reactors. In addition, the fuel elements might be recycled several times through the reactor and Spallator without reprocessing in what we call a <u>regenerative or refresh</u> cycle so as to increase burn-up and reduce reprocessing requirements. What I am suggesting here is a <u>fuel factory</u> which converts natural fertile material to fissile material for operation and utilization in well-run light water or gas-cooled thermal reactors upon which we are presently building our safe nuclear power reactor experience today. The Spallator is a true enrichment plant. The present so-called "enrichment plants" based on gaseous diffusion, centrifuges, and laser isotope separation are really "depletion plants". They take 6 tons of Uranium ore to make 1 ton of fuel and throw away 5 tons waiting for the breeder reactor to convert these 5 tons back to fissile Pu. The Spallator converts the natural U or Th directly to fissile Pu or U-233 for use in presently operating LWRs and can convert all of it.

The last issue, and in my opinion, the most important, from the point of view of survival, is the issue of proliferation of weapons material.

As everyone knows by now, the two superpowers have stock-piled at least 30,000 nuclear weapons on each side ready to be delivered and set off on a moment's notice. The amount of fissile material in these weapons amounts, roughly to about 600 tons. Will we live with this "sword of democlese forever over us - until the end of days". We are now hearing both from Chairman Gorbachev and President Reagan that not only do they want to limit the proliferation of weapons, but to actually reduce and eliminate the weapons in the not too distant future. Now, we are presented with a technical problem. How do we eliminate and get rid of nuclear weapons materials? To bury them is not to eliminate them, one would only create a plutonium mine. To eject the nuclear weapons materials into outer space does not eliminate them, and besides the space shuttle Challenger disaster has taught us well, that rocket disposal to outer space is far from fail-safe. The only way is to convert the Pu weapons material into fuel elements and burn the Pu up in nuclear power reactors. When I speak to the so-called "anti-nukes" they are unanimously anti-nuclear weapons for which one cannot fault them, however, I tell them that they should be pro-nuclear power, because if we stop the several hundred thermal power reactors in the world today, we will never get out of the nuclear age. The reason is that we will then have eliminated the capability of burning up the Pu and will then have to live with nuclear weapons for several hundred thousand years waiting for the Pu to decay. By burning weapons plutonium in the existing power reactors, not only do we rid ourselves of weapons materials but we also can gain the benefit of generating the much needed electrical power. I tell the anti-nukes that once we rid the world of the bulk of the weapons Pu by means of our present nuclear reactors, then and only then can we take up the debate as to whether nuclear fission is really safe and whether it is worth the risk. The anti-nukes then begin to listen and think of this option. An agreement will have to be made with the Soviets to do the same. We will not disarm unilaterally. Verification can consist of each bringing an equal mass of weapons Pu to a power reactor for burn up. There would then be no question that we are both conforming to the spirit of the agreement.

What I have suggested is by no means trivial. It is a "tall order" which has a large research and development effort and cost attached to it. However, I do not believe that with our past 40-odd years of experience in the nuclear age, the developments suggested here will be as expensive as that which we have already spent and which has brought us to a nuclear power standstill in many countries in the world. It behooves us to examine new alternatives, especially now in the U.S., when there is a nuclear hiatus, and so we can prepare for when the next wave of new nuclear power installations are needed, which may be within another 20 years.

I have two slides, showing a conventional fuel cycle and the proposed fuel cycle with the changes discussed. I will also show two slides which indicate the effect of recycling of TRUs and long-lived fission products (LLFPs) reaching long-term asymptotic value. The TRUs take relatively short time to reach equilibrium while the LLFPs take a much longer time.

The least we can do is to investigate the alternatives I have outlined and that is to (1) improve the safety of LWR reactors by eliminating the use of reducing metal in fuel elements and cladding, (2) recycle radioactive waste into LWRs, (3) produce fissile material for LWRs and other thermal reactors using the Spallator instead of converting all civilian reactors eventually to liquid metal sodium-cooled fast breeder reactors (LMFBRs), and (4) burn-up weapons materials in existing reactors. Given the incentive, which may soon be forced upon us, I have little doubt that these developments can be achieved at an economically competitive cost. My belief is based on the tremendous accomplishments we have already achieved in the nuclear industry over the past 40 years.

I will now call upon the other panel members one by one for their remarks, after which we will open the floor to questions and discussions.

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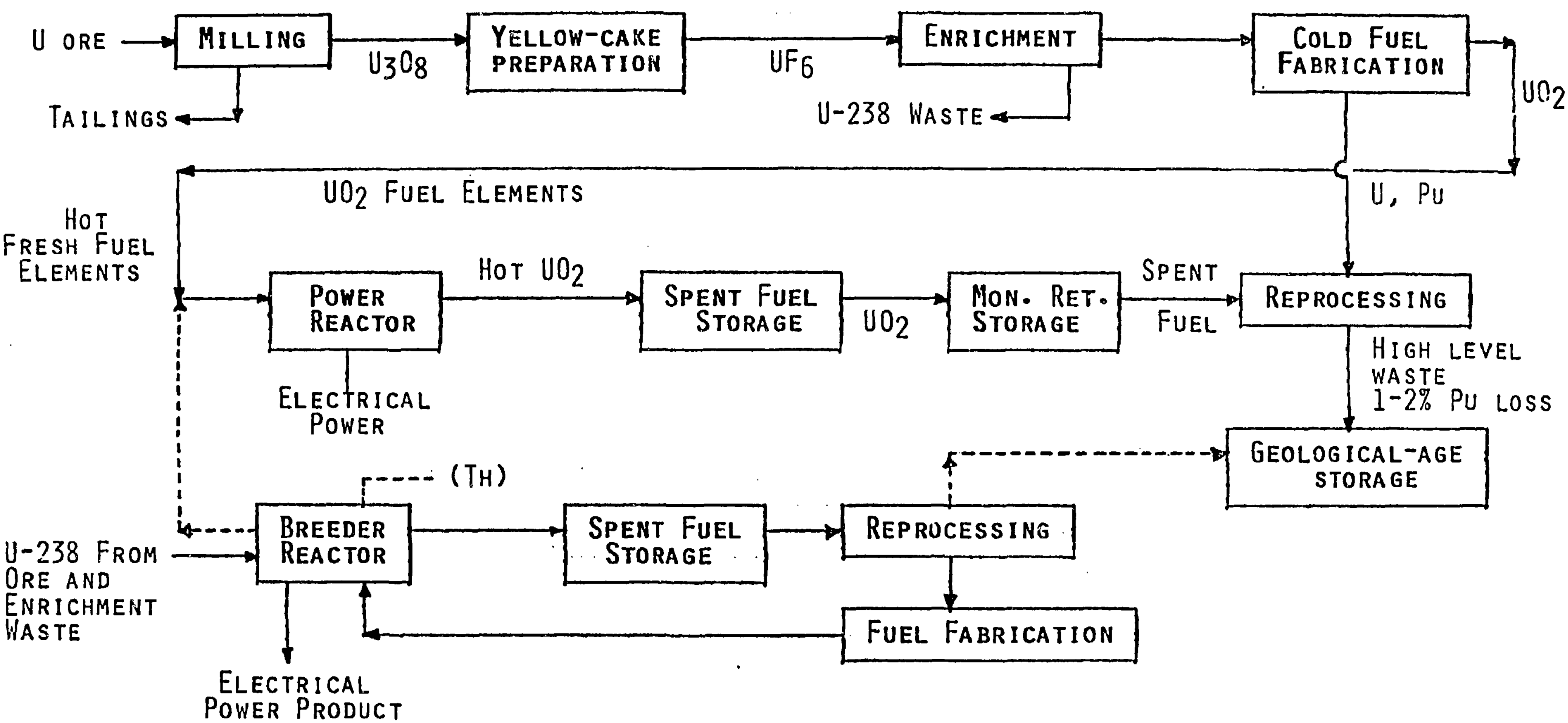
PRESENT NUCLEAR FUEL CYCLE

PUREX - GEOLOGICAL-AGE STORAGE - BREEDER



DISADVANTAGES:

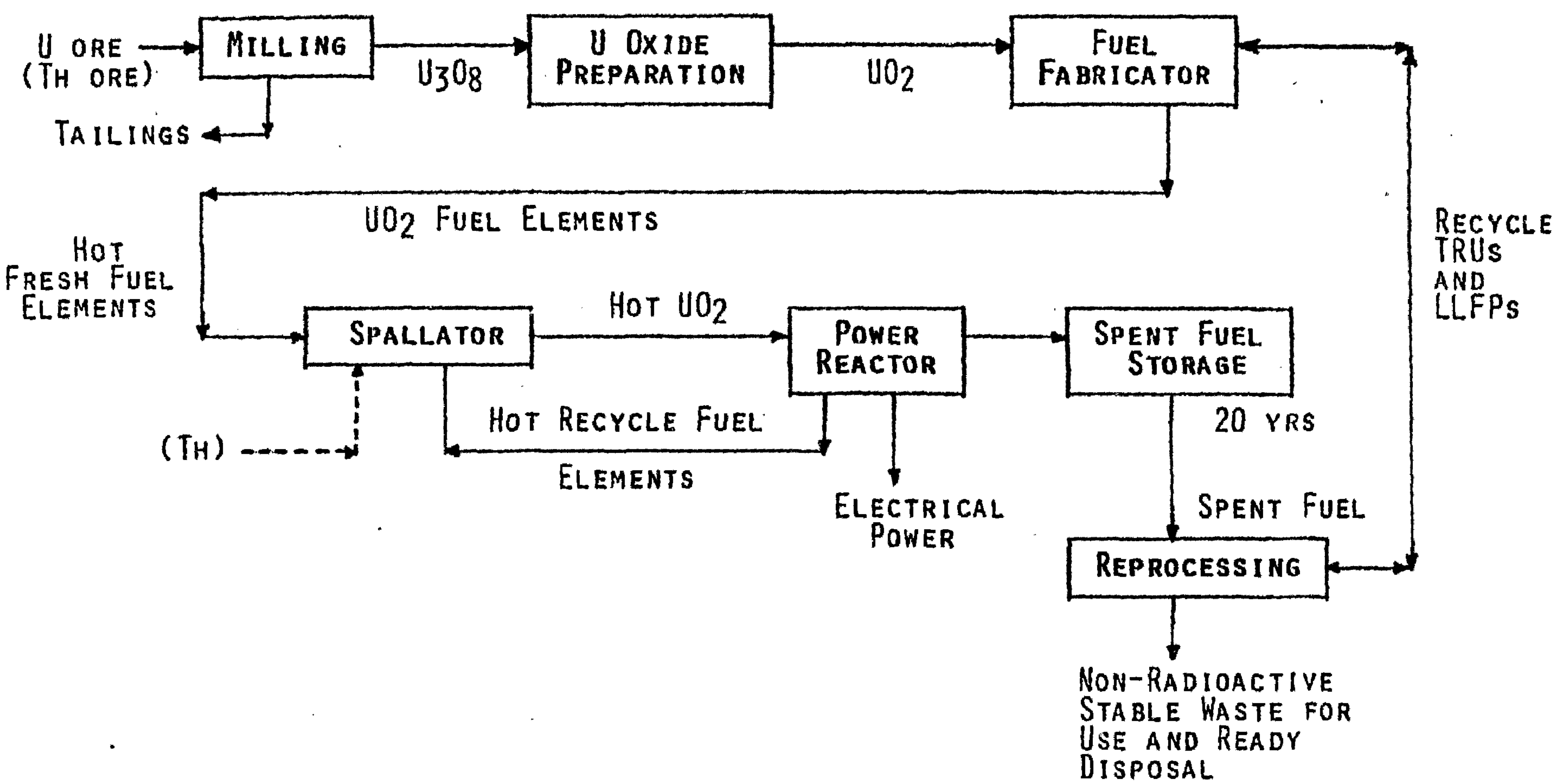
1) NEED BREEDERS.
2) NEED GEOLOGICAL-AGE STORAGE.
3) INCREASES PROLIFERATION (PU ECONOMY).

(B.1c)

Figure 1.

