THE CONSUMPTION OF ACTINIDES IN ADVANCED LIQUID METAL REACTORS (ALMR)

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ABSTRACT

This paper discusses an actinide recycle system, the ALMR, with its fuel cycle, capable of consuming actinides produced in existing light water reactors. The ALMR has a wide range of capabilities, including the use of existing actinides to produce additional actinides for future electrical energy production, if needed; to the consumption of actinides. Due to the worlds' nations attention on what to do with actinides, the focus of this paper is the consumption of actinides. This results in the elimination of safeguards of nuclear waste produced in nuclear reactors that is scheduled for storage in repositories. Rates of actinide consumption are identified.

In US nuclear energy scenario analyses for the 1991 National Energy Strategy (NES), a "lower reference" case was developed which assumed a modest growth of nuclear power capacity from the presently installed capacity of about 110 GW(e) to 195 GW(e) by 2030. This capacity growth is primarily with advanced light water reactors (ALWR) but assumes a modest growth of advanced liquid metal reactors (ALMR) starting after 2010. The specific ALMR growth depends on the assumptions associated with the "breeding" or "converting" of actinides in ALMR designs. Breeding creates more plutonium than is "burned" and converting burns more plutonium than is created.

To gain an understanding of the potential for modest growth of ALMRs, a case was analyzed for the NES in which a growth of ALMRs was chosen sufficient to consume essentially all of the LWR origin transuranics produced from ALWRs introduced coincident with the ALMR growth. An ALMR can consume ***actinides*** (elements of atomic number 89 and greater). Spent fuel from LWRs consists of roughly 96 percent uranium, one percent transuranics (TRU - plutonium, neptunium, americium, curium, etc.) and the remainder (3 percent) is fission products. Thus, if processing of LWR spent fuel is pursued, a system exists in which energy can be produced from LWR-origin spent fuel material that would otherwise be disposed of as waste. The energy produced in ALMRs from LWR "waste" can easily exceed the original LWR energy production by factors as high as 60 to 100.

In producing power, an ALMR annually consumes a small fraction of its core fissile/fertile material content (i.e., out of about 100 tonnes of core material, approximately one metric ton is needed to produce a gigawatt-year of electrical energy in a large ALMR plant). Therefore, during ALMR growth, the majority of actinides available from spent LWR fuel will be utilized for initial core inventories. Nevertheless, approximately one metric ton of actinide material per gigawatt-year will always be converted to fission products, the source being either uranium if the ALMR operates as a ***breeder***, or make-up transuranics and uranium if the ALMR operates as a ***converter***. Although current NES analysis to 2030 uses an ALMR "converter", economic performance of a "breeder" appears somewhat better than a "converter".

Therefore, commercialization of the ALMR may be achieved more readily in the "breeder" or "near-breeder" design. Nevertheless, a sufficient number of ALMRs could eventually be deployed offering the potential for operation as "converters" to significantly reduce actinides from LWR spent fuel.

To illustrate possible breeder and converter deployment, one breakeven and two converter cases (see Figures 1 through 3) are presented in which ALMR growth of 27 GW(e) to 2030 was assumed as part of the NES growth scenario. The independent variable indicated in Figures 1 through 3 was taken as the conversion ratio (CR) for the reactors, ranging from a low of 0.6 up to 1.06 (i.e., threshold "breeding"). The general plant design used for ALMRs was that of the current GE advanced liquid metal reactor concept (1866 MWe). Table 1 shows the key TRU (transuranic) parameters for the three cases and Figures 1 to 3 present the results. The three cases generally show that with modest ALMR growth all the transuranic material from LWR spent fuel produced during ALMR growth can be utilized in the ALMRs, thereby essentially being removed as material requiring long-term high level storage. This is true even for a breeder growth case, because of core inventory growth.

After a certain growth period, such as up to 2075, sufficient ALMRs, could be in existence so that if they were operated as converters, their internal consumption would be adequate to consume TRU from all existing LWR spent fuel. A ratio of about one ALMR at CR = 0.7 for each two-to-three LWRs could provide a symbiotic state regarding TRU production and use to that time frame (see Figure 4). At these ALMR deployment and TRU consumption rates, fissile material from some other source would be required for additional ALMR deployment to occur.

