CONF-801230--1

MASTER

COST AND AVAILABILITY OF NUCLEAR FUEL IN THE 1980'S

Minton J. Kelly[1] Jeffrey S. Baldwin[1,3] and Samuel C. Martin[2]

To be given at a conference sponsored by
The National Estimating Society
Energy Economics of the 80's
December 8-10, 1980
Sheraton Inn
Huntsville, Alabama

Research sponsored by the Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission under Interagency Agreement No. 40-549-75 with the U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

1. Oak Ridge National Laboratory
2. Science Applications, Inc.
3. Speaker

COST AND AVAILABILITY OF NUCLEAR FUEL IN THE 1980'S

Minton J. Kelly,[1] Jeffrey S. Baldwin[1,3] and Samuel C. Martin[2]

INTRODUCTION

The Nuclear Fuel Cycle may be conveniently divided into:

1. Uranium Mining and Milling
2. Uranium Conversion to UF_6
3. Uranium Enrichment
4. Reactor Fuel Fabrication
5. Interim Storage and Transporation of Spent Fuel
6. Final Disposal with or without Recovery of Remaining Fissile Material

Since the scope of this conference is limited to the present decade, only present options are considered in this paper.

These are: Light Water Reactors
Diffusion Plant Enrichment
Spent Fuel Storage without Reprocessing

Demand for Fuel Cycle Services

As a basis for further discussion it is necessary to establish the demand for nuclear fuel.

Table 1 documents present and expected additions in installed nuclear capacity through the coming decade. The NRC Office of Management and Program Analysis reported 145,000 MWe of nuclear generating capacity either operating or with construction permits and an additional 14,000 MWe under construction permit review as of June 30, 1980 which is consistent with the data in Table 1.

1. Oak Ridge National Laboratory
2. Science Applications, Inc.
3. Speaker

Actual operating results from both boiling-water and pressurized-water reactors are available (1) for both the initial reactor cycle and for subsequent operation. There is no significant difference in uranium usage except for the initial cycle. To calculate uranium demand for the initial core we have estimated 1.52 MWe-year per 0.91 MT (1 ton) of U_3O_8 based on 67% of new capacity being pressurized-water reactors. For refueling, we have used 3.11 MWe-year per 0.91 MT (1 ton) U_3O_8.

This gives an initial core requirement of 598 MT (658 tons) of U_3O_8 for 1000 MWe reactor. NUREG/CR-1041 (1) calculations give an initial core requirement of 473 MT (520 tons) of U_3O_8 per 1000 MWe for a pressurized-water reactor. This same source calculates 164 MT (180 tons) of U_3O_8 per year for refueling at a 0.75 capacity factor where we obtain 219 MT (241 tons) of U_3O_8 per year.

Actual reactor operating experience (2) has demonstrated that average specific energy for both boiling-water and pressurized-water reactors is 3.11 MWe-year per 0.91 MT (1 ton) of U_3O_8.

To calculate U_3O_8 demand we have used 473 MT (520 tons) per 1000 MWe for initial cores and 290 MT (320 tons) for refueling per 1000 MWe-year. At the realistic capacity factor of 0.60 this is 174 MT (191 tons) of U_3O_8 per 1000 MWe per year for refueling.

Table 2 gives the calculated demand for U_3O_8 over the decade of the 1980's which is the basis for conclusions drawn in this paper.

We have not included lead time effects since the present stockpiles of U_3O_8 are sufficiently large to cushion such impacts.

U_3O_8 Availability and Cost

We are now in a position to consider the availability of U_3O_8.

The Department of Energy (3) reported that 21 uranium mills were operating with a nominal capacity of 44,590 MT (49,050 tons) of ore per day with an estimated production capability of from 17,275 MT (19,000 tons) to 20,000 MT (21,000 tons) of U_3O_8 per year. During 1979 these mills produced 14,980 MT (16,480 tons) of U_3O_8 with 90.9% recovery of uranium from the ore processed.

Additional mills (4) are scheduled for start-up between 1980 and 1982 with a nominal capacity of 12,220 MT (13,440 tons) per day. With an expected average ore grade of 0.10%, an extraction efficiency of 93%, and operating 330 days per year, these mills could produce an additional 3,750 MT (4,125 tons) of U_3O_8 per year by the end of 1982. One mill has filed for a 1000 MT (1100 ton) per day expansion and an application was filed in July 1980 for a new 3000 MT (3300 ton) per day mill in Wyoming. These projects would add another 1000 MT (1,100 tons) per year of U_3O_8 production capacity for a total conventional mill capability by 1984 of about 22,000 MT (24,200 tons) of U_3O_8 production per year.

In addition to conventional mill production, 2,045 MT (2,250 tons) of U_3O_8 was produced in 1979 by solution mining (in-situ mining), as a by-product or by heap leaching.

The Department of Energy estimated as of January 1, 1980 the nominal capacity of solution mining operations was from 1,090 MT (1,200 tons) to 1,455 (1,600 tons) per year. The Pacific Northwest Laboratory (5) listed production figures for all operating solution mines and those in the licensing process as of May 1980. The 17 projects had a nominal production capacity of 3,375 MT (3,715 tons) of U_3O_8 per year. Other test projects are operating and may file permit applications for commercial production at any time. The U.S. Department of Energy (6) has projected that solution mining capability could reach 9700 MT (10,700 tons) of U_3O_8 per year by 1991 and hold at that level through the year 2000.

By-product uranium is recovered only as a result of production of other resources. Some U_3O_8 is recovered during copper or beryllium ore processing operations, but the primary source at present is recovery from phosphoric acid production. It was estimated (3) that production capability was 455 MT (500 tons) to 635 MT (700 tons) as of January 1, 1980. It was recently reported (7) that over 320 MT (350 tons) of U_3O_8 was produced from phosphoric acid operations in 1979. Over 455 MT (500 tons) is expected to be produced in 1980 with a production capability of over 1,090 MT (1,200 tons) annually by the end of 1980. Two new plants are under construction which will increase capacity to over 1,820 MT (2,000 tons) by 1982. Total by-product recovery has been estimated to be 4,275 MT (4,700 tons) annually by 1990 (6).

Summarizing:

U_3O_8 production capability by 1982 - 26,400 MT

U_3O_8 production capability without any further applications by 1983 - 27,440 MT

Highest annual U.S. requirement in decade - 26,595 MT

Average U.S. requirement over the decade - 20,982 MT

It is evident that there is and will be more production capability for U_3O_8 than is needed over this decade. Cost competition will determine which mines and mills will remain in production.

This result stems entirely from the decrease forecast in installed nuclear reactor capacity expected by 1990. From 170,000 MWe forecast in February 1979, (8) to 160,000 MWe in October 1979, (9) to the present estimate of 140,000 MWe in Table 1.

An extensive discussion of mining and milling costs is therefore not warranted other than to note that of the \$15/lb U_3O_8 potential resource estimates (3) 373,275 MT (415,000 tons) are listed as probable, 190,910 MT (210,000 tons) are listed as possible, and 68,180 (75,000 tons) are listed as speculative. As shown on Table 2, only 234,290 MT (257,720 tons) will be needed through 1990.

The $15/lb U_3O_8 forward cost estimates do not include a number of significant factors such as: past expenses, exploration and land aquisition costs, provisions for profits, marketing costs, interest costs, taxes and inflation. It is estimated (1) that the market price must be about twice the value used in the forward cost concept or about the present spot price of 30-32 $/lb U_3O_8. No escalation in the real price of U_3O_8 can be foreseen over the near term because of surplus production capacity.

UF_6 Conversion Requirements and Cost

Conversion of U_3O_8 to UF_6 is an established chemical process in a competitive market. Sufficient installed capacity exists to process demand for the 1980's. NUREG/CR-1041 (1) estimates that a new facility could produce UF_6 at a cost of $5.95/kg U (1979 dollars). Little, if any, real cost escalation can be expected (1).

Uranium Enrichment

Table 3 shows the forecast of installed enrichment capacity (10) together with projected U.S. reactor demand both for separative work and fuel fabrication.

The latter two demands were calculated from the information in Table 2 using 2.5% enrichment for initial fuel loading at 3000 SWU per metric ton of Uranium and 3.15% enrichment for refueling at 4640 SWU per metric ton and 0.2% tails assay.

Projected enrichment capability is much larger than expected demand even if potential processing requirements for foreign reactors and national defense are included.

This does not indicate competitive forces will stabilize the present price of $110/kg SWU since the government controls all U.S. enrichment facilities and the present policy of charging customers for the cost of developing new enrichment facilities as well as increasing power costs will probably steadily increase real costs.

Reactor Fuel Fabrication

USDOE has reported (11) that 2700 metric tons of heavy metal (MTHM) fuel fabrication capacity was available in 1975. As shown in Table 3, this provides excess capacity through 1983. Westinghouse Electric Corporation requested licensing of a new fuel fabrication plant to be constructed in Prattville, Alabama (12). Initial production of 400 MTHM is proposed rising to a design level of 1000 MTHM as needed.

Westinghouse presently has permits to expand its Columbia, South Carolina Plant capacity by 400 MTHM. Therefore, 4,100 MTHM installed capacity will be available against an apparent maximum annual requirement of about 3,700 MTHM.

Some seven fuel fabricators compete for this market and competition should lead to price stability except for inflation.

NUREG/CR-1041 (1) forecasts $120/kg (1979 dollars) which is a reasonable estimate.

Interim Storage, Transportation, and Final Disposal

The writers profess no particular expertise in the remaining steps in the fuel cycle. NUREG/CR-1041 (1) has estimated Transportation and Final Disposal (spent fuel-no reprocessing) as between 7.5 and 8.6% of lifetime fuel cycle requirements and costs, these values are reasonable. Away from reactor (or at reactor) spent fuel storage is presently under active study since a facility for permanent disposal does not appear to be available near-term. This could represent 2 to 4% of the fuel cycle cost.

Summary and Conclusions

Due to the decrease in expected nuclear reactor capacity growth, all portions of the fuel cycle can fulfill reactor needs throughout the 1980's with no expansion required except for fuel fabrication, where such expansion is already in the permit and regulatory system.

As a result, fuel cycle costs should not increase faster than the rate of inflation with the possible exception of enrichment costs. Enrichment cost increases may exceed the rate of inflation due to the recent rate increases initiated by TVA (TVA supplies the enrichment facilities with electrical power), and the present government policy of charging users of enrichment services for the cost of developing new enrichment facilities.

It is likely that uranium will remain very competitive with coal as a fuel on a dollars per million BTU basis. However, increasing capital costs for reactors, not considered in this paper, may change this scenario since overall Kw-hr costs include capital recovery.

Regardless of comparative overall costs, it is unlikely that any new reactor orders will be placed before the mid-1980's as forecast by Electrical World (13). This is expected because of a directive by Congress (14) to the Nuclear Regulatory Commission to rewrite the Code of Federal Regulations, Parts 50, 51 and 100 to better define siting regulations. It is doubtful that these rule changes will be in effect before 1983 and environmental and meteorological studies on a new site require up to two years before an application for construction can be approved.

References

1. NUREG/CR-1041, Fuel Cycle Cost Projections, December 1979, Appendix B, Table B.1.

2. Nuclear Assurance Corporation, Uranium Utilization in Light Water Reactors, Report COO-34012-1, 1979.

3. GJO-100 (80) Statistical Data of the Uranium Industry, USDOE, January 1, 1980.

4. NUREG-0706, Final Generic Environmental Impact Statement on Uranium Milling, September 1980, p.3-2.

5. PNL-3439/UC-11, Some Implications of In Situ Uranium Mining Technology Development, Pacific Northwest Laboratories, September 1980.

6. J. