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ALMR Deployment Economic Analysis

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EXECUTIVE SUMMARY

This analysis seeks to model and evaluate the economics of the use of Advanced Liquid Metal Reactors (ALMR) as a component of this country's future electricity generation mix. The ALMR concept has the ability to utilize as fuel the fissile material contained in previously irradiated nuclear fuel (i.e., spent fuel). While not a requirement for the successful deployment of ALMR power plant technology, the reprocessing of spent fuel from light water reactors (LWR) is necessary for any rapid introduction of ALMR power plants. In addition, the reprocessing of LWR spent fuel may reduce the number of high level waste repositories needed in the future by burning the long-lived actinides produced in the fission process. With this study, the relative economics of a number of potential scenarios related to these issues are evaluated. While not encompassing the full range of all possibilities, the cases reported here provide an indication of the potential costs, timings, and relative economic attractiveness of ALMR deployment.

The model used to evaluate the ALMR deployment economics was developed by the Engineering Economic Evaluations Group at Oak Ridge National Laboratory. The model calculates year-by-year costs, net present value costs, and levelized generation costs during an analysis period of 2010-2070. Developed in Lotus spreadsheet format, the analysis reflects the deployments of ALMR and LWR power plants, ALMR fuel recycle facilities, LWR reprocessing facilities, and high-level waste repositories. Data used in the model were supplied by the DOE ALMR program participants.

As mentioned above, several cases have been evaluated. Three reactor core designs (burner, breakeven, breeder) reflecting different fuel utilization strategies were considered. In addition, other parameters were varied individually as shown in Table E.1.

Table E.1. Parameters varied in current study

Item	Base Parameters	Parameter Variations[a]
Deploy ALMRs	Yes	No (null case)
Nominal capacity factor	0.86	0.80, 0.75
ALMR power in 2030, Gwe	27	Max achievable
Conversion/breeding ratio	0.69	1.04, 1.25
Pu available from weapons, MT	0	100
LWR fuel recovery cost, $/kgHM	350	200, 1000
Cost to implement repository, $B	7.2	15
LWR processing waste		
repository load factor	0.25	0.5
repository cost factor	0.75	0.5
LWR fuel processing costs charged to repository	No	Yes

[a]Parameters varied one at a time from base parameter set.

In addition to calculating the year-by-year absolute costs for each case, a relative comparison to a null case, where no ALMRs are deployed and all nuclear generation is supplied by once-through uranium burning plants, was made. This provides a useful relative measure of the economic attractiveness of the various scenarios. The results of the comparison are shown in Table E.2, ordered in ascending economic benefit. The values shown in the table represent the economic benefit or savings (or penalty for the one negative value) relative to the null, no ALMR, case. The values in Table E.2 are the differences in net present value between a particular ALMR case and the null case over the period 2010-2070. The wide range of $92 billion (1992$) indicates the economic sensitivity to particular assumptions. The $44 billion penalty, if $1,000/Kg HM processing costs are assumed, demonstrates the very sensitive nature of the LWR reprocessing cost assumption. At the other extreme, the breeding of additional fissile material within the ALMR permits additional ALMR plants to be deployed, thereby displacing uranium-burner plants, reducing the amount of LWR fuel to reprocess, reducing the upward price pressure on uranium ore, and making the existing uranium-burners cheaper to run.

Table E.2. Relative cost summary

Case	Relative Net present value[a] 2010-2070 (Billions 1992$)
Burner with $1000/kg LWR reprocessing	-43.74
No utilization of initial LWR spent fuel stocks (60,000 MTHM)	12.52
Maximum deployment of base case burner	14.09
Burner at 75% capacity factor	14.99
Burner at 80% capacity factor	16.30
Base case ALMR burner	**16.63**
ALMR breakeven (breeding ratio = 1.04)	19.54
Maximum deployment of breakeven plant	20.74
LWR reprocessing cost included with waste system	21.92
Burner with defense Pu	23.12
Burner with $200/kg LWR reprocessing	30.57
ALMR breeder (breeding ratio = 1.24)	41.41
Maximum deployment of breeder plant	46.82
Breeder plant with defense Pu	48.10

[a]Benefits compared to no ALMR case (null case).

One of the most striking observations of this set of cases involves the reduction in the number of repositories when ALMR plants are deployed. Because reprocessing removes the long-lived actinides (and their associated thermal load) from inclusion in a repository, more non-actinide material may be placed in the repository, thereby increasing the effective capacity of a repository. Figure E.1 shows the effective repository loading as a function of time for no ALMR deployment and the base case ALMR deployment. In the base case, the repository is assumed to accommodate four times the material in terms of initial heavy metal if the actinides are removed from the spent fuel. It is the Department of Energy's position that under no case does ALMR deployment displace the need for the first high-level waste repository and disposal of the current unprocessed spent fuel in that repository. The analysis in this study is focused on describing a range of economic performance using the stated assumptions. The study does not attempt to characterize likely or preferred deployment strategies.

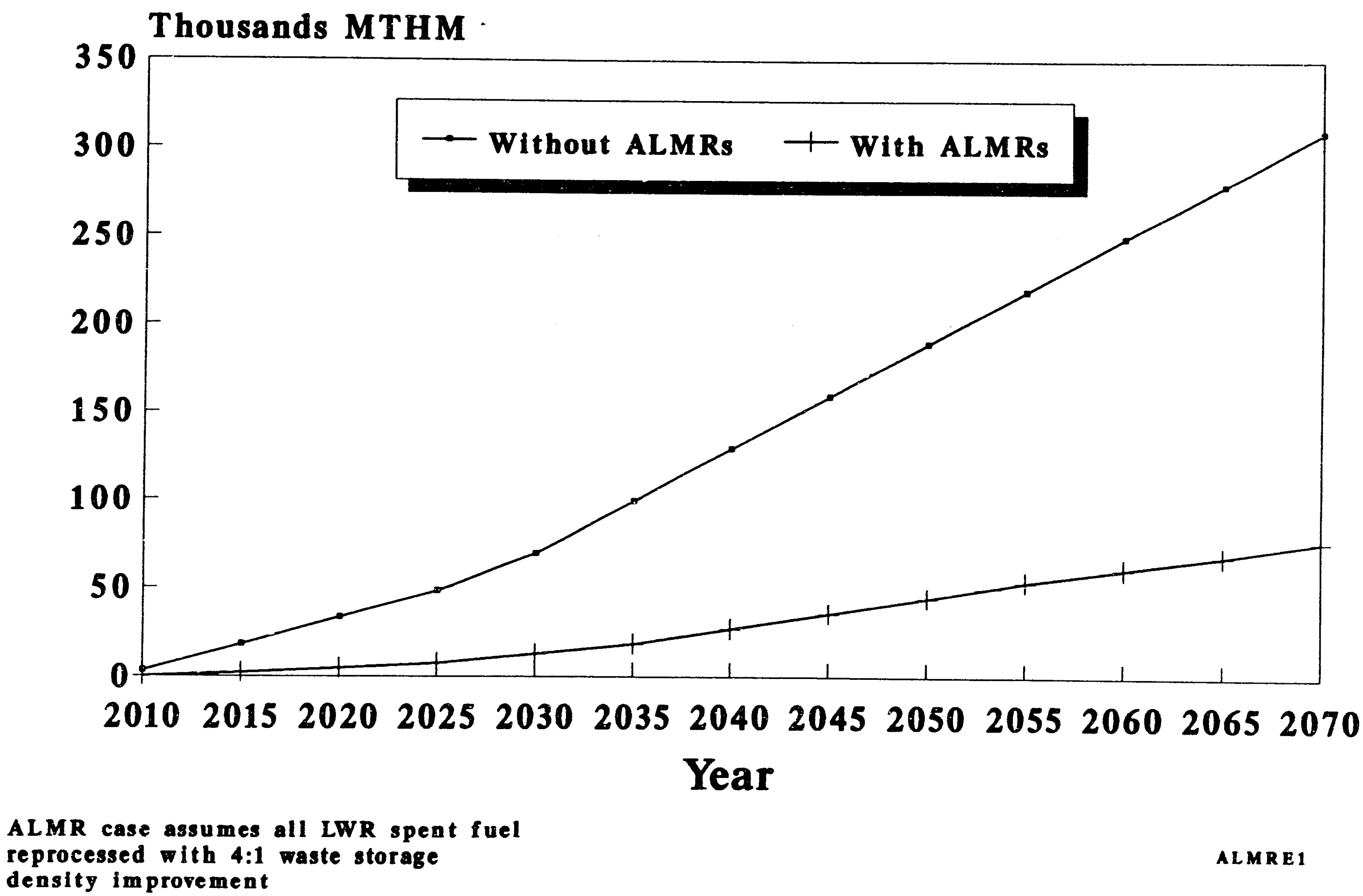


Fig. E.1. Equivalent heavy metal disposed of in repository: base case.

1. INTRODUCTION

Determining the relative economic value of various nuclear fuel cycle alternatives is an involved process. For cases that include fuel reprocessing, multiple potential sources of fissile material, and the determination of repository impacts, the model, by necessity, becomes large and complex. The Engineering Economic Evaluations Group at Oak Ridge National Laboratory was asked by the Department of Energy to develop an Advanced Liquid Metal Reactor (ALMR) deployment economics model and assess various cases of ALMR deployment. This report describes the model, and the input and results of several alternative scenarios.

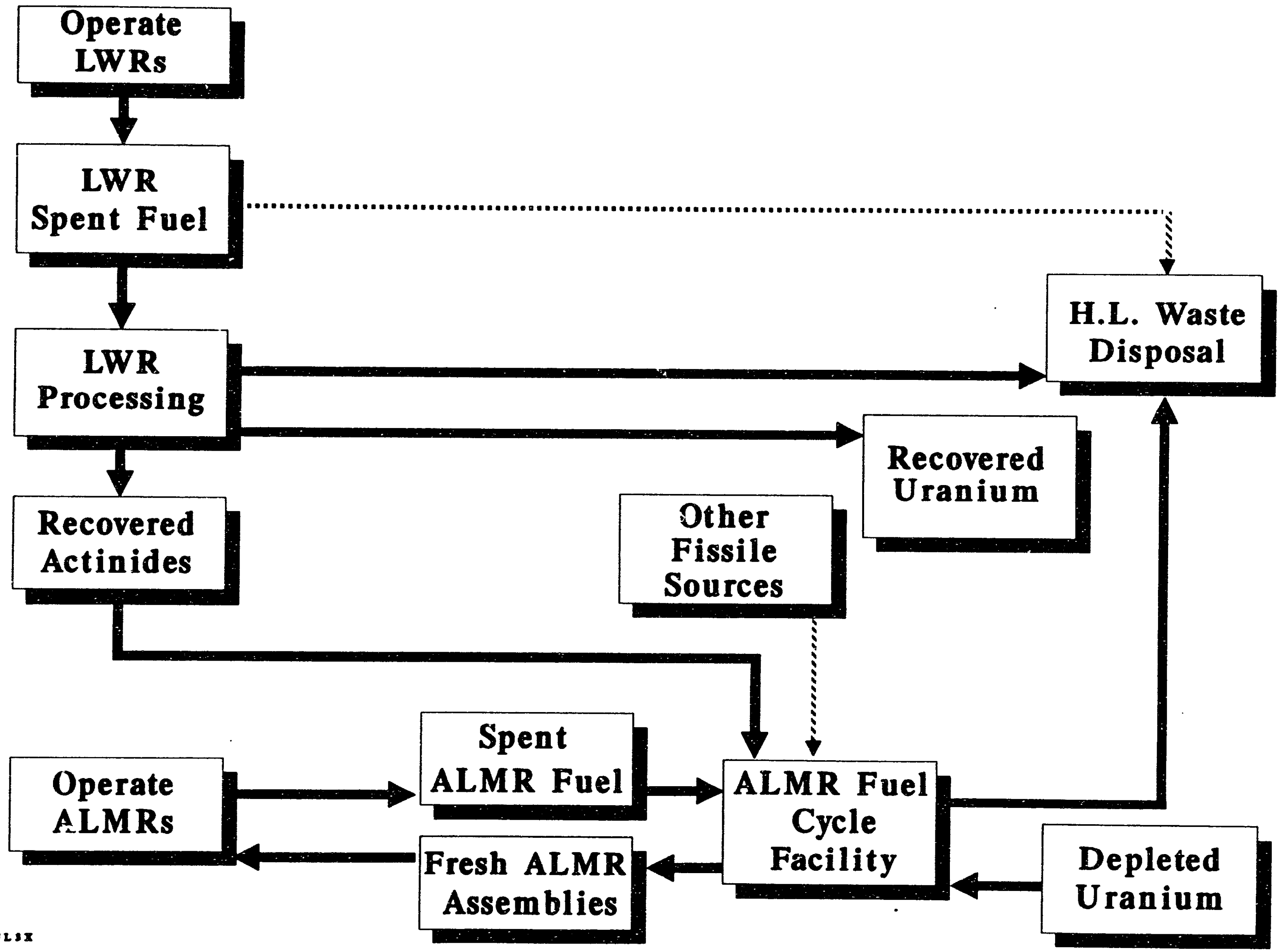
1.1 DEPLOYMENT ECONOMICS MODEL

The ALMR deployment economics model combines ALMR deployment, fuel cycle logistics, and high level waste repository logistics together with cost information, cash flow and revenue requirements methodology to obtain year-by-year costs and levelized power generation costs under various scenarios of ALMR deployment. The model is implemented in a Lotus 123 spreadsheet. The current model starts with the first commercial ALMR deployment in the year 2010 and provides ALMR deployment and year-by-year costs through the year 2070. A line-by-line description of the spreadsheet is given in Appendix B.

A pictorial description of the model is shown in Fig. 1. The ALMR is introduced into a nuclear power generation economy consisting of light water reactors (LWR). The maximum rate of ALMR deployment depends on the availability of fissile material which in turn depends on the reprocessing capacity and the quantity of spent LWR fuel available. The total nuclear power generation in any given year is that projected in the National Energy Strategy (NES) with extrapolations to the year 2070. Power not produced by ALMRs is assumed to come from LWRs. LWR spent fuel may either be disposed of directly or it can be reprocessed to obtain start-up fuel for ALMRs. An ALMR economy cannot exist without a source of start-up fuel. Actinides recovered from LWR spent fuel is a prime source for this material. Other potential sources of fissile material include surplus defense plutonium (Pu) or highly enriched uranium. A deployment model for the LWR reprocessing facility is included in the overall model. Reprocessing capacity is brought on-line as needed to sustain the growth of ALMRs. The growth rate of LWR spent fuel reprocessing capacity is restricted by the availability of spent fuel as well as by the demand for ALMR fuel. The deployment of these plants is also constrained by the economic need to have full capacity operation over the life of the facility.

The recovered actinides are sent to the fabrication end of an ALMR fuel recycle facility for fabrication into ALMR fuel assemblies. The reprocessing wastes are sent to the high level waste repository for permanent disposal and the uranium recovered from the LWR spent fuel is sent to storage. There is no provision in the current model for the re-enrichment of this spent fuel for use in LWRs.

ALMR fuel recycle facilities are deployed when adequate ALMR spent fuel inventories are available. Deployment is based on the availability of spent ALMR fuel, the need for fresh ALMR assemblies, and the economic desirability for nearly full capacity operation. In the model, the demand for ALMR fuel assemblies is met first by fuel from the ALMR recycle facility. Reload assemblies are provided for first and if any assemblies are left, they are used to satisfy initial core requirements for newly started plants. The current model includes a provision for the use of defense Pu up to a



ALMRFL3X

Fig. 1. ALMR deployment economics model.

maximum amount assumed available. If the use of defense Pu is included, it is used to satisfy demand for fuel assemblies after the supply from the recycle facility is exhausted. The LWR reprocessing plant is the highest cost source in the current model and is the source of last resort for ALMR fuel. Waste from the ALMR fuel recycle facility is sent to the high level waste repository. In the current model depleted uranium is used as the source of any makeup uranium needed for the fuel assemblies. Although not currently reflected in the model, recovered uranium from the LWR reprocessing plant could be used as an alternative uranium source.

A pictorial view of the ALMR economics model is shown in Fig. 2. A utility revenue requirements approach is used to calculate the year-by-year costs for the ALMR plants. Each plant coming on-line produces a future stream of cost associated with capital investment, operation and maintenance (O&M), final decommissioning of the plant, and for fuel. The basic revenue requirements method is discussed in the Nuclear Energy Cost Data Base[1] (NECDB). ALMR fuel cycle costs are based on the cost of the fuel assemblies purchased by the operating utilities. This assembly cost is capitalized and depreciated for tax purposes over the 5-year tax life currently allowed for nuclear fuel. The initial core fuel is depreciated for book purposes over a 30 year period whereas reload fuel is depreciated for book purposes over a fuel life of 5-years.

The fuel cycle facility (ALMR fuel recycle) plant is assumed to be industrially owned in the base set of calculations. The initial investment in this plant and its annual costs are modeled explicitly and a levelized cost of product (ALMR fuel assemblies) is calculated using an assumed 30-year plant life. The cost information for this plant was obtained from ALMR program information.[2] The cost structure for an LWR spent fuel reprocessing plant was not modeled explicitly. Instead, an input reprocessing cost in terms of $/kg of heavy metal ($/kgHM) was used. Defense program plutonium was assumed to be provided at a zero net cost to the ALMR. The cost of fuel assembly hardware was added to the cost of recovery to obtain the overall fuel assembly costs. Costs were estimated for the ALMR economy as a whole, and the cost of any specific reactor is not broken out separately in the model.

The LWR fuel cycle cost was estimated based on a revenue requirements calculation and 30-year mass flow requirements for an advanced LWR. The 30-year levelized unit fuel cost (mills/kWh) as a function of each fuel commodity price (i.e., uranium, conversion, enrichment and fabrication) was calculated. This sensitivity of levelized cost to commodity price was then used together with the annual power generation and the unit price of the commodity each year to obtain year-by-year fuel costs for the LWR. The capital, O&M, and decommissioning costs for the LWR plants operating in the same time frame as the ALMR plants were not modeled explicitly. Instead it was assumed that these costs will be the same for the two types of reactors.

The first repository and MRS system is assumed to be installed prior to the start-up of the first ALMR. The implementation and cost of subsequent repositories, and repository operating costs are estimated based on the quantity and type of high level waste disposal. These annual costs are considered to be part of the overall fuel cycle and are added to the annual costs from the ALMR and LWR fuel cycles after removal of the 1-mill/kWh waste disposal fee. The model calculates the total fuel/waste cost explicitly and independently of the assumed waste disposal fee. The reported costs are therefore net of the waste disposal fee.

The year-by-year costs are combined into Net Present Values (NPV), and these are levelized over the amount of ALMR or total nuclear energy produced in the same time period. Comparisons of these NPVs and levelized costs between any two scenarios gives the net savings or cost of implementing a specific strategy.