It should be noted that uranium is a major by-product of processing LWR-origin spent fuel. Significantly more uranium is recovered than is required for the ALMR growth analyzed for the NES. At the present time, the proper future role for the excess recovered uranium, which is slightly enriched to about 0.8%, could be storage as potential future ALWR or ALMR fuel or could be disposal as waste. Utilization of this uranium in ALWRs would require reenrichment and is being evaluated as part of the LWR actinide recycle program

For LWR spent fuel actinide recycle in the ALMR to be beneficial (and accepted) it is important that the system not create more waste and/or it must improve the waste form compared to the conventional once-through LWR system. Through the use of pyroprocessing (an innovative process for recovery of actinides from irradiated fuel) the waste generated per unit of electricity produced is estimated to be less than direct disposal of spent fuel in the repository. However, more importantly, the repository heat load after about 300 years approaches zero and the waste form is improved over the direct disposal of spent fuel. It is estimated that isotopics of concern (e.g., Tc99 and I129) released to the environment from the repository are decreased about three orders of magnitude. Additional analysis of the pyroprocess waste form is needed in the development program but preliminary results are favorable, as they are for the pyroprocess planned for recycle of ALMR spent fuel.

There is an estimated cost penalty of one to two mills/kwh for recovery of LWR spent fuel actinides over exclusive recycle of ALMR spent fuel. This penalty is for the initial cores for ALMR startup which would need to be fabricated using some fissile source other than LWR TRU if it were not available which would also represent some penalty. If recycled ALMR fuel or weapons grade plutonium were used, the penalty should be less. In these cases, however, there is only enough excess weapons plutonium to start up about three ALMRs and there will be no recycled fuel from ALMRs until there is an ALMR infrastructure and a significant number of ALMRs producing electricity.

It is concluded that there is a major incentive to recycle LWR spent fuel TRU to the ALMR to: (1) recycle a valuable resource capable of producing electricity indefinitely in the ALMR; (2) improve the waste form to impede release to the environment, and (3) remove fissile material from the repository to preclude the requirement for safeguards in perpetuity.

REFERENCES

1. M.L. Thompson and J.E. Quinn, "The ALMR System's Missions For Transmuting Waste into Energy", Global 93, Future Nuclear Systems: Fuel Cycle and Waste Disposal Options, Seattle, Washington, September 1993.

2. E.L. Gluekler and J.E. Quinn, "The Advanced Liquid Metal Reactor Actinide Recycle System", 9th Pacific Basin Nuclear Conference: Nuclear Energy, Science and Technology-Pacific Partnership, Sydney, Australia, May 1-6, 1994.

3. I.N. Taylor, M.L. Thompson and T.R. Johnson, "ALMR Fuel Process/Waste Material Balance Model Development", Global 93, Future Nuclear Systems: Fuel Cycle and Waste Disposal Options, Seattle, Washington, September 1993

4. M.L.Thompson, "The ALMR as a Weapons Plutonium Burner - Megatons to Megawatts", Global 93, Future Nuclear Systems: Fuel Cycle and Waste Disposal Options, Seattle, Washington, September 1993.

Table 1. ALMR Alternative Core TRU Data

	Heterogeneous Core	Homogeneous Cores	
Breeding or Conversion Ratio	1.06	0.7	0.6
Total Pu Consumed (makeup)/yr by 1866 MWe (kg)	-174	500	725
Total Pu Core Inventory for 1866 MWe (MT)	16.1	15.3	23.3
Total Pu Core Inventory Plus 2 Reloads for 1866 MWe Startup (MT)	25.9	23.4	35.6

DISPOSITION OF LWR-ORIGIN TRU WITH SMALL BURNER ALMR DEPLOYMENT TO CAP AT FIRST REPOSITORY
(NES Final Scenario - 195 GWe by 2030)

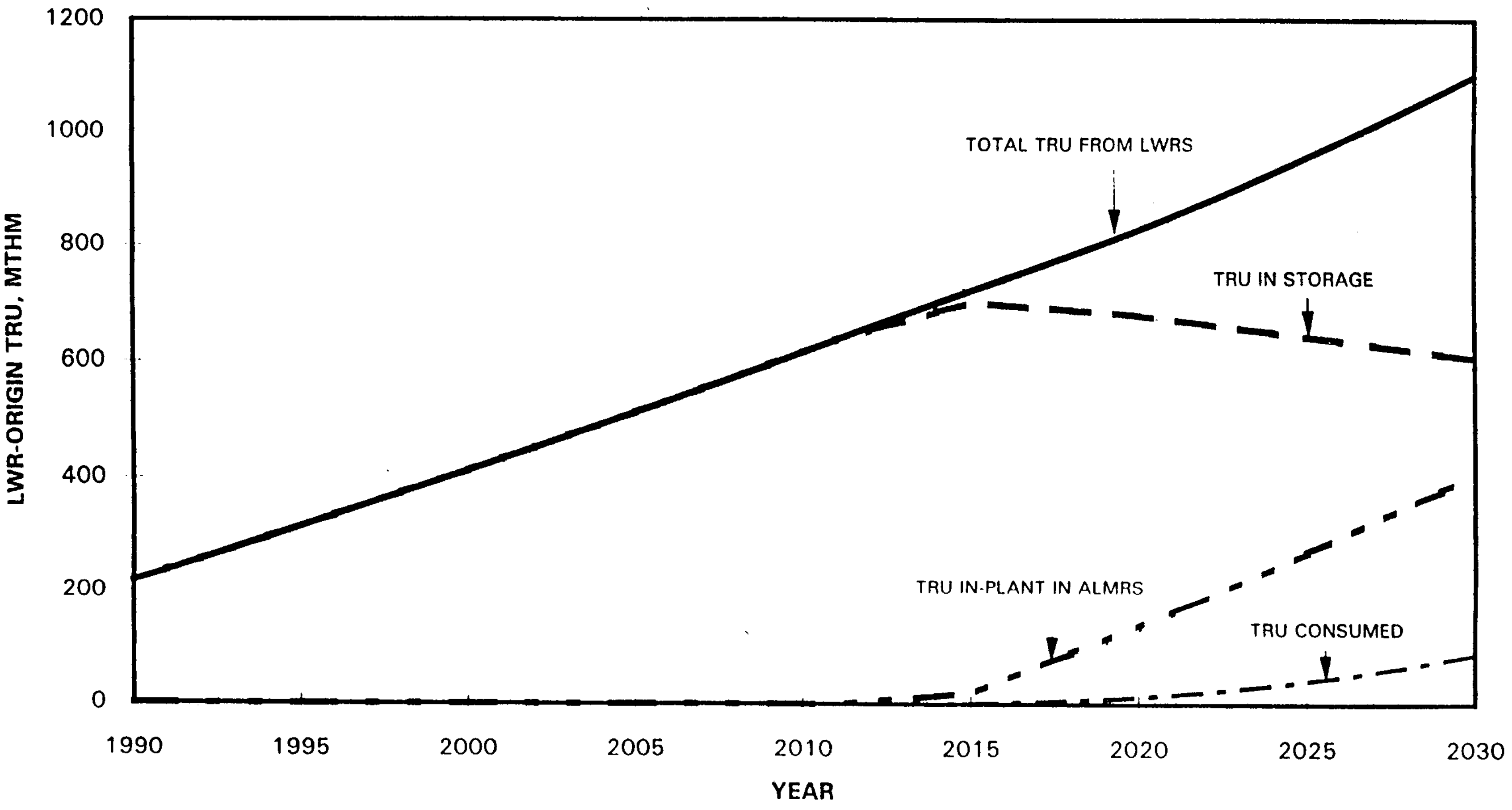

Figure 1

SMALL BURNER ALMR, CR = 0.72, DEPLOYMENT RATE TO CAP AT FIRST REPOSITORY

DISPOSITION OF LWR-ORIGIN TRU WITH LARGE BURNER ALMR DEPLOYMENT TO CAP AT FIRST REPOSITORY
(NES Final Scenario - 195 GWe by 2030)