PROPOSED NUCLEAR FUEL CYCLE

APEX - Recycling Avoids Geological-Age Storage - Spallator

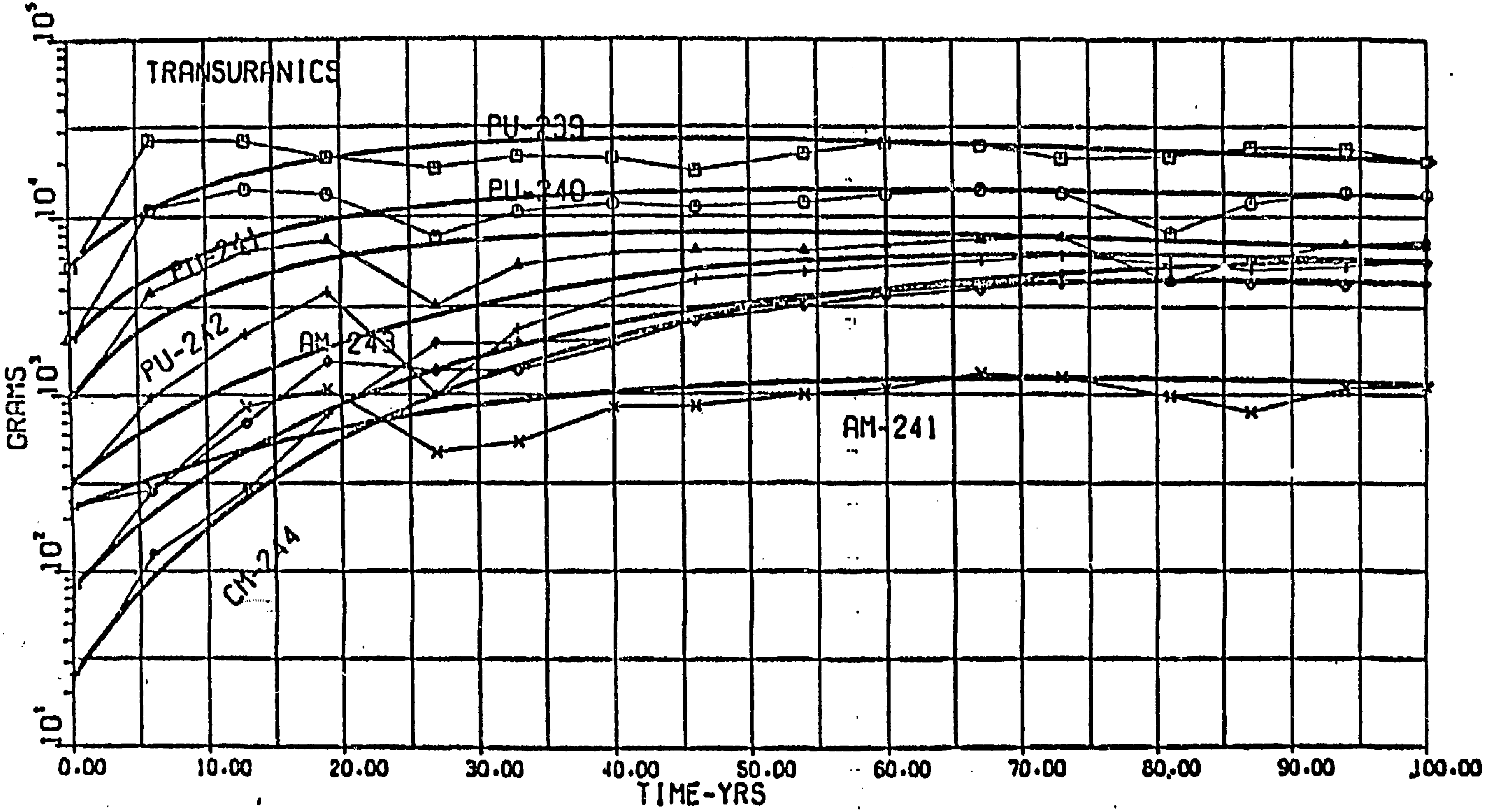


Advantages:

1) Avoid breeders.
2) Avoid geological-age storage.
3) Reduces proliferation.