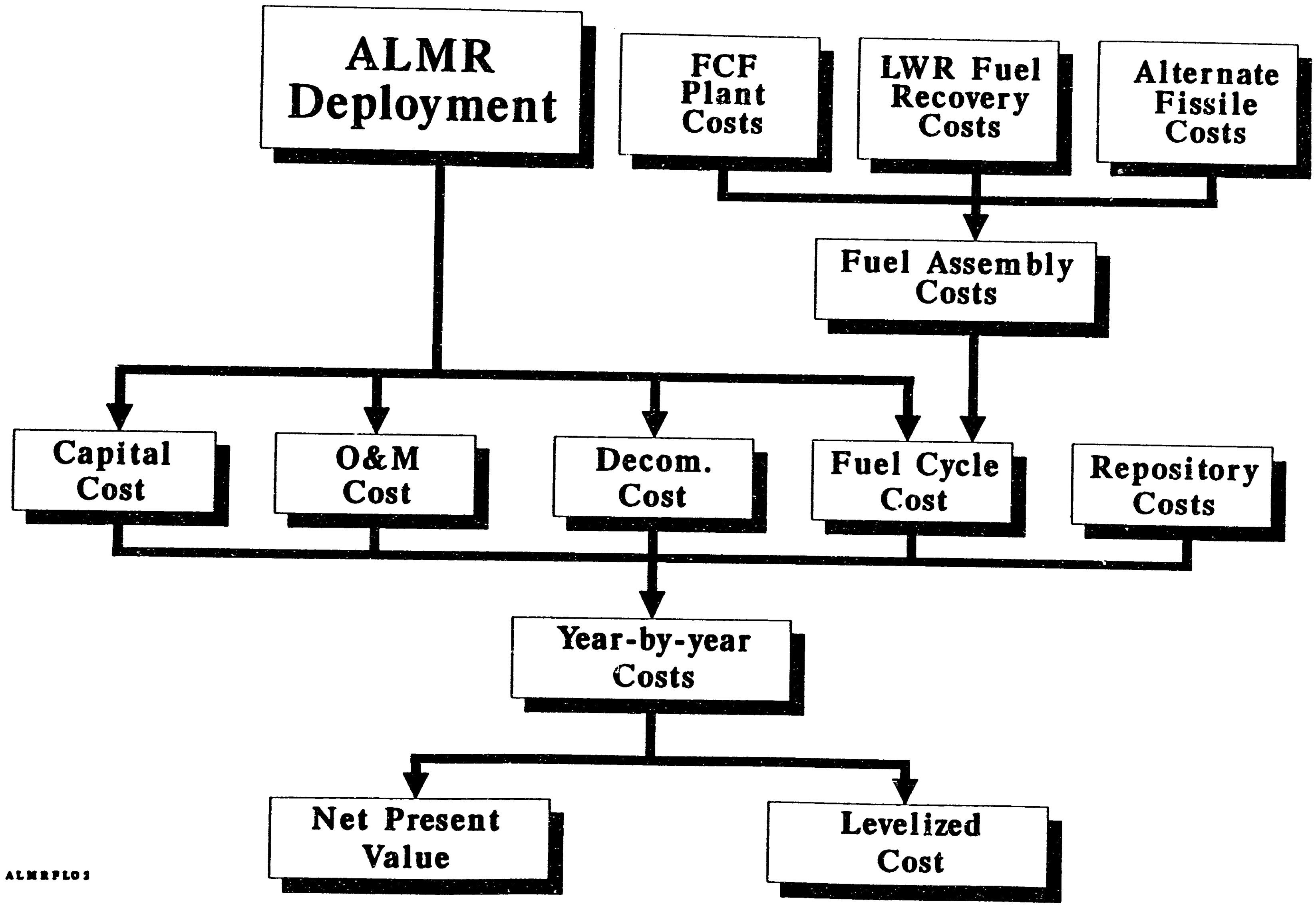


Fig. 2. ALMR economics model.

1.2 BASIC INPUT DATA

The basic input data to the Lotus 123 spreadsheet for the ALMR base case are shown in Tables 1-7. Items marked with an asterisk (*) are input parameters. Unmarked items are calculated internally in the spreadsheet. In addition to the data shown in Tables 1-7, the year-by-year ALMR power plant deployment and LWR reprocessing plant deployment must be input. The various deployment schedules are inter-related and are dependent on the fuel cycle mass flow characteristics for each case.

In Table 1, the reactor power, base capacity factor, and decommissioning cost were obtained from General Electric[3] (GE) for their Mod A reactor design. A January 1992 date was the reference date for cost information. The book depreciation life, decommissioning sinking fund rate, inflation rate, property tax rate, and plant capital interim replacement cost fraction (fraction of initial inflated plant capital cost) assumptions were obtained from DOE's Nuclear Energy Cost Data Base (NECDB) Report.[1] The year-by-year total nuclear power generation was obtained from the National Energy Strategy (NES) at 5-year increments from 2010 to 2030 with linear interpolation for the intervening years.[4] The rate of increase in nuclear power generation during the 2025-2030 period (39,400 GWh/year) was maintained after 2030.

Table 2 contains information on ALMR plant capital and O&M costs and on basic cost of money assumptions. The capital and operating costs were obtained from General Electric[1] for a first commercial plant and an Nth-of-a-kind plant. Not all of the capital investment is deductible for tax purposes. The tax deduction fraction is that calculated by the ORNL cost review team for the ALMR plant during a 1992 cost estimate review of the ALMR.[5] The learning factors (cost reduction fraction for a doubling in number of plants) shown were computed from the first-of-a-kind (FOAK) and Nth-of-a-kind (NOAK) cost assuming two doublings from FOAK to NOAK plant (i.e., fourth plant is assumed to be the NOAK plant). The capitalization fractions and returns on each type of capital for both utility and industrial operation are input. These values were obtained from the NECDB.[1] The industrial financing assumptions were used for the fuel cycle facilities.

ALMR fuel cycle data is shown on Table 3 for the base (burner) fuel cycle. Fuel cycle information for alternate fuel assumptions is discussed later in this report. The fuel cycle time, driver fuel assembly equivalent charge and discharge fissile material content, assembly heavy metal loading and the number of core and blanket assemblies for the initial core and each reload were provided by GE.[3] Where applicable, the equivalent fissile Pu discharge value includes Pu discharged in the blanket assemblies prorated to the driver assemblies. In the base case, there was assumed to be no alternative fissile material (e.g., weapons Pu) available. The fissile Pu in LWR spent fuel varies depending on fuel characteristics, spent fuel burnup, and time since discharge. The value shown is typical and will vary approximately in the range of 6 to 7 kg/MTHM.

The LWR actinide recovery (reprocessing) plant was sized to meet the fuel cycle needs while continuing to operate at full capacity. The $350/kgHM LWR spent fuel reprocessing cost is a program assumption based on preliminary estimates by ANL.[6] The initial core fuel loadings were depreciated for book purposes over the same period as the reactor plant (30 years). A 5-year book depreciation was assumed for the reload fuel. In all cases the fuel was depreciated for tax purposes over the 5-year tax depreciation schedule allowed for nuclear fuel. Any weapons Pu used in the analyses was assumed to be obtained at zero net cost.

Table 1. General Information

ALMR Deployment Model	Base Case Burner		
Date: 01-27-93	Case: ALMRA001		
Costs (1992 $) and rates:			
Reactor Power *	GWe	1.488	
Capacity Factor *		0.86	
Income Tax Rate *		0.3664	
Reference Year *	end of year	1991	
Book Depr. Life *	Years	30	
Decommissioning cost *	$M	508	
Decomm. Sinking fund rate *		0.070	
Annual Decommissioning cost		13.7	
Inflation factor *		1.050	
Equity Return		0.0650	
Avg. Cost of Money		0.1135	
After tax COM		0.0957	
Pres. Worth Factor		1.0957	
Const $ COM		0.04355	
Const $ P. Worth Fact		1.0436	
Property Tax Rate *		0.02	
Interim Replacement Rate *		0.0050	
Post-2030 Nucl. Generation Growth,TWh/yr.*		39.4	
Annual Power Production	GWh	11210	
NPV of Power, Noml $/Const $			
30 years (GWh)		109559	185750
Book Life (GWh)		109559	185750
2010-2050 (10^3 GWh)		1176.7	3703.3
2010-2060 (10^3 GWh)		1298.4	4856.8
2010-2070 (10^3 GWh)		1354.9	5728.0

* = Input parameters

Table 2. ALMR Cost Factors

ALMR Capital and O&M Costs

First Commercial Plant	
Initial Investment, $M *	2825.0
Tax Deduct Fraction *	0.8292
Depreciable Capital, $M	2342.5
Annual O&M costs, $M/yr*	113.3
NOAK Plants	
Initial Investment, $M *	2413.0
Tax Deduct Fraction *	0.8663
Depreciable Capital, $M	2090.4
Annual O&M costs, $M/yr*	89.6
Plant Learning Factors	
Capital Cost	0.924
O&M Costs	0.889

	Utility Capitalization	
	Fraction	Return
Debt *	0.500	0.097
Common *	0.400	0.140
Preferred *	0.100	0.090

	Industrial Capitalization	
	Fraction	Return
Debt *	0.300	0.097
Common *	0.700	0.170
Preferred *	0.000	0.090

* = Input parameters

Table 3. ALMR Fuel Cycle Parameters

ALMR Deployment Assembly needs
MOD A - 0.69 conversion ratio
Fuel Cycle Data

Fissile Material Balance Status		OK	
Fuel Cycle Time *	Months	15	
Equivalent Fissile Pu/Driver Assy ,kg			
Charged *		6.53	
Discharged *		6.12	
Recycle assemblies fabricated/discharged		0.9372	
Pu-239 Available from weapons,MT *		0.0	
Fissile Pu in LWR Spent Fuel,kg/MTHM *		6.35	
Assembly Heavy Metal, kg/assembly *			
Driver		69.4	
Blanket		0.0	
Core/Blanket Assemblies(full plant) *			
Initial core		1242.0	0.0
Reload		414.0	0.0
Blanket/driver assembly ratios			
Initial core		0.000	
Reload/discharge		0.000	
Driver Assemblies per MTHM Throughput		14.409	
LWR Actinide Rec Plant Size *	MTHM/yr	2000	
LWR Fuel Reprocessing cost *	$/KgHM	350	
Fuel Book Depr. Life *	Years		
Initial Fuel		30.000	
Recycle fuel		5.000	
Initial fuel tax deduct fraction		0.9416	
LWR-Actinide Recovery cost	$M/Ass	0.3599	
Weapons Pu Assembly cost *	$M/Ass	0.0000	

* = Input parameters

The input data given in Table 4 was mainly derived from the ALMR 1991 Fuel Cycle Cost Report[2] as modified in the DOE review.[5] A facility life of 30 years is assumed. The 2% property tax rate is the same as for the reactor plants. The base size for the recycle facility is 200 MTHM/year although various sizes were used in the analysis in order to maintain adequate flows of material.

The costs shown are for a FOAK plant. Unit learning curves were used to move from the FOAK to NOAK costs. NOAK cost factors were given in Ref. 2 and modified in the subsequent review.[5] Using the factors applicable to capital cost, the total reduction for a fourth-of-a-kind plant was computed. Plant costs were fixed at this level (a total reduction of 0.911^2) for all subsequent plants. The second and third plant were assumed to have a cost equal to 0.911 of the FOAK cost. The manpower and consumables costs were based on the cumulative driver assemblies recycled. The base amount for learning was the total number of assemblies required for 30-years of operation for a single full size plant from Ref. 2. The hardware cost is based on the cumulative driver assemblies fabricated. The learning factor applied over the number of cumulative quantity doublings shown gives the NOAK cost. This cumulative learning is approximately equal to the total learning between FOAK and NOAK plants from Ref. 5.

Table 5 shows the high level waste repository assumptions. There are many aspects of the repository and its costs which are uncertain and extrapolations had to be made from existing information in several instances. Basic technical and year-by-year cost information for several scenarios can be found in a DOE report.[7] This report, however, does not include any information on reprocessing waste disposal or the scenarios considered herein. The current repository capacity planned is 70,000 MTHM with 7,000 devoted to defense wastes, hence the assumed capacity of 63,000 MTHM. The model provides for either the disposal of intact LWR fuel assemblies or the reprocessing wastes therefrom. The current assumed spent fuel disposal rate[7] is 3,000 MTHM/year. The analysis assumes this rate for the first repository, however, this rate will not be adequate to dispose of all spent fuel in an expanding nuclear economy, so it was assumed that provision will be made to increase this maximum rate (doubled) for subsequent repositories. Spent fuel was assumed available for disposal or reprocessing 2-years after discharge from the reactor. At this point it entered an inventory available for disposal. Actual disposal follows availability by several years depending on the inventory magnitude.

The first repository is assumed to be in place by the initial year of this analysis (2010) and is the same for all scenarios considered in this study. With respect to this study, it is a sunk cost with an assumed zero incremental cost. The cost for subsequent repositories was derived from cost information for a second repository in Ref. 7, escalated to 1992 dollars. It is the total cost of all site characterization, licensing, construction, etc. paid toward putting a second repository in place.

Operating costs can be divided into fixed costs which are independent of the waste throughput and a variable component which is proportional to the waste disposal rate. The numbers shown are approximate values for the disposal of intact spent fuel and are based on this study's analysis of the reported cost estimates. The fixed cost is a per repository cost and is applied even if a repository is full.

Since more reprocessing wastes than assembly wastes (based on the heavy metal in the initial fuel) can be placed in a single can,[8,9] a cost reduction per unit of initial fuel can be expected. The magnitude of this savings is not well defined but could be significant. Estimates range from a 20–30% savings to as high as 75%. The latter is based on the amount of material that can be put in a single package and does not include consideration of concomitant costs such as increased costs of handling, additional expenditures for additional ventilation shafts, ventilation equipment, and power to run the equipment.[8] A cost factor (multiplier to variable cost of disposing of fuel assemblies) range of 0.5 to

Table 4. ALMR Fuel Cycle Facility Parameters

Reprocessing/Recycle Facilities

			ALMR FCF FOAK Plant
Tax Deduct. Fraction	*		0.7251
Initial Investment	*	$M	1263.1
Life of facility	*	Yrs	30.0
Decommissioning cost	*	$M	95.900
Nominal Throughput	*	MTHM/Yr	200.0
5 year repl. capital	*	$M	84.80
10-year repl. capital	*	$M	169.60
Equity Return			0.1190
Avg. Cost of Money			0.1481
After tax COM			0.1374
Pres. Worth Factor			1.1374
Depreciable Capital		$M	915.9
Annual Decom cost		$M	4.4
Const $ cost of Money factor			1.0833
Property Tax Rate	*		0.02
Annual Drivers Reprocessed			2881.8
Drivers available for Fabrication			2700.9
Const $ Cap. Rec Factor			0.0916
Annual Manpower cost	*	$M	53.7
Annual Consumables cost	*	$M	57.2
Unit Driver Fabr. Cost	*	$M/assy	0.1312
Unit Blanket Fabr Cost	*	$M/assy	0.0918

Unit learning	Basis	Base*	Factor*	Maximum Doublings*
FCF capital cost	Full plants deployed	1.0	0.911	2.0
Manpower	Cuml Recycle Drivers	3276.0	0.900	3.0
Consumables costs	Cuml Recycle Drivers	3276.0	0.940	3.0
Hardware costs	Cuml. Driver Assem	3276.0	0.900	4.0

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* = Input parameters

Table 5. Repository Model Parameters

Repository Model Parameters

Repository LWR Assem. Capacity*	MTHM	63000
Type of Disposal Indicator*		
0=LWR Fuel Ass., 1 = Repro waste		1.0
Max. Rate of Assembly Disposal	MTHM/yr	
First Repository*		3000.0
Subsequent Repositories*		6000.0
First Repository Capital Cost*	$M	0.0
Additional Repository Capital Cost*		7200.0
Annual Fixed Cost per Repository*	$M/yr	20.0
Unit cost of Assembly Disposal*	$/kgHM	145.0
Cost factor for REPRO waste disposal*		0.75
Unit Cost of Repro Waste Disp.	$/kgHM	108.8
Disposal Availability Lag Time*	years	2.0
Repro waste equiv factor*		0.25
Avg. LWR fuel Burnup 1992-2010*	MWd/kg	40.0
Waste Fee Escalation Factor*		1.05
H. L. Waste Fee*	Mills/kWh	1.0
Spent Fuel MRS Capacity Charge*	$/kgHM	20.0
Threshold for next repository*	MTHM	3000.0
Cumul. LWR HM @ 2009* MT-HM		60000
Cuml ore consumption 1992-2010*	Ktons	400.0

* = Input parameters

0.75 was considered in this study with a reference value of 0.75. In other words, the disposal of reprocessing wastes from a given amount of spent fuel is assumed to cost 75% of the cost of disposing of the same amount of intact spent fuel.

In addition to a cost impact, there is also a potential disposal density effect as a result of reprocessing. For this study, a reprocessed waste equivalence factor has been used as a measure of the repository's ultimate capacity. The base 0.25 factor assumes that four times as much initial heavy metal can be stored in a waste repository if the spent fuel has been reprocessed. This compaction is due to reduced long-term thermal loading. This factor is consistent with Refs. 8 and 9.

The LWR spent fuel burnup is assumed to be 40 MWd/kg throughout this study. The current high level waste fee of 1 mill/kWh is used with an escalation rate equal to the assumed 5% inflation rate. Consistent with the analysis in Ref. 7, an MRS is assumed to be in place prior to the time frame in this analysis. Examination of the repository program cost information indicates an incremental cost for added MRS storage of less than $20/kgHM. This value was used as the reference charge if the inventory of spent fuel increased over its previous maximum value. The amount of spent fuel available and the amount of uranium used in the future will depend on various factors. The total of 60,000 MTHM spent fuel in 2010 and the 400,000 tons of U_3O_8 consumption between 1992 and 2010 are consistent with current estimates.[10]

Table 6 contains LWR fuel cycle parameters. The study assumed for its baseline analysis an LWR spent fuel burnup of 40 MWd/kg. The projected burnup from U.S. reactors in the post 2010 period is generally in the 40–50 MWd/kg range.[10] The LWR fuel enrichment is a function of fuel burnup and is based on an algorithm derived from information on the Westinghouse AP-600 fuel cycle and sensitivities of enrichment versus burnup for Westinghouse PWRs. Optimal enrichment plant tails enrichments are a function of the fuel enrichment and prices for uranium and separative work. The 0.25% value has been projected for the post 2010 period.[10] The plant heat rate is for a plant thermal efficiency of 33.3%.

The uranium ore grade is not currently used in the model. While, this quantity is expected to decrease over time as the richer resources are used up, the value shown corresponds to a U_3O_8 content of 0.15% in the ore. The fuel cycle commodity prices shown are the estimated price in 1992 dollars in the year 2010. The prices assume a nuclear resurgence with new production coming on line. The uranium price is an estimate of the price to which uranium will have to rise before such new production will be economic in the United States. The enrichment price is the current price for a U.S. enrichment enterprise "Utility Service Contract." Conversion and fuel fabrication price are estimated prices from new facilities. As the resource is used up, the price of uranium should increase. There is a great deal of uncertainty as to what the future cost of uranium will be and on the quantity of uranium which will ultimately be available. The uranium price vs. cumulative consumption is based on the reported[11] reasonably assured reserves available at various forward costs of uranium. Information was given at $30, $50 and $100/lb. U_3O_8. The $150 point was obtained by making a linear extrapolation from the $50 and $100 points. The $150/lb value is about the minimum cost where uranium might be extracted from sea water so the price was projected to remain constant after 3.3 million tons U.S. uranium oxide consumption.

Table 7 shows parameters used in the LWR fuel cycle cost calculation. The only parameters not calculated internally in the program are the processing losses. The loss factors shown are those recommended in Ref. 1.

Table 6. LWR Fuel Cycle Information

LWR Fuel cycle parameters

Avg. LWR fuel Burnup*	MWD/kg	40.0	
Fuel enrichment	%	3.66	
Tails Enrichment*	%	0.25	
LWR plant heat rate*	BTU/kWh	10236	
Spent fuel/LWR GWh	kgHM/GWhe	3.125	
kg U per GWhe		23.5	
lbs-U3O8/GWhe		61.0	
kg-SWU per GWhe		16.2	
kg-Conversion/GWhe		23.3	
kg-Fuel Fab/GWhe		3.2	
Uranium Ore Grade lb.-U3O8/ton*		3.0	
Uranium base price, $/lb.-U3O8*		25.0	a
Enrichment Base Price, $/SWU*		125.0	a
Conversion Base Price, $/kg-U*		9.0	a
Fabrication Base Price, $/kg-U*		250.0	a

Uranium Pricing *

Used (10^3 tons)	Price ($/lb U3O8)	Scale $/lb/1000 tons
400.0	25.0	
1100.0	30.0	0.0071
1700.0	50.0	0.0333
3300.0	150.0	0.0625

* = Input parameters
a = Unit prices for the year 2010 in 1992 dollars

Table 7. LWR Fuel Cycle Parameters

Fuel cycle calculation		
Mass factor	kg U/kg-charged	7.393
U loss factor*		0.985
UF6 loss factor*		0.990
Enrichment loss factor*		0.990
Fabrication loss factor*		0.990
SWU/kg-charged calculation		
Value function-tails		5.959
Value function-natural		4.869
Value function-product		3.032
SWU/kg		5.132
kg-U charged/GWhe		3.125

* = Input parameters

1.3 INPUT VARIATIONS

The basic input was discussed in the previous section. Sensitivity of the results to variations in the input data was examined. Several reactor/fuel cycles were considered as given in Table 8. Mod A and Mod B are two different reactor designs being considered for the ALMR. Table 9 gives the reactor power and costs for these two systems. The information in Tables 8 and 9 were obtained from GE.[3] Other parameters varied in the sensitivity analysis are given in Table 10. Variations in cost parameters were made around the ALMR Base Case. A list of cases run in the analysis and their spreadsheet filenames are given in Appendix A.

Table 8. ALMR fuel cycle parameters

Reactor model	Mod A	Mod A	Mod B
Fuel cycle type	Burner	Breakeven	Breeder
Conversion/breeding ratio	0.69	1.05	1.24
Fuel cycle time, months	15	24	23
Equiv. fissile Pu/driver, kg			
charged	6.53	21.9	14.52
discharged	6.12	22.1	17.30
Assembly heavy metal, kg			
driver	69.4	88.0	120.03
blanket	NA	151.0	166.13
Full plant driver assemblies			
initial core	1242	594	756
reloads	414	198	252
Plant blanket assemblies			
initial core	0	648	648
reloads	0	162	180

Table 9. ALMR plant cost variations (million 1992 dollars)

Plant type	Mod A	Mod B
Reactor power, MWe	1488	1818
Decommissioning cost	508	524
First commercial plant		
initial investment	2825	2992
annual O&M cost	113.3	119.8
NOAK plant		
initial investment	2413	2556
annual O&M	89.6	94.9

Table 10. Additional parameters varied

Item	Base Parameters	Parameter Variations[a]
Deploy ALMRs	Yes	No (null case)
Nominal capacity factor	0.86	0.80, 0.75
ALMR power in 2030, Gwe	27	Max achievable
Conversion/breeding ratio	0.69	1.04, 1.25
Pu available from weapons, MT	0	100
LWR fuel recovery cost, $/kgHM	350	200, 1000
Cost to implement repository, $B	7.2	15
LWR processing waste		
repository load factor	0.25	0.5
repository cost factor	0.75	0.5
LWR fuel processing costs charged to repository	No	Yes

[a]Parameters varied one at a time from base parameter set.

2. CASE RESULTS

As described in Sect. 1.3, several different scenarios have been modeled. The selection of cases in this report is by no means exhaustive. They do show, however, the degree of economic sensitivity to changes in various input assumptions. In each ALMR case, the relative economic advantage as compared to a null (no ALMR) case was determined.

2.1 NO ALMR CASE (NULL CASE)

This case serves as a relative benchmark for all ALMR cases. In this case, it is assumed that all nuclear generation is provided by LWR plants and that unreprocessed spent fuel is buried in the repositories. The LWR fuel cycle costs were developed on the basis of the data provided in Tables 6 and 7. The assumed annual energy generation in terawatt-hours (TWhe) is shown in Fig. 3. Due to the growing amount of nuclear generation, demand for uranium ore increases as shown in Fig. 4. This results in an assumed increased price for ore as also shown in Fig. 4.

One of the most significant impacts of this case is the amount of spent fuel (heavy metal) that will have to be placed in repositories. As shown in Fig. 5, the limit of the first repository is reached in 2029, with new repositories needed approximately every 10 years. During the 60 year period shown in Fig. 5, five repositories would be needed at the current loading limit.

The cost summaries for this case are shown in Table 11. The ALMR cases that follow will compare their costs to those presented in this table.

2.2 BASE ALMR BURNER

For purposes of relative comparison, a set of ALMR data was selected to be the base case. The specific data for this case are described in Sect. 1.2. The annual energy generation assumed for this case is shown in Fig. 6. The uranium ore use and price for LWR plants are presented in Fig. 7. As a result of the deployment of ALMRs, the demand for uranium is less than in the no ALMR case depicted in Fig. 4.

One of the most striking features of this case, and for all ALMR cases, is the reduction in the rate in which waste repositories are filled. Owing to the removal of spent fuel actinides via reprocessing, and the resulting decrease in long-term thermal heat loading, more spent fuel material (i.e., fission products) can be volumetrically accommodated in the repositories. This leads to a thermal heavy metal equivalence which, in effect, fills the repositories at a much slower rate. With the base case 0.25 waste equivalency factor, four times as much initial heavy metal in the form of reprocessing wastes can be accommodated in a repository as compared to intact spent fuel assemblies. Therefore, one metric ton of ***equivalent*** heavy metal corresponds to four MTHM in an unprocessed (intact) state. As shown in Fig. 8, after reprocessing LWR spent fuel, the equivalent heavy metal disposed in the repositories is such as to not require a second repository (at the current loading limit of 63,000 MTHM) until 2061, 51 years after the start of the first repository.

The resulting costs for this case are shown in Table 12. The differential costs, comparing this case to the no ALMR case, are provided in Table 13. As shown, the higher cost of uranium and waste repositories in the no ALMR case are initially offset by the cost of the ALMR fuel cycle. In

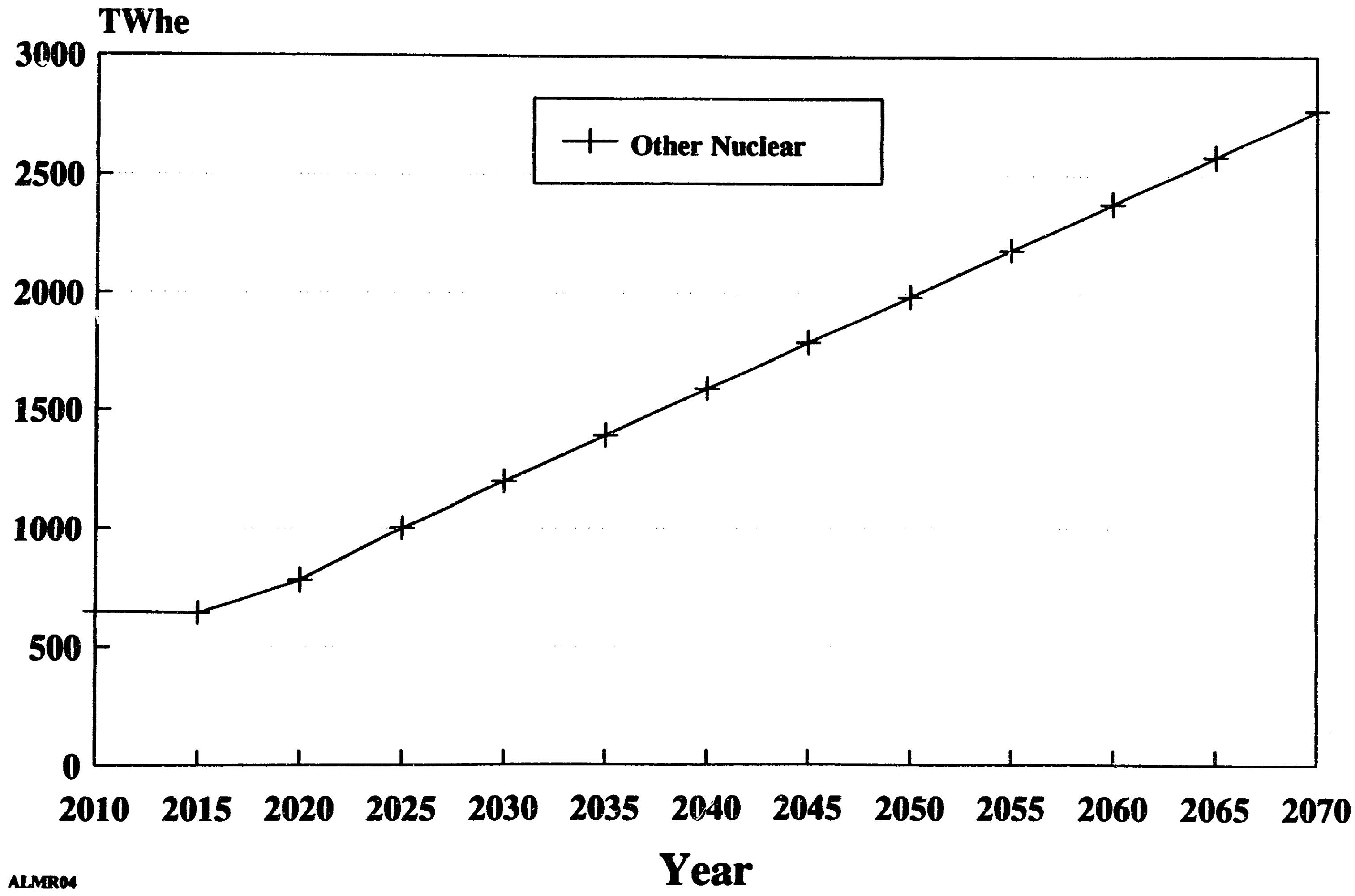
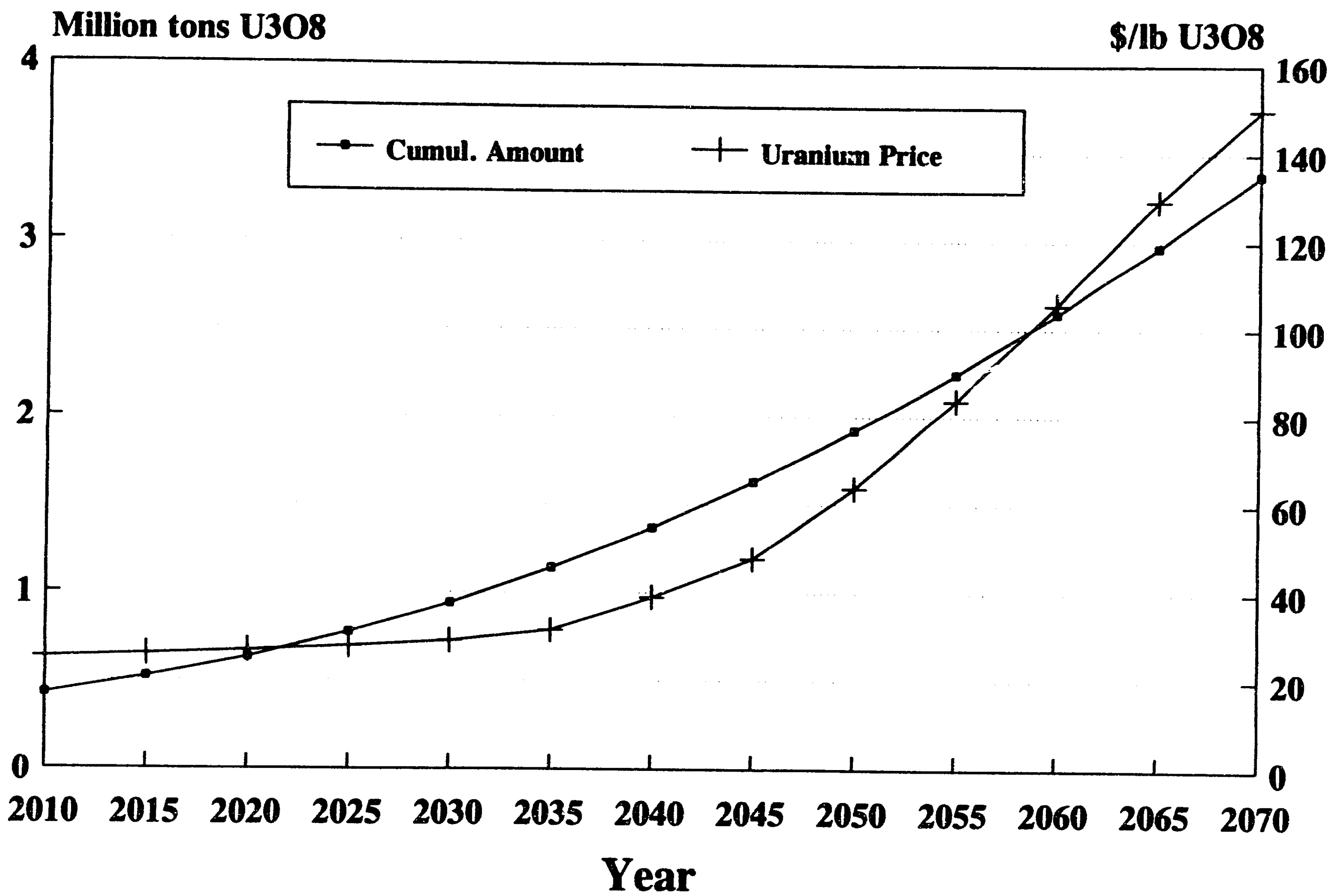


Fig. 3. Annual energy generation, no ALMR case.



ALMR06

Fig. 4. Uranium use and price, no ALMR case.

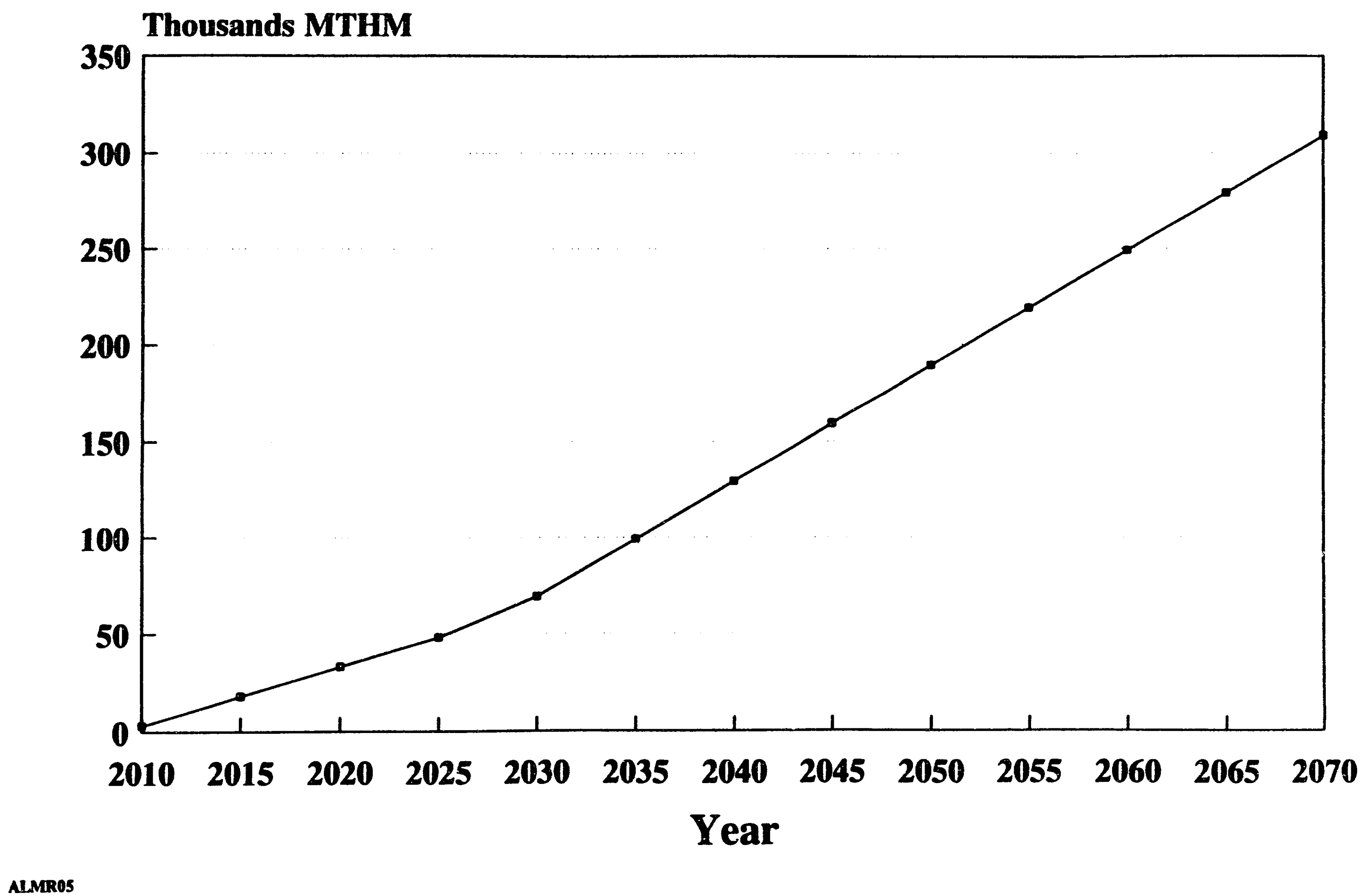


Fig. 5. Equivalent heavy metal disposed of in repository, no ALMR case.

Table 11

ALMR Deployment Model — Nul Case with no ALMR Deployment
Revised 01-26-93 — Case: ALMR0000

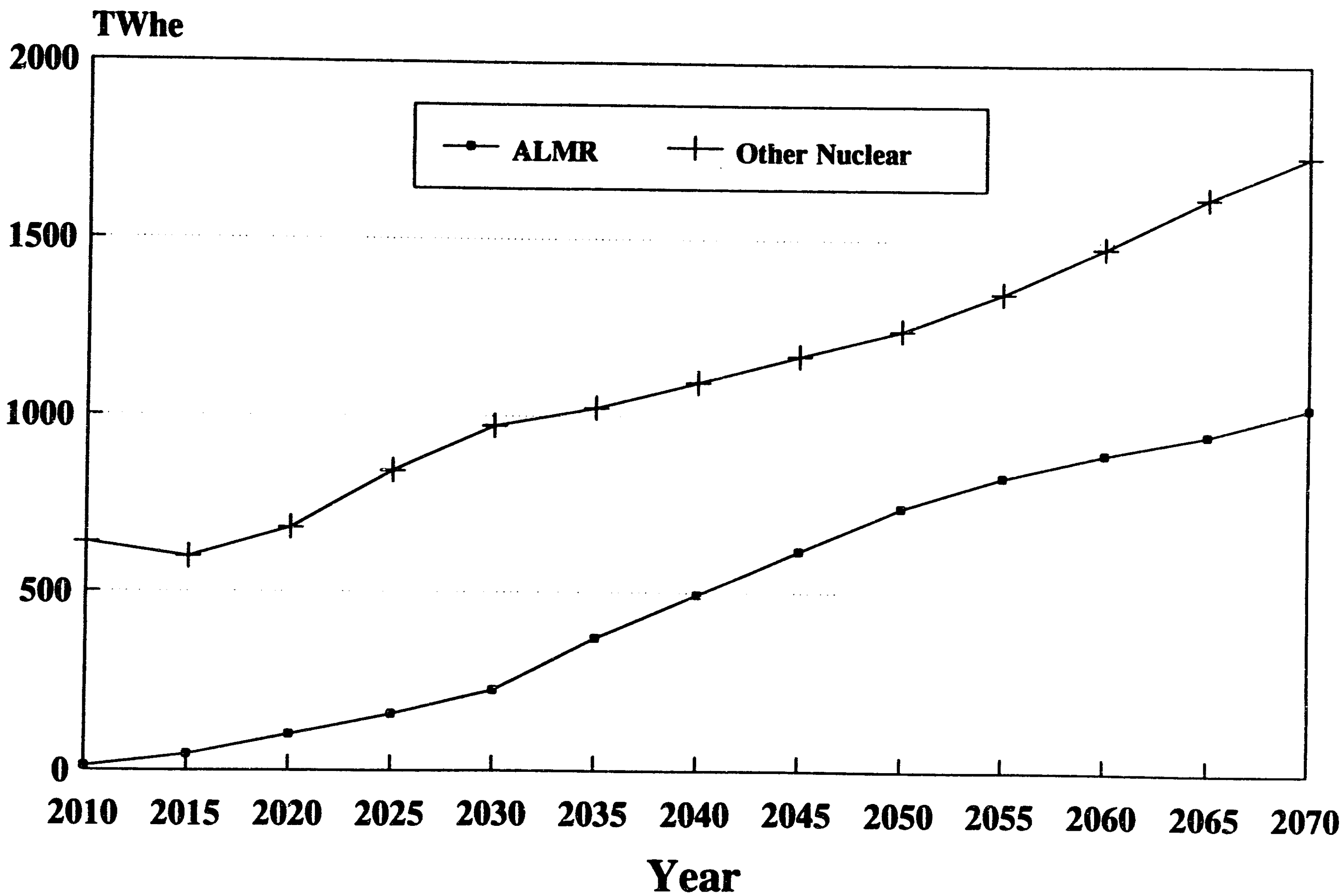
Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	0	0	0	0	0
LWR Power	TWh	10803	15357	19168	22203	24541
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	0	0	0	0	0
LWR Fuel Cycle	M$	88357	128170	167622	209176	251175
H.L. Waste Repos	M$	9629	14606	17840	19980	20859
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	87183	127420	166294	206954	247492

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	0.0	0.0	0.0	0.0	0.0
O&M	0.0	0.0	0.0	0.0	0.0
Decommissioning	0.0	0.0	0.0	0.0	0.0
Fuel (incl. waste fee)	0.0	0.0	0.0	0.0	0.0
Total Levelized ALMR Plant Cost	0.0	0.0	0.0	0.0	0.0

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	8.18	8.35	8.75	9.42	10.23
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	7.18	7.35	7.75	8.42	9.23
H. L. waste repository	0.89	0.95	0.93	0.90	0.85
Total Levelized Fuel Cost	8.07	8.30	8.68	9.32	10.08

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	7.77	8.42	8.84	10.20	13.40	17.33



ALMR01

Fig. 6. Annual energy generation, ALMR base case.

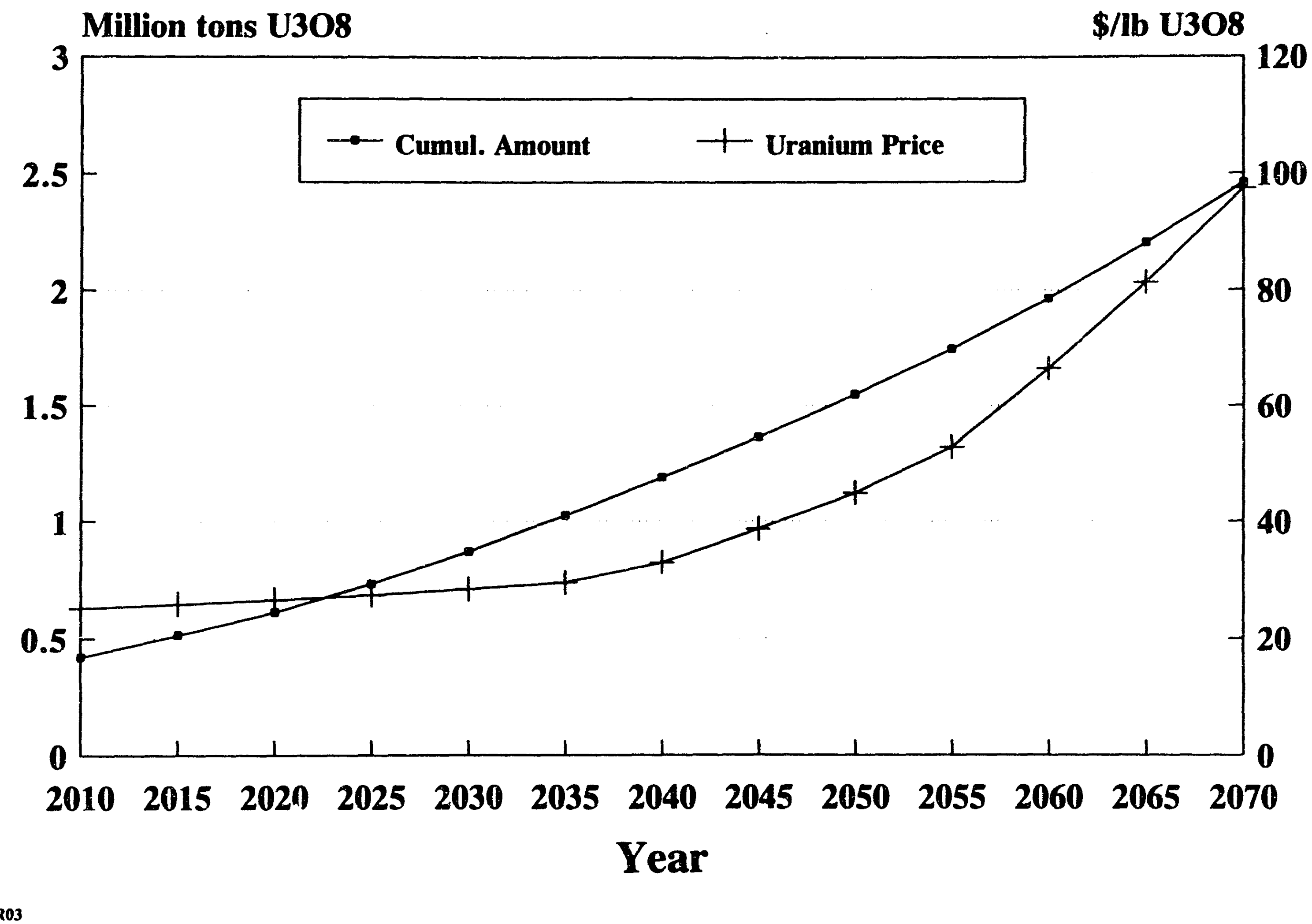
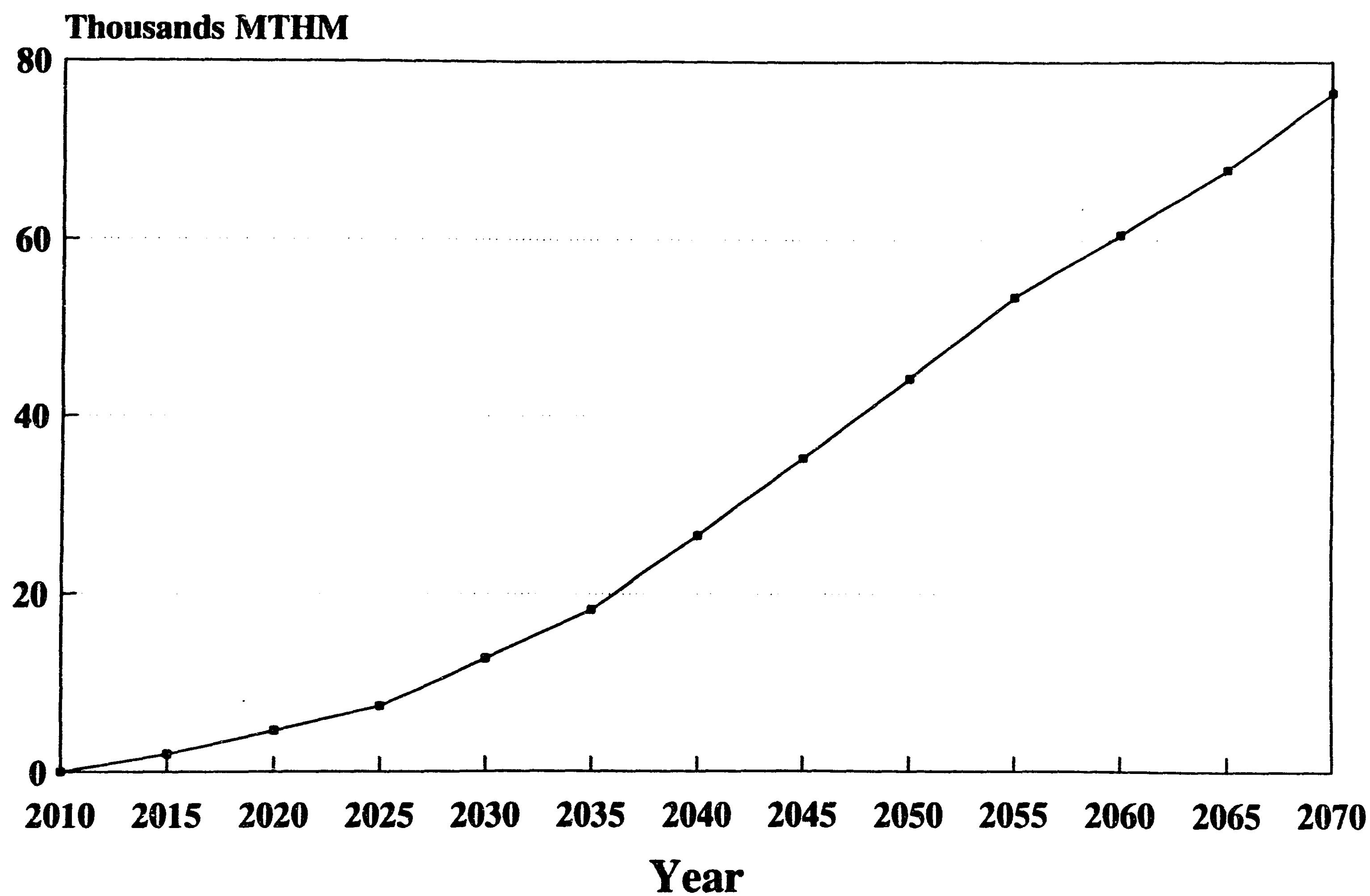


Fig. 7. Uranium use and price, ALMR base case.



ALMR02

Fig. 8. Equivalent heavy metal disposed of in repository, ALMR base case.

Table 12

ALMR Deployment Model   Base Case Convertor
Date: 01-27-93   Case: ALMRA001

Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1182	2377	3703	4857	5728
LWR Power	TWh	9621	12979	15464	17346	18813
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	19684	36793	53450	66603	75653
LWR Fuel Cycle	M$	78498	106974	130185	150488	170168
H.L. Waste Repos	M$	3454	5437	7107	8138	9579
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	90834	133847	171573	203025	230859

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	31.5	27.9	24.8	22.2	20.3
O&M	8.9	8.5	8.3	8.2	8.2
Decommissioning	2.1	2.1	2.1	2.1	2.1
Fuel (incl. waste fee)	16.7	15.5	14.4	13.7	13.2
Total Levelized ALMR Plant Cost	59.1	53.9	49.6	46.2	43.7

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	9.09	9.36	9.58	9.78	10.02
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	8.09	8.36	8.58	8.78	9.02
H. L. waste repository	0.32	0.35	0.37	0.37	0.39
Total Levelized Fuel Cost	8.41	8.72	8.95	9.14	9.41

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	8.09	8.78	9.44	9.90	10.36	11.90

Table 13

ALMR Deployment Model — ALMR v. no ALMR Case Summary

Date: 01-27-93 — Case: ALMR0000 - ALMRA001

============================

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-19684	-36793	-53450	-66603	-75653
LWR Fuel Cycle	M$	9859	21197	37437	58689	81006
H.L. Waste Repos	M$	6174	9170	10734	11842	11279
less Waste Fee Revenue	M$	-0	0	0	0	0
Net Fuel Cost NPV	M$	-3651	-6427	-5279	3928	16633

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-0.91	-1.02	-0.84	-0.36	0.22
less waste fee	-0.00	0.00	0.00	0.00	0.00
Net fuel cost	-0.91	-1.02	-0.84	-0.36	0.22
H. L. waste repository	0.57	0.60	0.56	0.53	0.46
Total Levelized Fuel Cost	-0.34	-0.42	-0.28	0.18	0.68

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-0.32	-0.36	-0.61	0.30	3.03	5.43

later years the price of uranium increases faster than ALMR fuel costs, leading to a $16.6 billion (1992$) net present value (NPV) advantage for the ALMR case over the 2010–2070 period.

2.3 BURNER WITH DEFENSE Pu

This case uses the same data as the ALMR Base Case discussed in the previous section except that 100 MT of defense-related plutonium is assumed to be made available to the ALMR system at no cost for the fissile material. The energy generation, uranium demands, and repository requirements are nearly identical to those shown in Figs. 6–8. Therefore, plots for this case have not been included in this report. The cost summaries are given in Tables 14 and 15. As shown in Table 15, there is an increased economic benefit of ALMRs relative to the no ALMR case due to the availability of fissile material at zero cost and the resulting delay in the need for LWR reprocessing. The differential NPV between this case and the null (no ALMR) case is $23.1 billion over the period 2010–2070.

2.4 MAXIMUM DEPLOYMENT OF BURNER

This case utilizes the same base burner data, but rather than constraining the number of ALMR plants to ~27 GWe in 2030, the maximum possible number of ALMR plants by 2030 are deployed. This deployment is limited only by the amount of fissile material available for starting up and sustaining the ALMR plants. This leads to 61 GWe of ALMR capacity in 2030 as compared to 27 GWe in the constrained base burner case described in Sect. 2.2. The additional ALMR generation is fueled by actinides recovered from LWR spent fuel. As shown in the cost summaries (Tables 16 and 17), the increased utilization and advanced timing of LWR reprocessing lowers the relative economics of this case compared to the cases in Sects. 2.2 and 2.3.

2.5 BURNER AT 75% CAPACITY FACTOR

This case utilizes the same base burner data, but the ALMR plant capacity factor was changed from 86% in the base case to ~75% in this case. As shown in the cost summaries (Tables 18 and 19), the decreased capacity factor causes the power from ALMRs to be somewhat more expensive since fixed costs (such as capital) are spread over less power generation, so that the relative economics of this case is less compared to the cases in Sects. 2.2 and 2.3. The differential NPV between this case and the null (no ALMR) case is $15.0 billion over the period 2010-2070.

2.6 BURNER AT 80% CAPACITY FACTOR

This case utilizes the same base burner data, but the ALMR plant capacity factor was changed from 86% in the base case to ~80% in this case. As shown in the cost summaries (Tables 20 and 21), the decreased capacity factor causes the power from ALMRs to be somewhat more expensive so that the relative economics of this case is less compared to the case in Sect. 2.2. The results indicate a NPV advantage for this case compared to the no ALMR case of $16.3 billion over the 2010–2070 period.

Table 14

ALMR Deployment Model   Base Case Convertor with DP Pu

Date: 01-27-93   Case: ALMRA002

Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1182	2408	3799	5010	5927
LWR Power	TWh	9621	12949	15368	17193	18614
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	14123	31532	48987	62774	72461
LWR Fuel Cycle	M$	78498	106708	129242	148758	167536
H.L. Waste Repos	M$	2497	4624	6436	7480	8915
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	84315	127507	165498	196809	224371

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	31.5	28.0	24.9	22.3	20.3
O&M	8.9	8.5	8.3	8.2	8.2
Decommissioning	2.1	2.1	2.1	2.1	2.1
Fuel (incl. waste fee)	12.0	13.1	12.9	12.5	12.2
Total Levelized ALMR Plant Cost	54.4	51.6	48.2	45.1	42.8

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	8.57	9.00	9.30	9.53	9.78
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	7.57	8.00	8.30	8.53	8.78
H. L. waste repository	0.23	0.30	0.34	0.34	0.36
Total Levelized Fuel Cost	7.81	8.30	8.63	8.86	9.14

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	7.20	8.52	9.48	9.97	10.32	11.79

Table 15

ALMR Deployment Model ALMR v. no ALMR Case Summary
Date: 01-27-93 Case: ALMR0000 - ALMRA002

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-14123	-31532	-48987	-62774	-72461
LWR Fuel Cycle	M$	9859	21463	38379	60419	83639
H.L. Waste Repos	M$	7131	9982	11405	12500	11944
less Waste Fee Revenue	M$	-0	0	0	0	0
Net Fuel Cost NPV	M$	2867	-87	797	10144	23121

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-0.39	-0.66	-0.55	-0.11	0.46
less waste fee	-0.00	0.00	0.00	0.00	0.00
Net fuel cost	-0.39	-0.66	-0.55	-0.11	0.46
H. L. waste repository	0.66	0.65	0.60	0.56	0.49
Total Levelized Fuel Cost	0.27	-0.01	0.04	0.46	0.94

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	0.57	-0.09	-0.65	0.23	3.08	5.55

Table 16

ALMR Deployment Model — Base Case Convertor with Maximum Deployment Rate
Date: 01-27-93 — Case: ALMRA003

=============================

Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	2278	3930	5226	6256	7084
LWR Power	TWh	8525	11427	13942	15947	17457
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	35689	56083	70314	81276	89960
LWR Fuel Cycle	M$	69390	93726	116409	137268	156941
H.L. Waste Repos	M$	5994	7632	8682	9552	11041
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	100271	142085	176237	205893	233400

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	31.8	26.2	22.6	20.6	19.3
O&M	8.5	8.3	8.2	8.2	8.1
Decommissioning	2.1	2.1	2.1	2.1	2.1
Fuel (incl. waste fee)	15.7	14.3	13.5	13.0	12.7
Total Levelized ALMR Plant Cost	58.0	50.8	46.4	43.8	42.2

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	9.73	9.76	9.74	9.84	10.06
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	8.73	8.76	8.74	8.84	9.06
H. L. waste repository	0.55	0.50	0.45	0.43	0.45
Total Levelized Fuel Cost	9.28	9.25	9.19	9.27	9.51

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	8.49	10.20	9.18	8.96	9.77	11.76

Table 17

ALMR Deployment Model   ALMR v. no ALMR Case Summary
Date: 01-27-93   Case: ALMR0000 - ALMRA003

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-35689	-56083	-70314	-81276	-89960
LWR Fuel Cycle	M$	18966	34444	51212	71909	94234
H.L. Waste Repos	M$	3635	6974	9158	10427	9818
less Waste Fee Revenue	M$	-0	0	0	-0	-0
Net Fuel Cost NPV	M$	-13088	-14666	-9943	1061	14092

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-1.55	-1.41	-1.00	-0.42	0.17
less waste fee	-0.00	0.00	0.00	-0.00	-0.00
Net fuel cost	-1.55	-1.41	-1.00	-0.42	0.17
H. L. waste repository	0.34	0.45	0.48	0.47	0.40
Total Levelized Fuel Cost	-1.21	-0.95	-0.52	0.05	0.57

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-0.72	-1.78	-0.35	1.24	3.63	5.57

Table 18

ALMR Deployment Model   Base Case Convertor with low (75.25%) capacity factor
Date: 01-27-93   Case: ALMRA004

Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1034	2094	3301	4374	5227
LWR Power	TWh	9769	13262	15867	17829	19315
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	18262	33666	49418	62179	71509
LWR Fuel Cycle	M$	79727	109435	134007	155660	176099
H.L. Waste Repos	M$	3154	5183	6829	7923	9430
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	90341	132927	171087	203559	232498

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	35.9	31.9	28.5	25.5	23.4
O&M	10.2	9.7	9.5	9.4	9.3
Decommissioning	2.4	2.4	2.4	2.4	2.4
Fuel (incl. waste fee)	17.7	16.1	15.0	14.2	13.7
Total Levelized ALMR Plant Cost	66.2	60.0	55.3	51.5	48.8

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	9.07	9.32	9.57	9.81	10.09
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	8.07	8.32	8.57	8.81	9.09
H. L. waste repository	0.29	0.34	0.36	0.36	0.38
Total Levelized Fuel Cost	8.36	8.66	8.93	9.17	9.47

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	8.07	8.71	9.35	10.01	10.70	12.37

Table 19

ALMR Deployment Model ALMR v. no ALMR Case Summary
Date: 01-27-93 Case: ALMR0000 - ALMRA004

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-18262	-33666	-49418	-62179	-71509
LWR Fuel Cycle	M$	8629	18735	33614	53516	75075
H.L. Waste Repos	M$	6475	9423	11012	12057	11428
less Waste Fee Revenue	M$	0	0	0	-0	-0
Net Fuel Cost NPV	M$	-3158	-5508	-4792	3395	14994

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-0.89	-0.97	-0.82	-0.39	0.15
less waste fee	0.00	0.00	0.00	-0.00	-0.00
Net fuel cost	-0.89	-0.97	-0.82	-0.39	0.15
H. L. waste repository	0.60	0.61	0.57	0.54	0.47
Total Levelized Fuel Cost	-0.29	-0.36	-0.25	0.15	0.61

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-0.30	-0.28	-0.52	0.19	2.70	4.96

Table 20

ALMR Deployment Model Base Case Convertor with medium (80.63%) capacity factor

Date: 01-28-93 Case: ALMRA005

Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1108	2214	3470	4585	5452
LWR Power	TWh	9695	13143	15697	17618	19089
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	19167	34997	51026	64125	73554
LWR Fuel Cycle	M$	72073	108268	132113	152905	172738
H.L. Waste Repos	M$	3163	5203	6861	7965	9445
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	90601	133111	170832	202792	231196

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	33.5	29.7	26.5	23.8	21.8
O&M	9.5	9.0	8.8	8.8	8.7
Decommissioning	2.2	2.2	2.2	2.2	2.2
Fuel (incl. waste fee)	17.3	15.8	14.7	14.0	13.5
Total Levelized ALMR Plant Cost	62.6	56.7	52.2	48.8	46.2

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	9.09	9.33	9.55	9.77	10.04
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	8.09	8.33	8.55	8.77	9.04
H. L. waste repository	0.29	0.34	0.36	0.36	0.38
Total Levelized Fuel Cost	8.39	8.67	8.91	9.13	9.42

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	8.07	8.76	9.33	9.90	10.53	12.14

Table 21

ALMR Deployment Model — ALMR v. no ALMR Case Summary

Date: 01-27-93 — Case: ALMR0000 - ALMRA005

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-19167	-34997	-51026	-64125	-73554
LWR Fuel Cycle	M$	9283	19902	35508	56272	78437
H.L. Waste Repos	M$	6465	9403	10980	12015	11414
less Waste Fee Revenue	M$	0	0	0	0	0
Net Fuel Cost NPV	M$	-3419	-5692	-4538	4161	16296

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-0.91	-0.98	-0.81	-0.35	0.20
less waste fee	0.00	0.00	0.00	0.00	0.00
Net fuel cost	-0.91	-0.98	-0.81	-0.35	0.20
H. L. waste repository	0.60	0.61	0.57	0.54	0.47
Total Levelized Fuel Cost	-0.32	-0.37	-0.24	0.19	0.66

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-0.30	-0.33	-0.50	0.30	2.87	5.19

2.7 BURNER WITH $200/KG LWR REPROCESSING

This case is exactly the same as the base case ALMR burner (Sect. 2.2) except that the assumed cost of LWR spent fuel reprocessing was changed from $350/kgHM to $200/kgHM. The power plant, fuel cycle facilities and repository deployment were unchanged from the base case. As shown in the cost summaries (Tables 22 and 23), the decreased reprocessing cost causes the ALMR fuel cost to be less expensive so that the relative economics of this case is better compared to the case in Sect. 2.2. The differential NPV between this case and the base case with $350/kgHM is $13.9 billion demonstrating the sensitivity of the results to the cost of LWR fuel reprocessing. The results indicate a NPV advantage for this case compared to the no ALMR case of $30.6 billion over the 2010–2070 period.