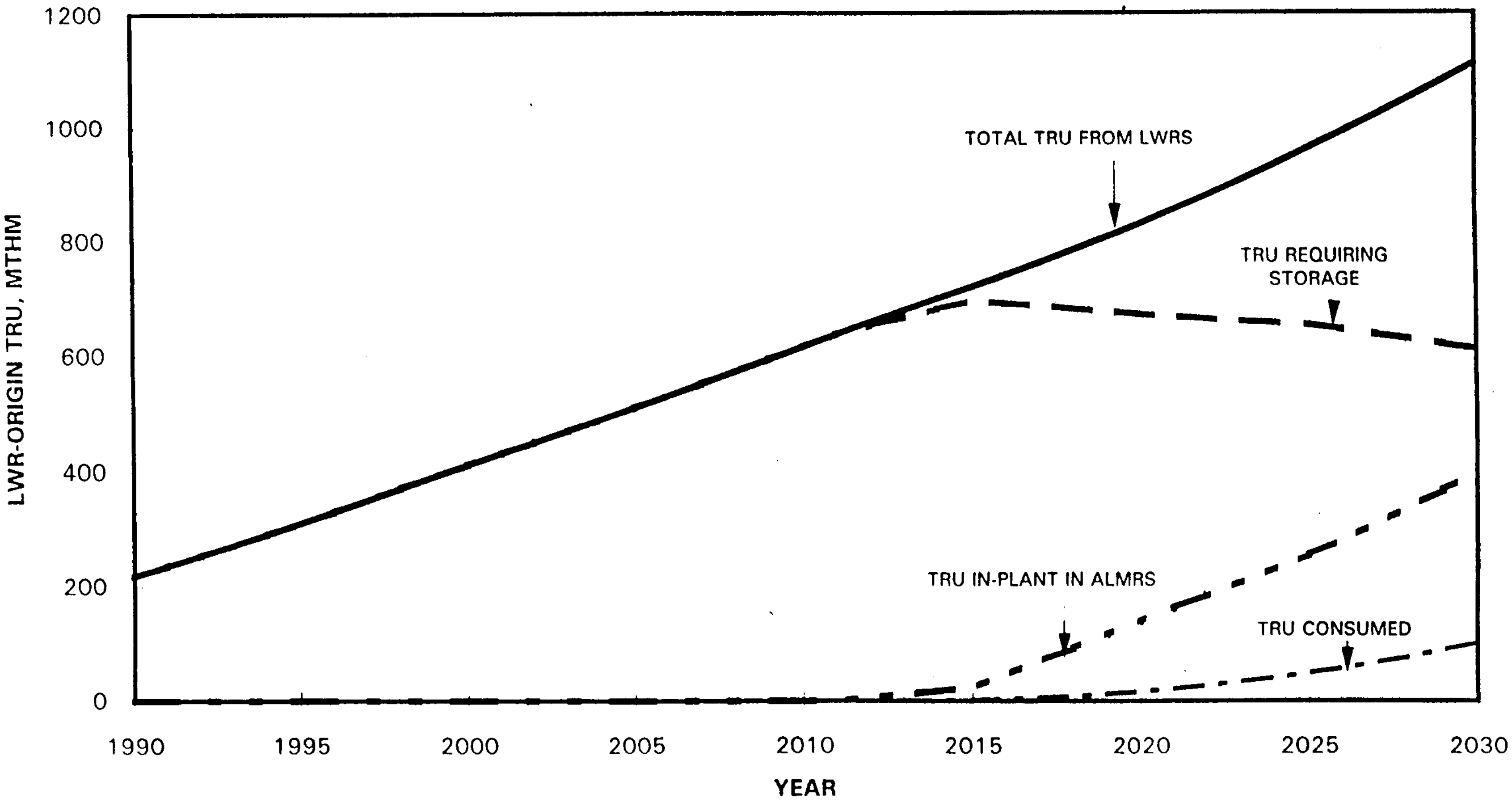

Figure 2

LARGE BURNER ALMR, CR = 0.59; DEPLOYMENT RATE TO CAP AT FIRST REPOSITORY

DISPOSITION OF LWR-ORIGIN TRU WITH BREAKEVEN ALMR DEPLOYMENT TO CAP AT FIRST REPOSITORY STRATEGY
(NES Final Scenario - 195 GWe by 2030)

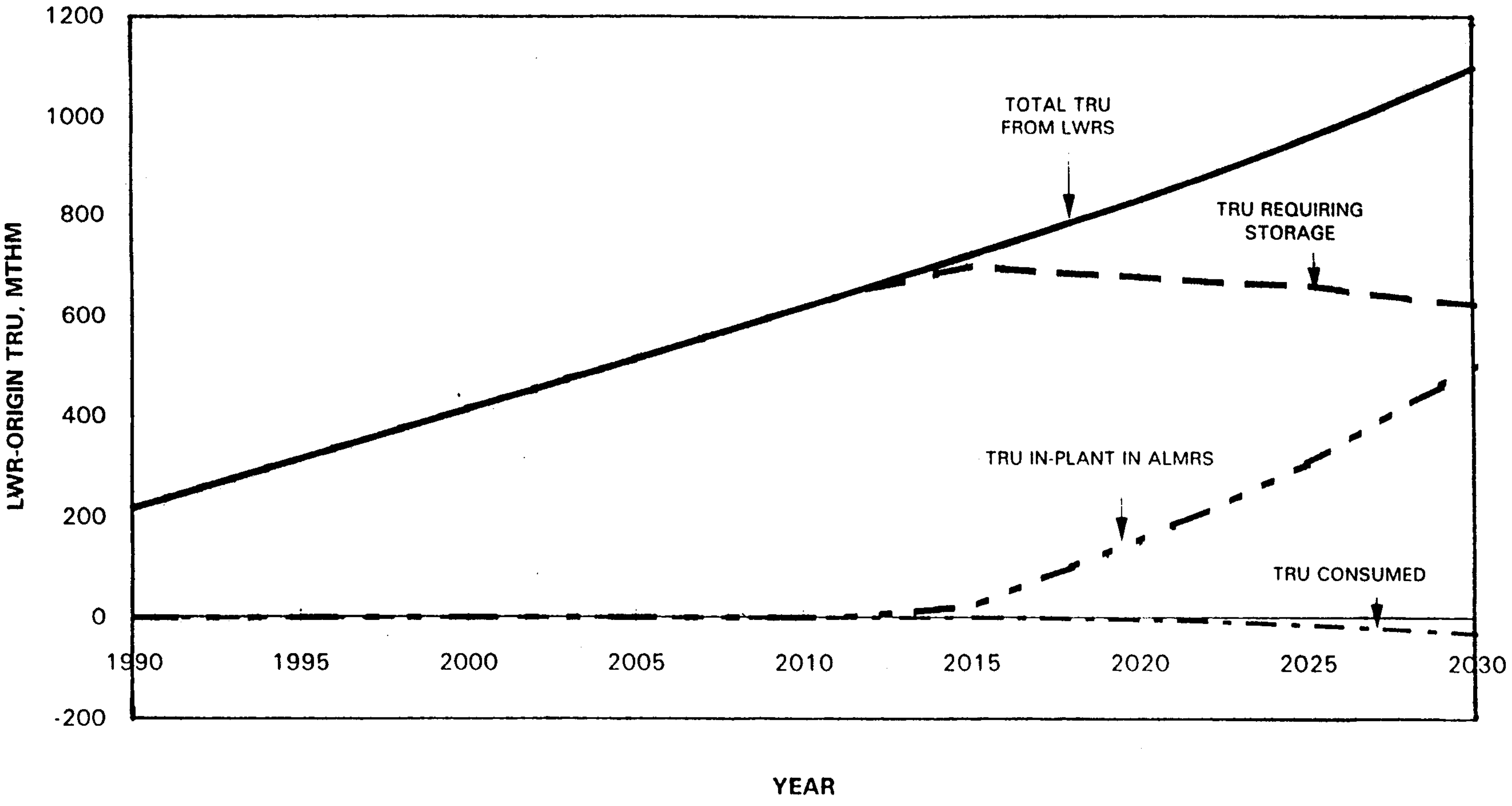

Figure 3

BREAKEVEN BREEDER ALMR, CR = 1; DEPLOYMENT RATE TO CAP AT FIRST REPOSITORY

EFFECT OF ACTINIDE RECYCLE ON LWR-ORIGIN TRU INVENTORY, SMALL BURNER ALMR DEPLOYED (27 GWE BY 2030)