(B.1c)

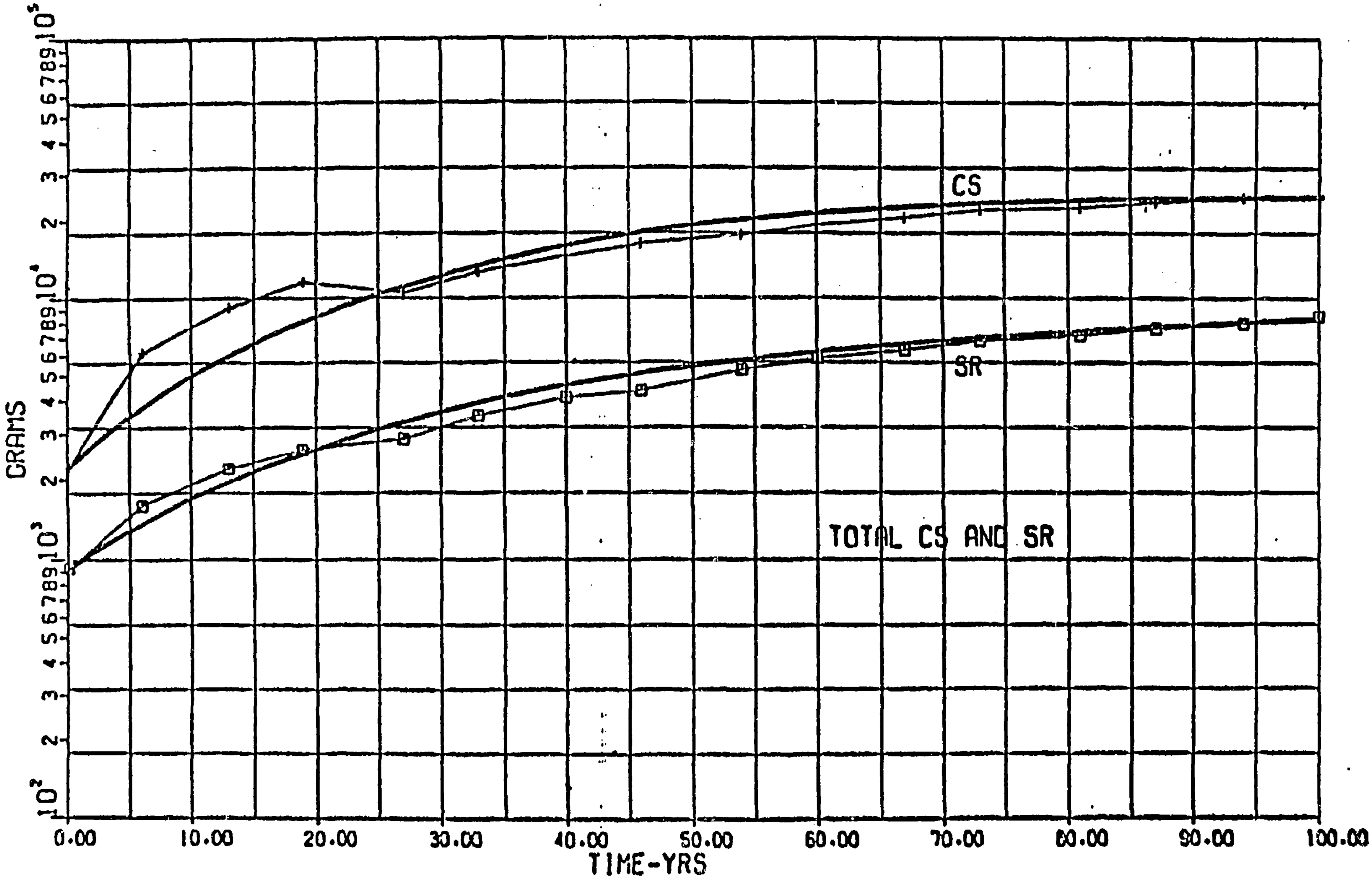
Figure 2.



The TRU buildup-g/tonne versus time APEX-27-yr cycle.

Recycling TRUs.

Figure 3.



Cs and Sr LLFP buildup-g/tonne HM versus time PEX-27-yr cycle.

Recycling LLFP - Cs and Sr.

Figure 4.