2.8 BURNER WITH $1000/KG LWR REPROCESSING

This case is exactly the same as the base case ALMR burner (Sect. 2.2) except that the assumed cost of LWR spent fuel reprocessing was changed from $350/kgHM to $1000/kgHM. As with the case in Sect. 2.7, the power plant, fuel cycle facilities and repository deployment were unchanged from the base case. As shown in the cost summaries (Tables 24 and 25), the increased reprocessing cost causes the ALMR fuel cost to be significantly more expensive so that the relative economics of this case are much worse compared to the case in Sect. 2.2. The differential NPV between this case and the null (no ALMR) case is -$43.7 billion over the period 2010-2070. As demonstrated by this case and the one in Sect. 2.7, the economic viability of the ALMR is greatly influenced by cost of reprocessing spent fuel from LWRs.

2.9 BURNER WITH 0.5 WASTE EQUIVALENT MASS FACTOR

This case is exactly the same as the base case ALMR burner (Sect. 2.2) except that the assumption on the effective repository capacity when disposing of reprocessing wastes as compared to intact LWR assembly disposal was changed. This case assumes that the repository can accommodate only two times the waste quantity as compared to the base assumption that a repository could handle four times as much reprocessing wastes as intact assemblies (based on initial heavy metal). ALMR plant and infrastructure deployment and uranium use and price is unchanged in this case compared to the base case. The number of repositories needed is increased compared to the base case with the second repository coming on line in 2044 and a third in 2062.

The resulting costs for this case are shown in Table 26. The differential costs, comparing this case to the no ALMR case, are provided in Table 27. The results indicate a NPV advantage for this case compared to the no ALMR case of $15.0 billion over the 2010-2070 period. This is approximately $1.7 billion less than the ALMR base case.

2.10 BURNER WITH 0.5 REPOSITORY DISPOSAL COST FACTOR

This case is exactly the same as the base case ALMR burner (Sect. 2.2) except that the variable cost of disposing of reprocessing wastes compared to intact LWR spent fuel assembly wastes was 0.5 instead of 0.75 in the base case. The power plant, fuel cycle facilities and repository deployment were unchanged from the base case. As shown in the cost summaries (Tables 28 and 29),

Table 22

ALMR Deployment Model $200/kg LW Repro.Case

Date: 01-27-93 Case: ALMRA006

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Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1182	2377	3703	4857	5728
LWR Power	TWh	9621	12979	15464	17346	18813
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	14987	28445	42229	53612	61721
LWR Fuel Cycle	M$	78498	106974	130185	150488	170168
H.L. Waste Repos	M$	3454	5437	7107	8138	9579
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	86137	125498	160352	190034	216927

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	31.5	27.9	24.8	22.2	20.3
O&M	8.9	8.5	8.3	8.2	8.2
Decommissioning	2.1	2.1	2.1	2.1	2.1
Fuel (incl. waste fee)	12.7	12.0	11.4	11.0	10.8
Total Levelized ALMR Plant Cost	55.1	50.4	46.5	43.5	41.3

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	8.65	8.82	8.99	9.19	9.45
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	7.65	7.82	7.99	8.19	8.45
H. L. waste repository	0.32	0.35	0.37	0.37	0.39
Total Levelized Fuel Cost	7.97	8.17	8.37	8.56	8.84

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	7.73	8.25	8.64	9.15	9.78	11.50

Table 23

ALMR Deployment Model   ALMR v. no ALMR Case Summary
Date: 01-27-93   Case: ALMR0000 - ALMRA006

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Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-14987	-28445	-42229	-53612	-61721
LWR Fuel Cycle	M$	9859	21197	37437	58689	81006
H.L. Waste Repos	M$	6174	9170	10734	11842	11279
less Waste Fee Revenue	M$	-0	0	0	0	0
Net Fuel Cost NPV	M$	1046	1922	5942	16919	30565

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-0.47	-0.47	-0.25	0.23	0.79
less waste fee	-0.00	0.00	0.00	0.00	0.00
Net fuel cost	-0.47	-0.47	-0.25	0.23	0.79
H. L. waste repository	0.57	0.60	0.56	0.53	0.46
Total Levelized Fuel Cost	0.10	0.13	0.31	0.76	1.25

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	0.03	0.17	0.19	1.05	3.62	5.83

Table 24

ALMR Deployment Model $1000/kg Repro. cost
Date: 01-27-93 Case: ALMRA007

Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1182	2377	3703	4857	5728
LWR Power	TWh	9621	12979	15464	17346	18813
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	40039	72970	102074	122897	136024
LWR Fuel Cycle	M$	78498	106974	130185	150488	170168
H.L. Waste Repos	M$	3454	5437	7107	8138	9579
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	111188	170024	220198	259320	291230

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	31.5	27.9	24.8	22.2	20.3
O&M	8.9	8.5	8.3	8.2	8.2
Decommissioning	2.1	2.1	2.1	2.1	2.1
Fuel (incl. waste fee)	33.9	30.7	27.6	25.3	23.7
Total Levelized ALMR Plant Cost	76.3	69.1	62.7	57.8	54.3

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	10.97	11.72	12.12	12.31	12.48
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	9.97	10.72	11.12	11.31	11.48
H. L. waste repository	0.32	0.35	0.37	0.37	0.39
Total Levelized Fuel Cost	10.29	11.07	11.49	11.68	11.87

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	9.62	11.07	12.92	13.17	12.89	13.64

Table 25

ALMR Deployment Model — ALMR v. no ALMR Case Summary

Date: 01-27-93 — Case: ALMR0000 - ALMRA007

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-40039	-72970	-102074	-122897	-136024
LWR Fuel Cycle	M$	9859	21197	37437	58689	81006
H.L. Waste Repos	M$	6174	9170	10734	11842	11279
less Waste Fee Revenue	M$	-0	0	0	0	0
Net Fuel Cost NPV	M$	-24006	-42604	-53903	-52366	-43738

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-2.79	-3.37	-3.37	-2.89	-2.24
less waste fee	-0.00	0.00	0.00	0.00	0.00
Net fuel cost	-2.79	-3.37	-3.37	-2.89	-2.24
H. L. waste repository	0.57	0.60	0.56	0.53	0.46
Total Levelized Fuel Cost	-2.22	-2.77	-2.81	-2.36	-1.78

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-1.86	-2.65	-4.08	-2.96	0.51	3.69

Table 26

ALMR Deployment Model   0.5 waste equiv. mass factor
Date: 01-27-93   Case: ALMRA008

Present worth at utility COM, Ref. year $

		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1182	2377	3703	4857	5728
LWR Power	TWh	9621	12979	15464	17346	18813
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	19684	36793	53450	66603	75653
LWR Fuel Cycle	M$	78498	106974	130185	150488	170168
H.L. Waste Repos	M$	3454	5437	8754	9813	11238
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	90834	133847	173220	204700	232517

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	31.5	27.9	24.8	22.2	20.3
O&M	8.9	8.5	8.3	8.2	8.2
Decommissioning	2.1	2.1	2.1	2.1	2.1
Fuel (incl. waste fee)	16.7	15.5	14.4	13.7	13.2
Total Levelized ALMR Plant Cost	59.1	53.9	49.6	46.2	43.7

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	9.09	9.36	9.58	9.78	10.02
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	8.09	8.36	8.58	8.78	9.02
H. L. waste repository	0.32	0.35	0.46	0.44	0.46
Total Levelized Fuel Cost	8.41	8.72	9.04	9.22	9.47

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	8.09	8.78	9.44	10.33	10.37	11.89

Table 27

ALMR Deployment Model — ALMR v. no ALMR Case Summary

Date: 01-27-93 — Case: ALMR0000 - ALMRA008

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-19684	-36793	-53450	-66603	-75653
LWR Fuel Cycle	M$	9859	21197	37437	58689	81006
H.L. Waste Repos	M$	6174	9170	9087	10167	9621
less Waste Fee Revenue	M$	-0	0	0	0	0
Net Fuel Cost NPV	M$	-3651	-6427	-6926	2253	14975

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-0.91	-1.02	-0.84	-0.36	0.22
less waste fee	-0.00	0.00	0.00	0.00	0.00
Net fuel cost	-0.91	-1.02	-0.84	-0.36	0.22
H. L. waste repository	0.57	0.60	0.47	0.46	0.39
Total Levelized Fuel Cost	-0.34	-0.42	-0.36	0.10	0.61

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-0.32	-0.36	-0.61	-0.13	3.02	5.44

Table 28

ALMR Deployment Model   0.5 repos. disposal cost factor
Date: 01-27-93   Case: ALMRA009

Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1182	2377	3703	4857	5728
LWR Power	TWh	9621	12979	15464	17346	18813
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	19684	36793	53450	66603	75653
LWR Fuel Cycle	M$	78498	106974	130185	150488	170168
H.L. Waste Repos	M$	2396	3739	4867	5564	6798
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	89776	132149	169333	200451	228078

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	31.5	27.9	24.8	22.2	20.3
O&M	8.9	8.5	8.3	8.2	8.2
Decommissioning	2.1	2.1	2.1	2.1	2.1
Fuel (incl. waste fee)	16.7	15.5	14.4	13.7	13.2
Total Levelized ALMR Plant Cost	59.1	53.9	49.6	46.2	43.7

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	9.09	9.36	9.58	9.78	10.02
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	8.09	8.36	8.58	8.78	9.02
H. L. waste repository	0.22	0.24	0.25	0.25	0.28
Total Levelized Fuel Cost	8.31	8.61	8.83	9.03	9.29

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	8.00	8.67	9.30	9.76	10.25	11.81

Table 29

ALMR Deployment Model — ALMR v. no ALMR Case Summary

Date: 01-27-93 — Case: ALMR0000 - ALMRA009

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-19684	-36793	-53450	-66603	-75653
LWR Fuel Cycle	M$	9859	21197	37437	58689	81006
H.L. Waste Repos	M$	7233	10867	12974	14416	14061
less Waste Fee Revenue	M$	-0	0	0	0	0
Net Fuel Cost NPV	M$	-2593	-4730	-3039	6502	19414

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-0.91	-1.02	-0.84	-0.36	0.22
less waste fee	-0.00	0.00	0.00	0.00	0.00
Net fuel cost	-0.91	-1.02	-0.84	-0.36	0.22
H. L. waste repository	0.67	0.71	0.68	0.65	0.57
Total Levelized Fuel Cost	-0.24	-0.31	-0.16	0.29	0.79

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-0.24	-0.24	-0.47	0.44	3.14	5.52

the reduced cost factor results in improved economics for the waste repository for the ALMR deployment case. The results indicate a NPV advantage for this case compared to the no ALMR case of $19.4 billion over the 2010-2070 period. This is approximately $2.8 billion more than the ALMR base case.

2.11 BURNER WITH $15 BILLION FOLLOW-ON REPOSITORY COST

This case is exactly the same as the base case ALMR burner (Sect. 2.2) except that the cost of the follow-on waste repositories was increased from the $7.2 billion value in the base case to $15 billion in this case. The power plant, fuel cycle facilities and repository deployment were unchanged from the base case. The change in the repository cost effects both this case and that for no ALMR deployment (Sect. 2.1).

The resulting costs for a $15 billion repository cost for the no ALMR and ALMR cases are shown in Tables 30 and 31. The differential cost between these two cases are shown in Table 32. The increased repository cost results in increased costs for both ALMR and no ALMR deployment. The results indicate a NPV advantage for this case compared to the no ALMR case of $23.5 billion over the 2010-2070 period. This is approximately $6.9 billion more than the differential for the ALMR base case.

2.12 LWR REPROCESSING COST INCLUDED WITH WASTE SYSTEM

This case is exactly the same as the base case ALMR burner (Sect. 2.2) except that LWR spent fuel reprocessing is made part of the waste disposal system. The cost of LWR spent fuel reprocessing was charged to the waste repository and the recovered actinides were provided at zero cost to the ALMR. The power plant, fuel cycle facilities, and repository deployment were unchanged from the base case. As shown in the cost summaries (Tables 33 and 34) and comparing these against the cost summaries for the base case (Tables 12 and 13), the ALMR fuel cost is decreased significantly and the repository costs are increased significantly. The results indicate a NPV advantage for this case compared to the no ALMR case of $24.5 billion over the 2010-2070 period. This is $7.9 billion more than for the ALMR base case.

2.13 BASE ALMR BREAKEVEN

Alternate reactor fuel cycles were considered in addition to the base case burner. In this case, a breakeven fuel cycle with a breeding ratio of 1.04 was considered. All other cost factors were unchanged from the base case. A comparison of this fuel cycle with the base case was given in Table 8. The cost summaries for this case (Tables 35 and 36) indicate an improvement over the base case burner (Tables 12 and 13). The results indicate a NPV advantage for this case compared to the no ALMR case of $19.5 billion over the 2010-2070 period. This is $2.9 billion more than for the ALMR base case burner.

Table 30

ALMR Deployment Model — Nul Case with no ALMR Deployment

Revised 01-26-93 — Case: ALMR0010

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Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	0	0	0	0	0
LWR Power	TWh	10803	15357	19168	22203	24541
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	0	0	0	0	0
LWR Fuel Cycle	M$	88357	128170	167622	209176	251175
H.L. Waste Repos	M$	12954	20102	24695	27721	28600
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	90508	132916	173149	214695	255233

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	0.0	0.0	0.0	0.0	0.0
O&M	0.0	0.0	0.0	0.0	0.0
Decommissioning	0.0	0.0	0.0	0.0	0.0
Fuel (incl. waste fee)	0.0	0.0	0.0	0.0	0.0
Total Levelized ALMR Plant Cost	0.0	0.0	0.0	0.0	0.0

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	8.18	8.35	8.75	9.42	10.23
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	7.18	7.35	7.75	8.42	9.23
H. L. waste repository	1.20	1.31	1.29	1.25	1.17
Total Levelized Fuel Cost	8.38	8.66	9.03	9.67	10.40

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	7.77	9.09	9.31	10.56	13.69	17.33

Table 31

ALMR Deployment Model $15B cost for add-on repos.
Date: 01-27-93 Case: ALMRA010

Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1182	2377	3703	4857	5728
LWR Power	TWh	9621	12979	15464	17346	18813
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	19684	36793	53450	66603	75653
LWR Fuel Cycle	M$	78498	106974	130185	150488	170168
H.L. Waste Repos	M$	3454	5437	7107	8138	10429
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	90834	133847	171573	203025	231709

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	31.5	27.9	24.8	22.2	20.3
O&M	8.9	8.5	8.3	8.2	8.2
Decommissioning	2.1	2.1	2.1	2.1	2.1
Fuel (incl. waste fee)	16.7	15.5	14.4	13.7	13.2
Total Levelized ALMR Plant Cost	59.1	53.9	49.6	46.2	43.7

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	9.09	9.36	9.58	9.78	10.02
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	8.09	8.36	8.58	8.78	9.02
H. L. waste repository	0.32	0.35	0.37	0.37	0.42
Total Levelized Fuel Cost	8.41	8.72	8.95	9.14	9.44

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	8.09	8.78	9.44	9.90	10.36	12.26

Table 32

ALMR Deployment Model — ALMR v. no ALMR Case Summary

Date: 01-27-93 — Case: ALMR0010 - ALMRA010

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Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-19684	-36793	-53450	-66603	-75653
LWR Fuel Cycle	M$	9859	21197	37437	58689	81006
H.L. Waste Repos	M$	9499	14666	17588	19583	18171
less Waste Fee Revenue	M$	-0	0	0	0	0
Net Fuel Cost NPV	M$	-326	-931	1576	11670	23525

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-0.91	-1.02	-0.84	-0.36	0.22
less waste fee	-0.00	0.00	0.00	0.00	0.00
Net fuel cost	-0.91	-1.02	-0.84	-0.36	0.22
H. L. waste repository	0.88	0.96	0.92	0.88	0.74
Total Levelized Fuel Cost	-0.03	-0.06	0.08	0.53	0.96

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-0.32	0.31	-0.13	0.66	3.33	5.07

Table 33

ALMR Deployment Model Base Case with reprocessing in repository costs
Date: 02-03-93 Case: ALMRA014

Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1182	2377	3703	4857	5728
LWR Power	TWh	9621	12979	15464	17346	18813
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	8724	17313	27267	36290	43145
LWR Fuel Cycle	M$	78498	106974	130185	150488	170168
H.L. Waste Repos	M$	15834	24167	30524	33948	36803
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	92253	133097	168808	198523	225575

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	31.5	27.9	24.8	22.2	20.3
O&M	8.9	8.5	8.3	8.2	8.2
Decommissioning	2.1	2.1	2.1	2.1	2.1
Fuel (incl. waste fee)	7.4	7.3	7.4	7.5	7.5
Total Levelized ALMR Plant Cost	49.8	45.7	42.5	40.0	38.1

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	8.07	8.09	8.21	8.41	8.69
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	7.07	7.09	7.21	7.41	7.69
H. L. waste repository	1.47	1.57	1.59	1.53	1.50
Total Levelized Fuel Cost	8.54	8.67	8.81	8.94	9.19

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	8.35	8.76	8.97	9.37	9.79	11.57

Table 34

ALMR Deployment Model — ALMR v. no ALMR Case Summary

Date: 01-27-93 — Case: ALMR0000 - ALMRA014

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Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-8724	-17313	-27267	-36290	-43145
LWR Fuel Cycle	M$	9859	21197	37437	58689	81006
H.L. Waste Repos	M$	-6205	-9561	-12684	-13968	-15944
less Waste Fee Revenue	M$	-0	0	0	0	0
Net Fuel Cost NPV	M$	-5071	-5677	-2514	8430	21917

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	0.11	0.25	0.53	1.01	1.54
less waste fee	-0.00	0.00	0.00	0.00	0.00
Net fuel cost	0.11	0.25	0.53	1.01	1.54
H. L. waste repository	-0.57	-0.62	-0.66	-0.63	-0.65
Total Levelized Fuel Cost	-0.47	-0.37	-0.13	0.38	0.89

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-0.58	-0.34	-0.13	0.83	3.61	5.77

Table 35

ALMR Deployment Model   Breakeven Breeder with Base Parameters

Date: 01-27-93   Case: ALMRB001

Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1182	2287	3452	4473	5311
LWR Power	TWh	9621	13069	15715	17729	19231
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	21425	36778	49681	59440	66762
LWR Fuel Cycle	M$	78498	107766	132656	154881	175609
H.L. Waste Repos	M$	4206	6273	7716	8685	10121
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	93326	135461	170886	200803	227950

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	31.5	27.5	24.4	22.0	20.4
O&M	8.9	8.5	8.3	8.2	8.2
Decommissioning	2.1	2.1	2.1	2.1	2.1
Fuel (incl. waste fee)	18.1	16.1	14.4	13.3	12.6
Total Levelized ALMR Plant Cost	60.6	54.2	49.2	45.6	43.2

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	9.25	9.41	9.51	9.65	9.88
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	8.25	8.41	8.51	8.65	8.88
H. L. waste repository	0.39	0.41	0.40	0.39	0.41
Total Levelized Fuel Cost	8.64	8.82	8.92	9.04	9.29

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	8.32	9.01	9.25	9.30	9.86	11.61

Table 36

ALMR Deployment Model — ALMR v. no ALMR Case Summary

Date: 01-27-93 — Case: ALMR0000 - ALMRB001

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Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-21425	-36778	-49681	-59440	-66762
LWR Fuel Cycle	M$	9859	20404	34966	54296	75566
H.L. Waste Repos	M$	5423	8333	10124	11295	10738
less Waste Fee Revenue	M$	-0	0	0	0	0
Net Fuel Cost NPV	M$	-6143	-8041	-4591	6151	19542

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-1.07	-1.07	-0.77	-0.23	0.36
less waste fee	-0.00	0.00	0.00	0.00	0.00
Net fuel cost	-1.07	-1.07	-0.77	-0.23	0.36
H. L. waste repository	0.50	0.54	0.53	0.51	0.44
Total Levelized Fuel Cost	-0.57	-0.52	-0.24	0.28	0.80

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-0.55	-0.59	-0.42	0.91	3.54	5.73

2.14 MAXIMUM DEPLOYMENT OF BREAKEVEN PLANT

This case utilizes the same fuel cycle as the previous case but the deployment by 2030 was increased to the maximum possible number of ALMR plants that can be deployed by this date. This deployment is limited only by the amount of fissile material available for starting up and sustaining the ALMR plants. This leads to 51 GWe of ALMR capacity in 2030 as compared to 27 GWe in the constrained ALMR breakeven case described in Sect. 2.13. The additional ALMR generation is fueled by the more rapid recovery of actinides from LWR spent fuel. As shown in the cost summaries (Tables 37 and 38), the increased utilization and advanced timing of ALMRs increases the relative economics of this case compared to the case in Sect. 2.13 by about $4.1 billion.

2.15 BASE ALMR BREEDER

A second alternate reactor fuel cycle was considered in addition to the base ALMR breakeven case. In this case a fuel cycle with a breeding ratio of 1.24 was considered for the ALMR. A comparison of this fuel cycle with the base case was given in Tables 8 and 9. All other cost factors were unchanged from the base burner case (Sect. 2.2). The annual energy generation for this case is shown in Fig. 9. The uranium ore use and price for LWR plants are presented in Fig. 10. As a result of the deployment of the breeder ALMRs, the demand for uranium is less than that for the burner case depicted in Fig. 7. This is because the burner deployment was limited by the availability of spent LWR fuel whereas the breeder creates an excess amount of fuel which can be used to start-up other ALMRs. The waste repository loadings are shown in Fig. 11 and are similar to that for the burner case.

The cost summaries for this case (Tables 39 and 40) indicate a NPV of over $41 billion for the 2010 to 2070 period compared to the no ALMR case. This is a substantial improvement resulting in nearly $25 billion more savings than for the ALMR base case burner.

2.16 BREEDER PLANT WITH DEFENSE Pu

This case uses the same data as the ALMR Base Case Breeder discussed in the previous section except that 100 MT of defense-related plutonium is assumed to be made available to the ALMR system at no cost for the fissile material. The energy generation, uranium demands, and repository requirements are nearly identical to those shown in Figs. 9–11. The cost summaries are given in Tables 41 and 42. As shown in Table 42, there is an increased economic benefit of ALMRs relative to the no ALMR case due to the availability of no cost fissile material and the resulting delay in the need for LWR reprocessing. The differential NPV between this case and the null (no ALMR) case is $48.1 billion over the period 2010-2070 or about $25 billion more than the differential for the base case burner given in Sect. 2.3.

2.17 MAXIMUM DEPLOYMENT OF BREEDER PLANT

This case utilizes the same fuel cycle as the previous case but the deployment by 2030 was increased to the maximum possible number of ALMR plants that can be deployed by this date. This deployment is limited only by the amount of fissile material available for starting up the ALMR plants. This leads to 80 GWe of ALMR capacity in 2030 as compared to 27 GWe in the constrained case described in Sect. 2.15. The additional ALMR generation is fueled by the more rapid recovery of actinides from LWR spent fuel and from the quantity of excess fissile material produced by the breeder. The annual energy generation estimated for this case is shown in Fig. 12. The uranium ore use and price for LWR plants are presented in Fig. 13. The equivalent heavy metal disposed of in the repository is shown in Fig. 14. While there are differences in the year-by-year values between these three figures and the comparable ones in Sect. 2.15, the long term year 2070 values for the ALMR power production, uranium use and price, and waste repository loadings are nearly the same here as found in Sect. 2.15.

The cost summaries for this case (Tables 43 and 44) indicate a greater improvement over the base case burner (Tables 12 and 13) than found in the slower deployment case. The results indicate a NPV advantage for this case compared to the no ALMR case of $46.8 billion over the 2010-2070 period. This is $5.4 billion more than for the ALMR base case breeder.

2.18 NO UTILIZATION OF INITIAL LWR SPENT FUEL STOCKS

All the previous ALMR cases have assumed that all LWR spent fuel is processed to recover the useful fissile materials as fuel for ALMR power plants. This case addresses the scenario in which the total amount of LWR spent fuel accumulated as of the inception of ALMR commercial deployment (i.e., 60,000 MTHM in the year 2010) is not processed to recover the actinides but rather is disposed intact in the first repository, starting in 2010. Only LWR spent fuel generated in 2010 and beyond is assumed to be processed for actinide recovery. As shown in Fig. 15, a second repository will be required by 2035 with a third repository needed by 2070. This compares to a third repository requirement by 2040 for the null case with no ALMR deployment. The cost summaries for this case are given in Tables 45 and 46. The outcome of this scenario is influenced by the initial lack of fissile material for ALMR startups. Not utilizing the accumulated LWR spent fuel limits the number of ALMR plants that can be deployed. As a result, more nuclear energy is obtained from uranium burning plants, thereby increasing the demand and therefore cost of the uranium-burner fuel cycle. In addition, the assumed intact disposal of spent fuel assemblies requires an earlier second repository and is more costly than the disposal of process waste assumed in the ALMR base burner case of Sect. 2.2. The resulting ALMR NPV benefit relative to the null (no-ALMR) case is $12.5 billion, which is $4.1 billion less than the ALMR burner case utilizing all available LWR spent fuel.

Table 37

ALMR Deployment Model   Base case Breakeven Breeder with Maximum Deployment
Date: 02-03-93   Case: ALMRB003

Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	2026	3423	4614	5615	6438
LWR Power	TWh	8776	11934	14554	16588	18103
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	32789	48345	59896	68904	75947
LWR Fuel Cycle	M$	71479	98036	122060	143766	164049
H.L. Waste Repos	M$	6461	7909	9004	9871	11301
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	99927	138933	171792	200337	226754

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	31.2	26.0	22.8	20.9	19.6
O&M	8.6	8.4	8.3	8.2	8.2
Decommissioning	2.1	2.1	2.1	2.1	2.1
Fuel (incl. waste fee)	16.2	14.1	13.0	12.3	11.8
Total Levelized ALMR Plant Cost	58.0	50.6	46.2	43.4	41.6

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	9.65	9.53	9.49	9.58	9.78
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	8.65	8.53	8.49	8.58	8.78
H. L. waste repository	0.60	0.52	0.47	0.44	0.46
Total Levelized Fuel Cost	9.25	9.05	8.96	9.02	9.24

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	8.85	9.72	8.56	8.62	9.40	11.30

Table 38

ALMR Deployment Model — ALMR v. no ALMR Case Summary

Date: 01-27-93 — Case: ALMR0000 - ALMRB003

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-32789	-48345	-59896	-68904	-75947
LWR Fuel Cycle	M$	16877	30135	45561	65411	87126
H.L. Waste Repos	M$	3167	6697	8836	10109	9558
less Waste Fee Revenue	M$	-0	0	0	0	0
Net Fuel Cost NPV	M$	-12744	-11513	-5498	6616	20738

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-1.47	-1.19	-0.75	-0.16	0.46
less waste fee	-0.00	0.00	0.00	0.00	0.00
Net fuel cost	-1.47	-1.19	-0.75	-0.16	0.46
H. L. waste repository	0.29	0.44	0.46	0.46	0.39
Total Levelized Fuel Cost	-1.18	-0.75	-0.29	0.30	0.85

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-1.08	-1.29	0.27	1.58	3.99	6.04

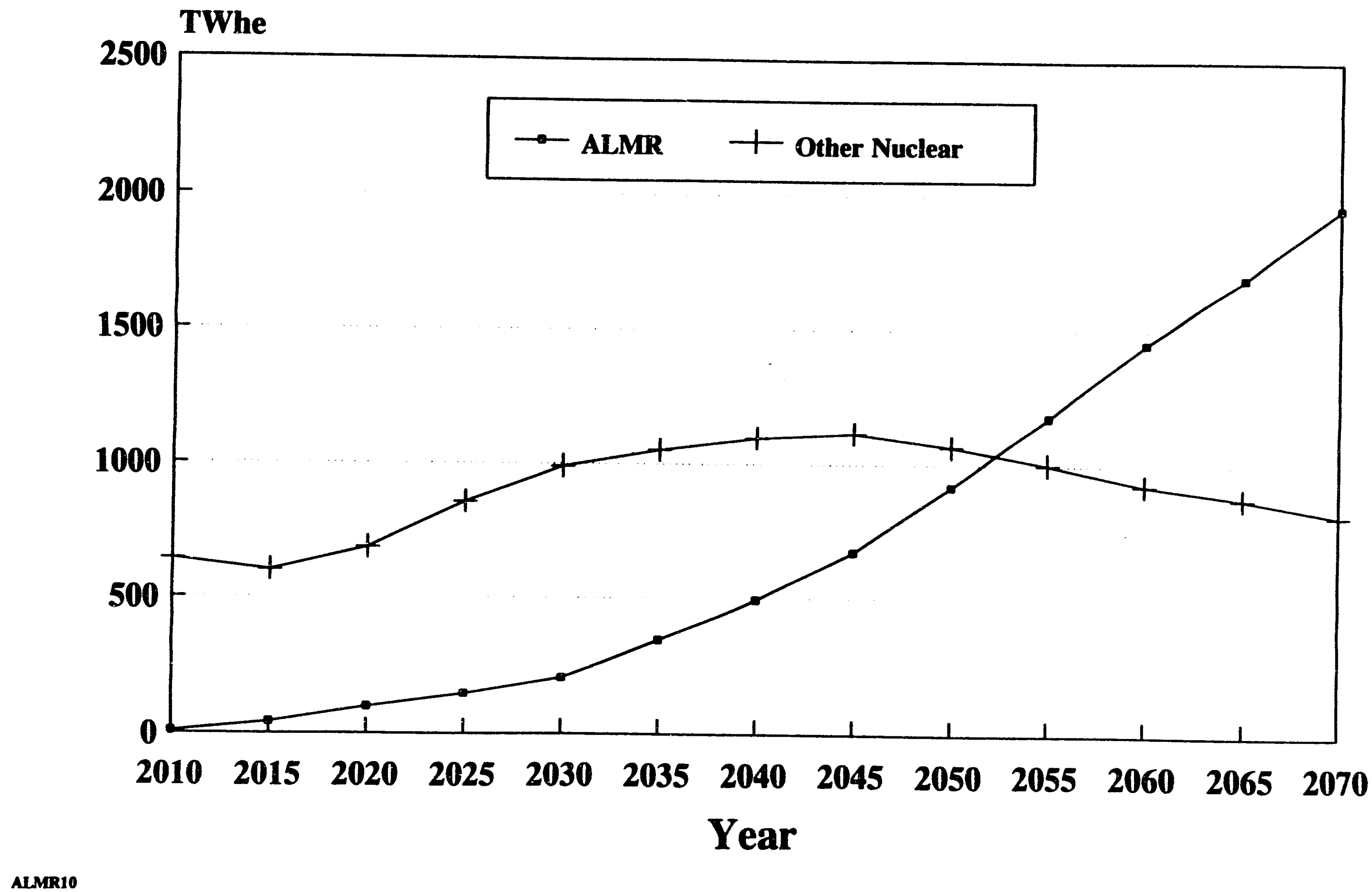
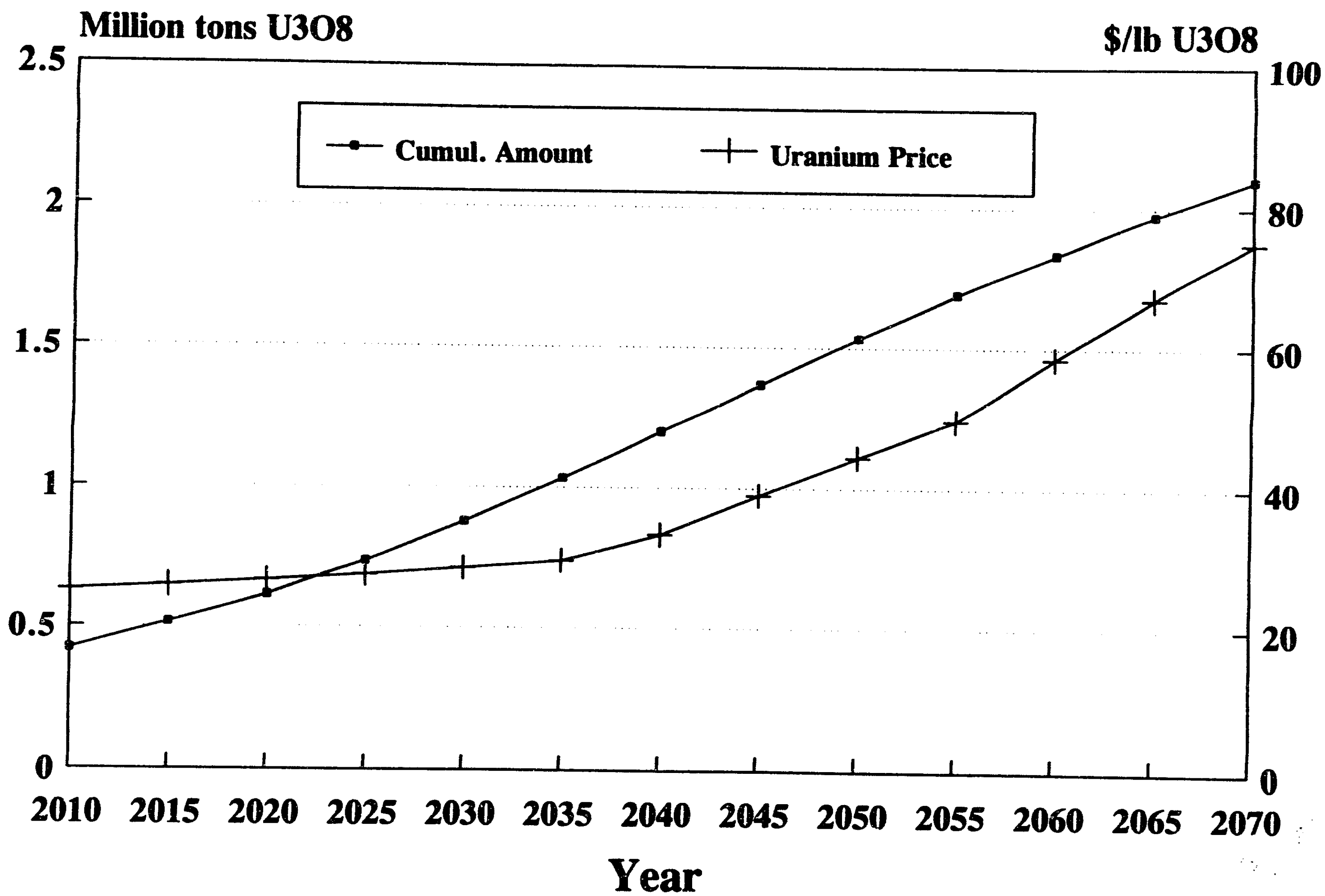
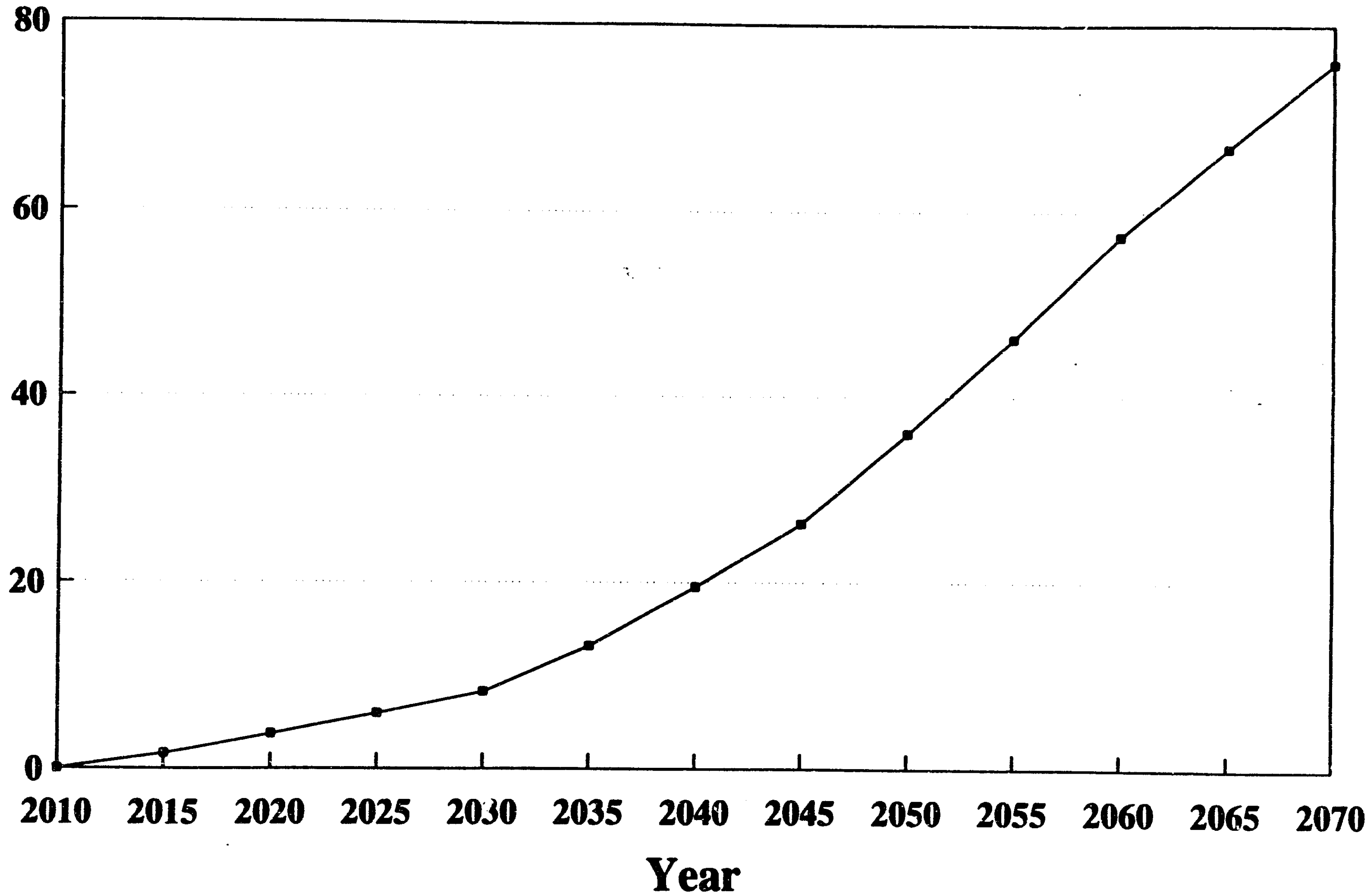


Fig. 9. Annual energy generation, ALMR breeder base case.



ALMR12

Fig. 10. Uranium use and price, ALMR breeder base case.



ALMR11

Fig. 11. Equivalent heavy metal disposed of in repository, ALMR breeder base case.

Table 39

ALMR Deployment Model — ALMR Mod B breeder-B.R.=1.24

Date: 01-27-93 — Case: ALMRC001

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Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1090	2222	3688	5338	6889
LWR Power	TWh	9713	13135	15480	16865	17652
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	15544	27989	41505	55798	67975
LWR Fuel Cycle	M$	79260	108320	130220	144658	154088
H.L. Waste Repos	M$	2602	4227	5761	7076	8563
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	86603	125178	158318	185328	206084

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	27.4	24.4	22.2	20.4	18.9
O&M	8.0	7.4	7.2	7.1	7.1
Decommissioning	1.8	1.8	1.8	1.8	1.8
Fuel (incl. waste fee)	14.3	12.6	11.3	10.5	9.9
Total Levelized ALMR Plant Cost	51.4	46.1	42.4	39.8	37.6

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	8.78	8.88	8.96	9.03	9.05
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	7.78	7.88	7.96	8.03	8.05
H. L. waste repository	0.24	0.28	0.30	0.32	0.35
Total Levelized Fuel Cost	8.02	8.15	8.26	8.35	8.40

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	7.81	8.26	8.47	8.70	8.90	8.88

Table 40

ALMR Deployment Model   ALMR v. no ALMR Case Summary
Date: 01-27-93   Case: ALMR0000 - ALMRC001

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-15544	-27989	-41505	-55798	-67975
LWR Fuel Cycle	M$	9097	19851	37402	64519	97087
H.L. Waste Repos	M$	7027	10380	12080	12904	12295
less Waste Fee Revenue	M$	0	0	0	0	0
Net Fuel Cost NPV	M$	580	2241	7977	21625	41408

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-0.60	-0.53	-0.21	0.39	1.19
less waste fee	0.00	0.00	0.00	0.00	0.00
Net fuel cost	-0.60	-0.53	-0.21	0.39	1.19
H. L. waste repository	0.65	0.68	0.63	0.58	0.50
Total Levelized Fuel Cost	0.05	0.15	0.42	0.97	1.69

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-0.04	0.17	0.36	1.50	4.50	8.46

Table 41

ALMR Deployment Model — Mod B breeder with use of defense Pu

Date: 02-03-93 — Case: ALMRC002

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Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1090	2364	4086	5868	7508
LWR Power	TWh	9713	12993	15082	16335	17034
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	10357	24655	40780	56277	68691
LWR Fuel Cycle	M$	79260	107066	126351	139077	147050
H.L. Waste Repos	M$	1821	3813	5563	6782	8194
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	80635	120178	153527	179933	199393

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	27.4	24.9	22.5	20.4	18.7
O&M	8.0	7.4	7.2	7.1	7.1
Decommissioning	1.8	1.8	1.8	1.8	1.8
Fuel (incl. waste fee)	9.5	10.4	10.0	9.6	9.1
Total Levelized ALMR Plant Cost	46.6	44.4	41.4	38.8	36.7

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	8.30	8.58	8.72	8.80	8.79
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	7.30	7.58	7.72	7.80	7.79
H. L. waste repository	0.17	0.25	0.29	0.31	0.33
Total Levelized Fuel Cost	7.46	7.83	8.01	8.10	8.12

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	7.02	7.98	8.68	8.75	8.70	8.32

Table 42

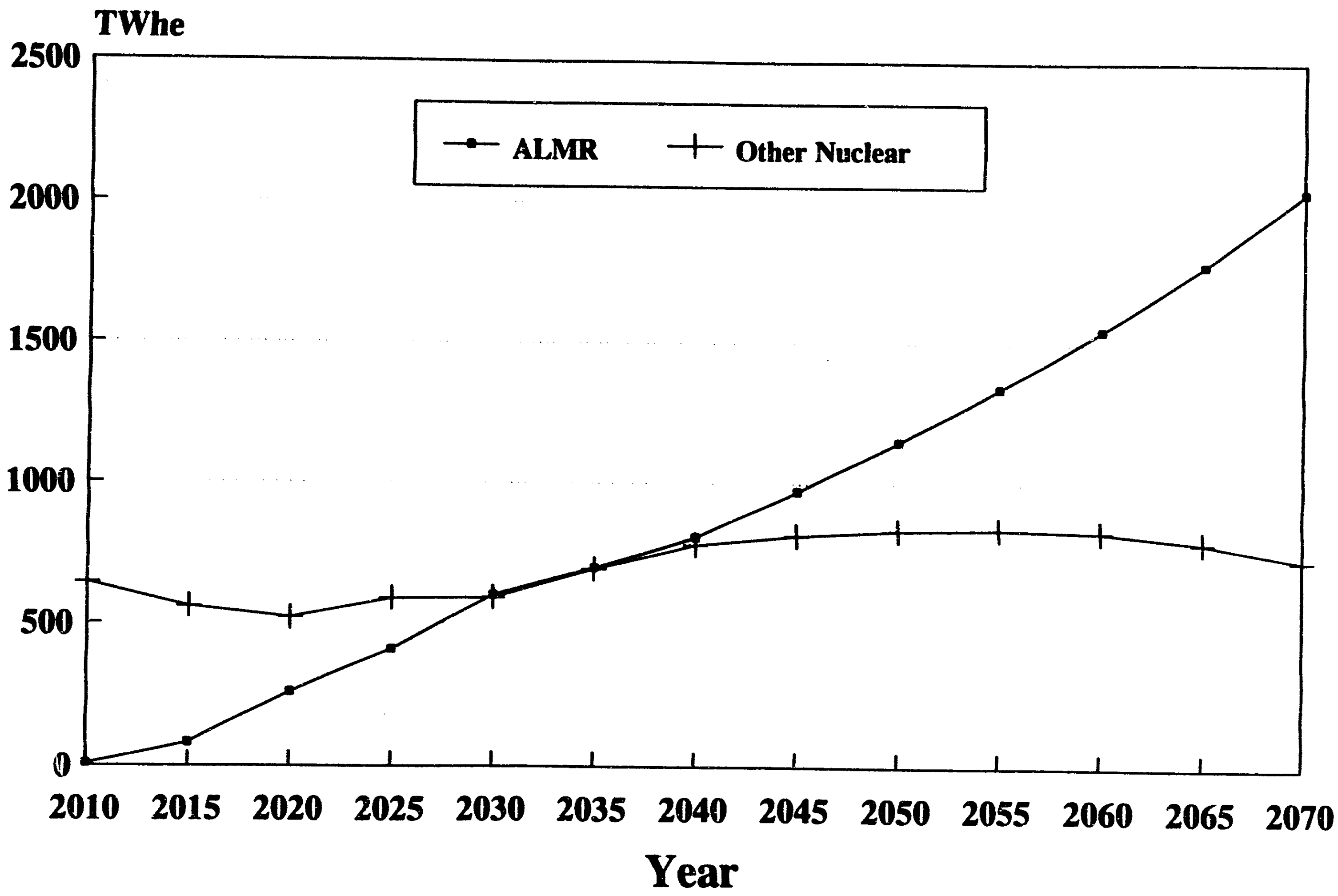
ALMR Deployment Model   ALMR v. no ALMR Case Summary

Date: 01-27-93   Case: ALMR0000 - ALMRC002

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-10357	-24655	-40780	-56277	-68691
LWR Fuel Cycle	M$	9097	21104	41271	70100	104125
H.L. Waste Repos	M$	7808	10793	12277	13198	12665
less Waste Fee Revenue	M$	0	0	0	0	0
Net Fuel Cost NPV	M$	6548	7242	12767	27020	48099

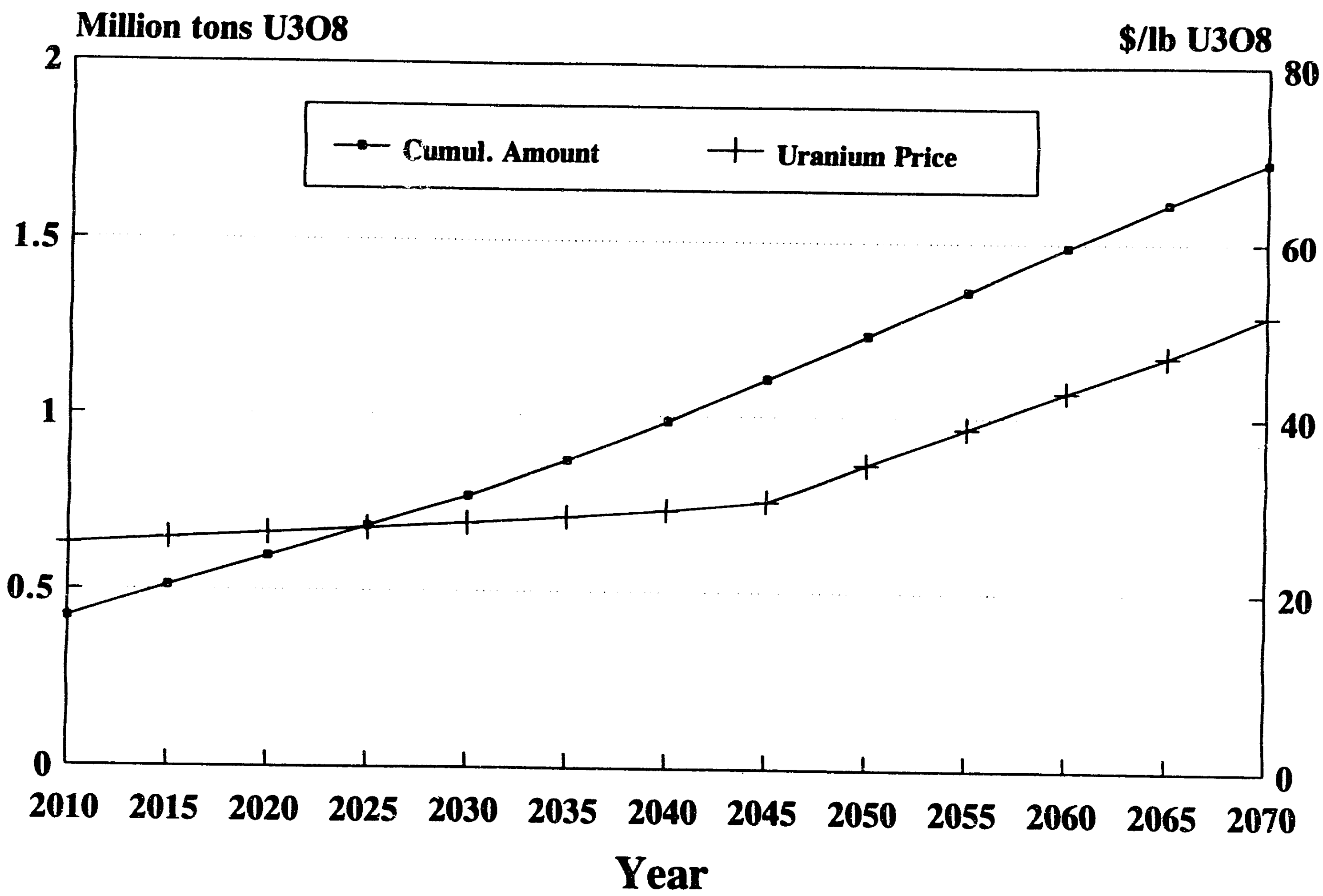
Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-0.12	-0.23	0.03	0.62	1.44
less waste fee	0.00	0.00	0.00	0.00	0.00
Net fuel cost	-0.12	-0.23	0.03	0.62	1.44
H. L. waste repository	0.72	0.70	0.64	0.59	0.52
Total Levelized Fuel Cost	0.61	0.47	0.67	1.22	1.96

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	0.75	0.44	0.15	1.45	4.70	9.01



ALMR13

Fig. 12. Annual energy generation, ALMR breeder maximum deployment.



ALMR15

Fig. 13. Uranium use and price, ALMR breeder maximum deployment.

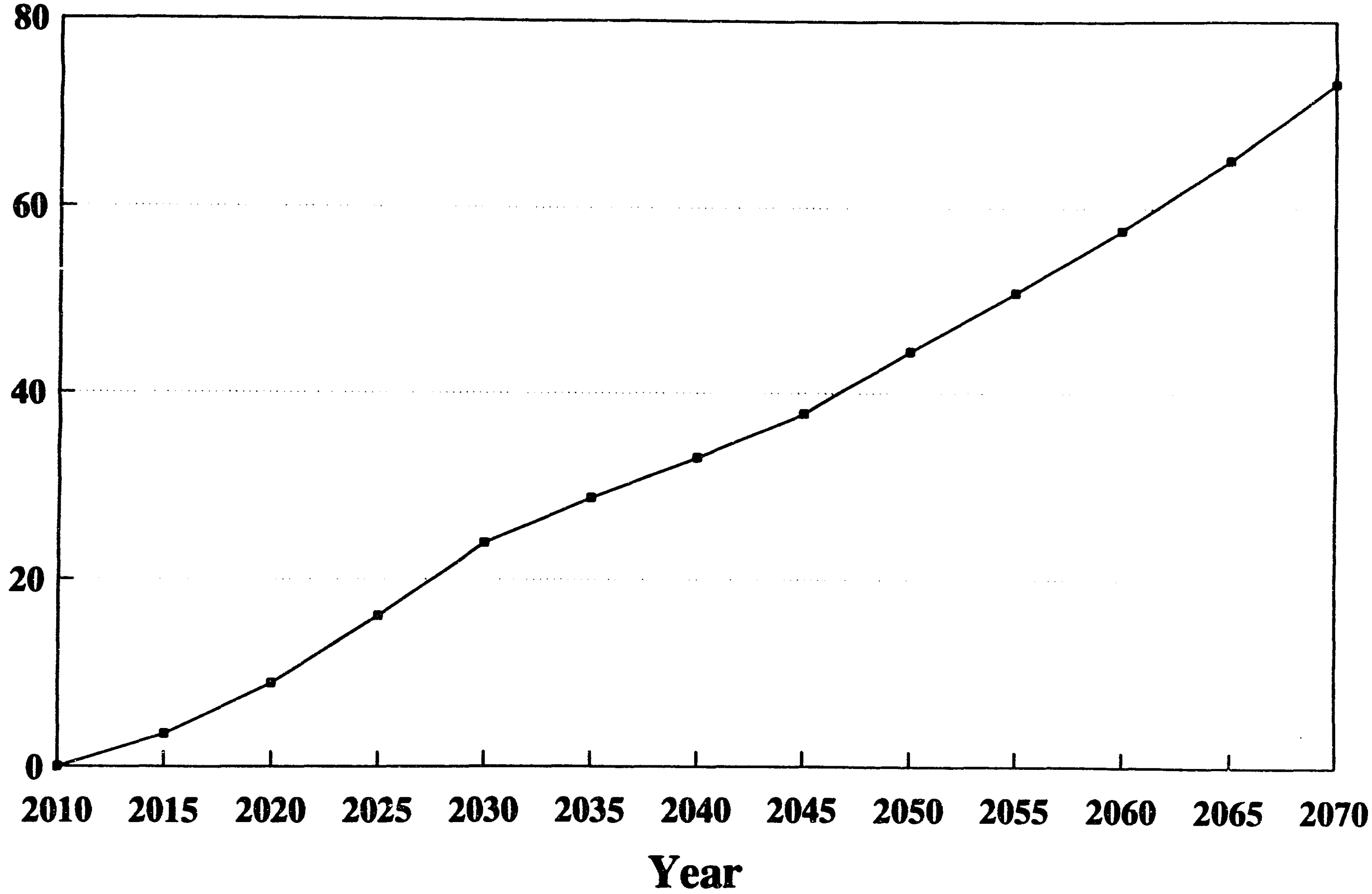


Fig. 14. Equivalent heavy metal disposed of in repository, ALMR breeder maximum deployment.

Table 43

ALMR Deployment Model ALMR Mod B breeder-Max. Deployment rate
Date: 02-03-93 Case: ALMRC003

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Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	2921	5201	7279	9151	10779
LWR Power	TWh	7882	10155	11888	13052	13763
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	36448	56689	72921	86699	98306
LWR Fuel Cycle	M$	64069	83029	97911	108756	115934
H.L. Waste Repos	M$	6324	7712	8790	9608	10973
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	96038	132074	160455	182860	200671

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	27.6	22.9	20.2	18.5	17.4
O&M	7.3	7.2	7.1	7.1	7.0
Decommissioning	1.8	1.8	1.8	1.8	1.8
Fuel (incl. waste fee)	12.5	10.9	10.0	9.5	9.1
Total Levelized ALMR Plant Cost	49.1	42.7	39.1	36.8	35.3

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	9.30	9.10	8.91	8.80	8.73
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	8.30	8.10	7.91	7.80	7.73
H. L. waste repository	0.59	0.50	0.46	0.43	0.45
Total Levelized Fuel Cost	8.89	8.60	8.37	8.24	8.18

Decade Levelized Costs	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	8.53	9.31	7.91	7.45	7.38	7.62

Table 44

ALMR Deployment Model — ALMR v. no ALMR Case Summary

Date: 01-27-93 — Case: ALMR0000 - ALMRC003

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-36448	-56689	-72921	-86699	-98306
LWR Fuel Cycle	M$	24288	45141	69710	100421	135241
H.L. Waste Repos	M$	3305	6894	9051	10372	9885
less Waste Fee Revenue	M$	-0	0	0	0	0
Net Fuel Cost NPV	M$	-8855	-4654	5840	24094	46821

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-1.13	-0.75	-0.17	0.62	1.51
less waste fee	-0.00	0.00	0.00	0.00	0.00
Net fuel cost	-1.13	-0.75	-0.17	0.62	1.51
H. L. waste repository	0.31	0.45	0.47	0.47	0.40
Total Levelized Fuel Cost	-0.82	-0.30	0.30	1.09	1.91

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-0.76	-0.89	0.92	2.75	6.01	9.72

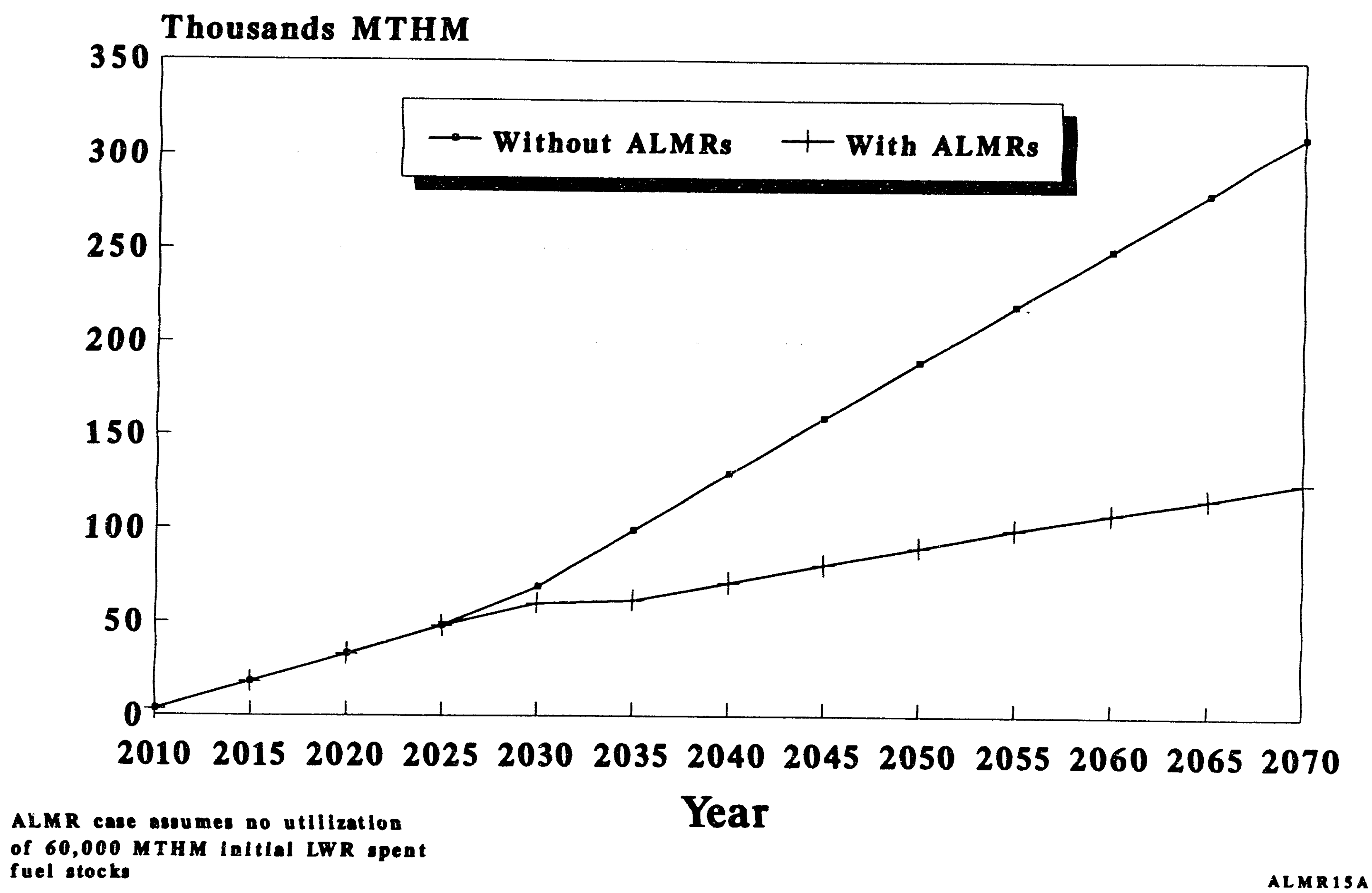

Fig. 15. Equivalent heavy metal disposed of in repository.

Table 45

ALMR Deployment Model — Base Conv. w/o use of 60K MTHM

Date: 02-25-93 — Case: ALMRA020

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Present worth at utility COM, Ref. year $		2010 to: 2030	2040	2050	2060	2070
ALMR Power	TWh	1128	2081	3041	3918	4659
LWR Power	TWh	9674	13276	16127	18285	19882
Total Nuclear Power	TWh	10803	15357	19168	22203	24541

Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	18671	31509	43352	53582	61738
LWR Fuel Cycle	M$	78940	109580	136696	161257	184201
H.L. Waste Repos	M$	6002	9935	11754	12882	13573
less Waste Fee Revenue	M$	10803	15357	19168	22203	24541
Net Fuel Cost NPV	M$	92810	135667	172634	205518	234970

ALMR Levelized Plant Costs, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Capital	31.6	27.2	24.1	21.9	20.4
O&M	9.0	8.5	8.4	8.3	8.2
Decommissioning	1.2	1.2	1.2	1.2	1.2
Fuel (incl. waste fee)	16.5	15.1	14.3	13.7	13.2
Total Levelized ALMR Plant Cost	58.4	52.1	47.9	45.1	43.1

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	9.04	9.19	9.39	9.68	10.02
less waste fee	1.00	1.00	1.00	1.00	1.00
Net fuel cost	8.04	8.19	8.39	8.68	9.02
H. L. waste repository	0.56	0.65	0.61	0.58	0.55
Total Levelized Fuel Cost	8.59	8.83	9.01	9.26	9.57

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	8.41	8.80	9.41	9.70	10.83	12.59

Table 46

ALMR Deployment Model — ALMR v. no ALMR Case Summary

Date: 02-25-93 — Case: ALMR0000 - ALMRA020

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Present worth Nuclear Fuel Cost		2010 to: 2030	2040	2050	2060	2070
ALMR Fuel Cycle	M$	-18671	-31509	-43352	-53582	-61738
LWR Fuel Cycle	M$	9416	18591	30925	47920	66974
H.L. Waste Repos	M$	3627	4671	6087	7098	7286
less Waste Fee Revenue	M$	-0	0	0	0	0
Net Fuel Cost NPV	M$	-5627	-8247	-6340	1435	12522

Fuel cost levelized over all nuclear generation, mills/kWh	2010 to: 2030	2040	2050	2060	2070
Fuel	-0.86	-0.84	-0.65	-0.26	0.21
less waste fee	-0.00	0.00	0.00	0.00	0.00
Net fuel cost	-0.86	-0.84	-0.65	-0.26	0.21
H. L. waste repository	0.34	0.30	0.32	0.32	0.30
Total Levelized Fuel Cost	-0.52	-0.54	-0.33	0.06	0.51

Decade Levelized Costs							
	Year Start	2010-	2021-	2031-	2041-	2051-	2061-
	Year End	2020	2030	2040	2050	2060	2070
	mills/kwh	-0.64	-0.38	-0.58	0.50	2.56	4.74

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2. *ALMR Fuel Cycle Assessment-1991,* GEFR-00898, GE Nuclear Energy (September 1991).

3. B. H. Hutchins, GE, personal communications with J. G. Delene, ORNL.

4. National Energy Strategy, Technical Annex 2, *Integrated Analysis Supporting the National Energy Strategy: Methodology, Assumptions and Results,* DOE/S-0086P, 1991/1992.

5. *Review of 1991 Cost Estimate for the Advanced Liquid Metal Reactor,* prepared by Oak Ridge National Laboratory for the U.S. Department of Energy (1992).

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7. *Analysis of the Total System Life-Cycle Cost for the Civilian Radioactive Waste Management Program,* DOE/RW-0236 (May 1989).

8. Allen G. Croff, *A Concept for Increasing the Effective Capacity of a Unit Area of a Geological Repository,* Oak Ridge National Laboratory Draft Report (December 8, 1992).

9. C. C. McPheeters and R. O. Pierce, *Nuclear Waste from Phyrochemical Processing of LWR Spent Fuel for Actinide Recycle,* ANL-IFR-165 (March 1992 draft).

10. *World Nuclear Fuel Cycle Requirements 1991,* DOE/EIA-0436 (91) (October 1991).

11. *Uranium Industry Annual 1990,* Energy Information Administration, DOE/EIA-0748 (90) (September 1991).

Appendix A. SPREADSHEET CASE NAMES

ALMR0000	Null case with no ALMR deployment
ALMRA001*	Base Case Scenario - Mod A burner with 86% capacity factor, 27 GWe on line in 2030
ALMRA002	Base case with use of available defense Pu
ALMRA003	Base case with maximum possible ALMR deployment
ALMRA004	Base case with 75% capacity factor
ALMRA005	Base case with 80% capacity factor
ALMRA006	Base case with $200/kg LWR reprocessing cost
ALMRA007	Base case with $1000/kg LWR reprocessing cost
ALMRA008	Base case with 0.5 waste equivalent mass factor
ALMRA009	Base case with 0.5 repository disposal cost factor
ALMRA010	Base case with $15B cost for add-on repositories
ALMRA014	Base case with LWR reprocessing cost made part of waste system cost - 0 fissile cost to ALMR
ALMRA020	Base case without use of initial 60,000 MTHM LWR spent fuel
ALMRB001	Mod A breakeven base case
ALMRB003	Mod A breakeven case with maximum ALMR deployment
ALMRC001	Mod B breeder base case
ALMRC002	Mod B breeder with use of available defense Pu
ALMRC003	Mod B breeder with maximum ALMR deployment

* Fifth letter of name refers to particular fuel/core design:

ALMRA***	Mod A burner (C.R.=.69).
ALMRB***	Mod A with breakeven fuel cycle (B.R.=1.04).
ALMRC***	Mod B breeder (B.R.=1.24).

Appendix B. SPREADSHEET ROW DESCRIPTIONS

Row Number	Description
1-44	Cost data and economic parameters. Those items marked with an asterisk "*" are input variables, other (non-marked) items are either fixed (such as 5 and 15 year tax depreciation schedules) or are calculated from other parameters.
46-58	ALMR deployment and power generation information.
48	Year
50*	Full plants added in a given year (year on line 48).
51*	Full plants removed from service in a given year (none shown in example calculation).
52	Number of ALMR plants on-line.
53	Reactor years of ALMR operation.
54	On-line ALMR capacity.
55	Energy generated by ALMRs in a given year.
57*	Total nuclear generation in a given year.
	The number of ALMR plants that can be added to the grid is constrained (not automatic in the present model) by the availability of fissile material. There must always be adequate fissile material available or an error (ERR) will appear in Cell "W5."
58	Nuclear power generated by sources other than ALMRs (assumed to be LWRs).
60-165	Capital Cost Model.
62	Capital investment cost at start-up for plants coming on-line in each year. There is learning until the fourth plant is reached which is assumed to be the NOAK plant.
64-127	Revenue requirements generated in each year for plants coming on-line in a specified year. This array uses year-by-year revenue requirements for the first commercial plants (lines 135-150) and for NOAK plants (lines 151-165).
128-130	Total revenue requirements for a given year in nominal (line 129) and constant (line 130) reference year dollars.
131	Average annual cost (constant $) for capital in each year in Mills/kWh.
132	The levelized capital cost over the period from 2011 to 2050 in constant $ mills/kWh.

135-149 Year-by-year revenue requirements for FOAK ALMR plants normalized to $1 million initial investment (start of operation dollars).

151-165 Year-by-year revenue requirements for NOAK ALMR plants normalized to $1 million initial investment (start of operation dollars).

167-172 Annual O&M costs. A learning factor is applied based on cumulative ALMR operating years (line 53).

174-180 Decommissioning cost for each year. No learning is assumed. Annual cost based on input decommissioning cost and sinking fund over plant book life.

181-301 Fuel cycle logistics and economics section.

184-186 ALMR driver assembly needs (line 186) for a full sized ALMR in each year relative to plant start-up (line 184). The initial core is assumed to be purchased one year before start-up and each reload is purchased at the beginning of the year in which it is needed.

188-200 Copy of lines 46-58.

203 The number of assemblies required in each year for initial cores.

205-265 The driver assemblies required in a given year for plant reloads for plants starting operation in a specified year.

267 Total reload driver assemblies required in each year.

269-272 Driver assemblies available for recycle with an assumed two-year (nominal) cooling period.

270 Driver assemblies becoming available for recycle in a given year. They lag discharge from the ALMR by two years in the current model.

271 Blanket assemblies available for recycle are also shown here, although all bookkeeping is done on driver assemblies since the ratio of blanket assemblies/driver assemblies is a constant for recycle.

272 Net drivers available for reprocessing
= Old Balance - Drivers reprocessed during previous year (line 282)
+ Drivers becoming available this year (line 270).

274-301 ALMR Fuel Cycle Facility (FCF) Plants.

276-277 FCF plants started and shutdown in a given year.

Plant start-ups are input. The plants are assumed to have a 30-year life except for the first (25 MTHM/year) demo plant which is integrated into the first full size (nominally 200 MTHM/year) plant. Capacity additions are not automatic and are constrained by the availability of material to be recycled.

279 Capital cost learning factor for FCF plants relative to FOAK FCF plant. Cumulative capital cost learning factor is specified in cell "AH32."

280 Fixed (capital) cost for FCF plants in a given year. This is based on FCF plant revenue requirements (lines 455-482), arriving at a levelized annual constant $ cost for a nominal 200 MTHM/year FOAK FCF plant (cell "D485") escalated to the given year.

282 Driver assemblies reprocessed in given year. Blanket assemblies are assumed to be reprocessed along with these drivers.

283 Driver assemblies awaiting reprocessing at end of year.

284 Cumulative driver assemblies reprocessed from all FCF plants.

285 Number of driver assemblies that can be fabricated out of recovered material.

287 Labor learning based on cumulative driver assemblies reprocessed (line 284), and labor learning rate (cell "AH33").

288 Base labor costs (Cell "AG24") adjusted for number of plants, inflation, and learning.

290 Consumables learning based on cumulative driver assemblies reprocessed and consumables learning rate (cell "AH34").

291 Base consumables costs (Cell "AG25") adjusted for number of plants, inflation, and learning.

293-294 Driver assemblies, fabricated using recycled ALMR material, loaded into reactor. Drivers from recycle fuel are loaded first. Drivers from other alternative sources (e.g. defense plutonium) are next in line followed by drivers derived from LWR spent fuel actinides. Drivers are available first for makeup and then if any are left, for initial cores. Assemblies fabricated using material recovered during a given year is not assumed to be available for use until the end of the year.

295 End-of-year recycle assembly balance.

296-300 Costs in a given year are pro-rated to assemblies manufactured in that year. This gives a cost per assembly (before hardware costs).

301 End-of-year inventory cost (before hardware) per assembly.

304-326 LWR actinide recovery model.

306* LWR fuel actinide recovery plant start-ups. These additions are done manually in current model. Capacity additions must be such that adequate actinides are available for ALMR start-up and operation, but not so great as to use up the spent fuel inventory before the end of the plant life.

307 Plant shutdowns are automatic after plant book life is reached.

309 On-line LWR fuel reprocessing capacity.

310 Cumulative LWR spent fuel mass reprocessed. Plants are assumed to run at full capacity output.

311 Fissile Pu recovered from spent LWR fuel in a given year.

313 New LWR spent fuel becoming available for reprocessing in a given year.

314 Unreprocessed LWR spent fuel inventory.

316 Total fissile Pu (derived from LWR fuel) available for ALMR assemblies at beginning of year.

317 Equivalent driver assemblies that can be manufactured out of available Pu.

318 Beginning of year inventory cost for fissile Pu inventory (based on cost of recovery and carrying charges on unused material).

320-321 Makeup and initial core driver assemblies manufactured in a given year using LWR spent fuel actinides.

322 Fissile Pu in driver assemblies derived from LWR spent fuel.

323 Cost per driver assembly from ALMR actinide source (before fabrication hardware).

325 LWR derived fissile Pu stockpile at end of year.

326 This line checks if enough fissile Pu is available to meet demand. If any value on line 306 is less than zero, an error ("ERR") will occur on this line and in cell "W5."

328-334 Assemblies derived from defense Pu source. Assemblies are manufactured until Pu used reaches the maximum available (cell "W11").

335 Unit assembly cost (before hardware cost) for assemblies derived from DP Pu. A plug number unit cost "W32" is assumed.

337-345 Assembly Fabrication. Fabrication labor, capital and consumables are assumed to be part of the reprocessing cost. Hardware cost is treated separately. Unit hardware cost will be the same no matter the source of the fissile material. Total driver (line 339) and blanket (line 341) assemblies fabricated are the sum of those from the 3 sources. Cumulative assemblies fabricated are also estimated (lines 340 and 342). The hardware learning (line 343) is based on input learning factor (cell "AH35") and cumulative driver assemblies fabricated (line 340). The unit driver and blanket hardware costs (lines 344 and 345) are equal to the base input costs (cells "AG26" and "AG27") times the inflation escalation times the learning factor.

347-420 Fuel Cycle Revenue Requirements.

349 The amount paid in a given year for initial core fuel assemblies.

350	The amount paid in a given year for reload fuel assemblies.
352-415	Fuel cycle revenue requirements in a given year for fuel assembly purchases for ALMR plant starting operation in a specific year.
417	Revenue requirements for assembly purchase (Nominal $).
418	High-level waste fee (Nominal $).
419-420	Total Revenue Requirements for ALMR fuel cycle in each year in nominal and constant dollars.
421	Annual fuel cycle cost in Mills/kWh (constant $).
422	Levelized fuel cycle cost over the period from 2010-2050 (mills/kWh).
425-438	Year-by-year revenue requirements for initial core assemblies normalized to a $1 million investment.
440-452	Year-by-year revenue requirements for reload core assemblies normalized to a $1 million investment.
455-482	Revenue requirements calculation for FOAK FCF capital related costs.
483	Present worth of FCF plant capital related revenue requirements (cell D483).
D484-D487	Constant dollar levelized annual costs for a FOAK FCF by cost component.
D488-D493	Constant dollar per assembly levelized costs for a FOAK FCF by cost component.
495-536	Repository model.
497	Relative year for repository cash flows for capital, R&D, siting, and regulatory costs for all repositories after first.
499	Cash flows (This information is presently not used).
501	Repeat of year.
503	Beginning of year cumulative non-reprocessed LWR spent fuel (same as line 314).
504	LWR spent fuel reprocessed during year (same as line 309).
505	LWR spent fuel assembly disposal during year.
509	Peak inventory of LWR spent fuel (before reprocessing or disposal) to date.
511	Un-reprocessed ALMR spent fuel inventory.
512	ALMR Spent fuel Reprocessed in year.

513 Equivalent LWR Waste Inventory available for disposal. Note the assumption of a two-year lag time between reprocessing and availability for disposal.

515 Repositories installed.

516 LWR Assembly capacity of all repositories commissions to date.

518 Reprocessing waste disposal in repository based on initial MTHM of fuel.

519 Equivalent LWR waste disposal. The additional repository capacity created by disposing of reprocessing wastes instead of full assemblies is accounted for here. If the repository can accommodate four times as much reprocessing wastes as spent fuel assemblies (0.25 factor in cell AQ17) and there is no full assembly disposal (line 505), then the values on line 519 will be 0.25 times the numbers on line 509.

520 Unused repository capacity in terms of full assembly LWR spent fuel disposal (initial MTHM).

522-527 High Level waste repository costs. Net present values for 2010-2050 are shown in Column D.

523 Pre-commissioning costs accounted for in year of repository commissioning. Note that first repository pre-2010 costs are not shown.

524 Fixed annual operating costs.

525 Variable operating cost. Cost proportional to quantity of material placed in repository.

526 Incremental costs associated with MRS.

527 Total cost for each year in nominal dollars. Cell "D527" is the Net Present Value of the costs from 2010-2050.

530-534 Revenues from the 1 mill/kwh (escalated for inflation) high level waste disposal charge for all nuclear plants.

536 Cell "E536" gives the net present value (NPV) of the waste fee revenues from 2010-2050.

539-550 Cost summary table for ALMR deployment in 2010-2050 period. Both levelized cost and NPV are shown by cost component.

553-580 Uranium Fuel Model.

555 Annual uranium consumption for U.S. LWRs.

556 Cumulative U.S. uranium consumption from 1992 through date. Cell "E556" gives uranium consumption through 2009.

557 U.S. uranium price projected for given year.

558	U.S. enrichment consumption for given year.
559	U.S. conversion for given year.
560	U.S. LWR Fuel Fabrication in given year.
562-567	Annual costs for U.S. LWR fuel cycle components.
570-571	Total annual costs for U.S. LWR fuel on nominal and constant dollars.
C574-C580	Levelized LWR fuel cycle cost for 2010-2050 period in constant dollars.
583-646	Summary table.
588-593	Annual fuel cycle costs in nominal dollars.
593	Annual net fuel related costs for total nuclear system. Excludes high level waste fee but includes waste repository costs.
595-600	Present worth of nuclear power production by source for periods starting in 2010 and ending in years 2030, 2040, 2050, 2060, and 2070.
603-605	Present worth to 2010 (in reference years dollars) of ALMR capital, O&M and decommissioning costs for same periods as for power (lines 598-600).
608-616	Present worth to 2010 (in reference years dollars) ALMR and LWR fuel costs, repository and waste fee for same periods as above. Net fuel cost includes repository cost but excludes waste fee.
623-629	Constant dollar levelized ALMR costs for periods starting in 2010 and ending in years 2030, 2040, 2050, 2060, and 2070. The fuel cost includes a 1 mill/kwh waste fee but excludes any direct repository costs or credits.
633-641	Levelized fuel cost for entire nuclear industry in constant dollars. Levelization periods are the same as above. The net fuel cost (line 638) excludes the waste fee and the total levelized cost includes the waste repository costs.
646	The levelized total fuel cost for decades starting in 2010 and ending in 2070.
649-682	A continuation of the LWR fuel cost model. This section takes a single LWR plant and calculates fuel cycle investments and revenue requirements for a 30-year period by cost component. Levelized costs were calculated for each component based on the input (cells AW14-AW17) commodity prices. The levelized cost, normalized to unit commodity price, is calculated in cells F677-F680. This normalized cost, together with the annual LWR power generation, commodity price in a given year, and inflation since reference year are used to calculate the annual fuel costs in line 563-566. The component fuel costs shown in cells D677-D680 were benchmarked against an AP-600 fuel cycle cost calculation using the PC version of the REFCO83 code and were found to be in excellent agreement.

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