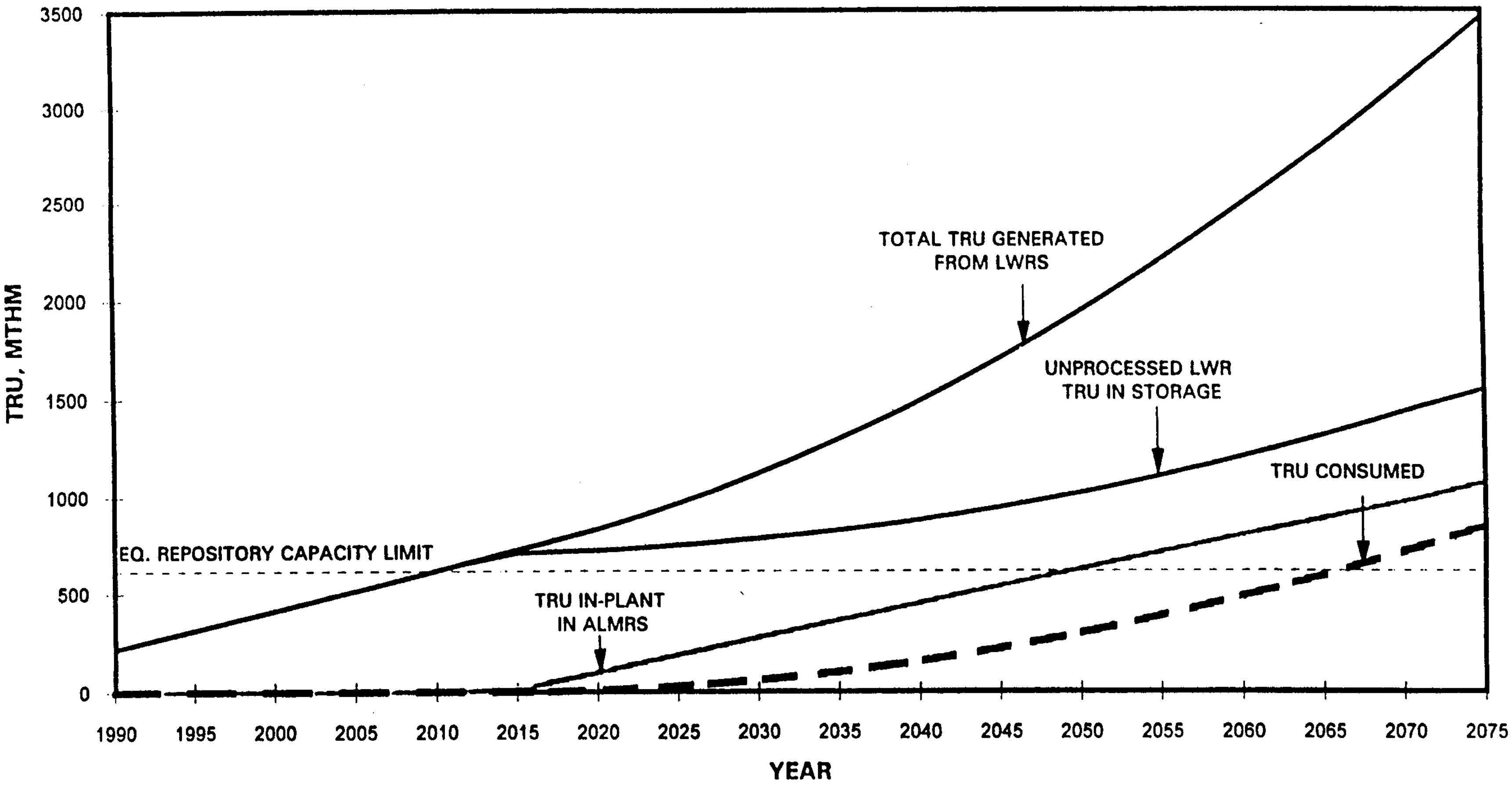

Figure 4

SMALL BURNER ALMR; DEPLOYMENT RATE AFTER 2030 SAME AS AT 2030; 20-YR PLEX FOR BOTH ALMR LWRS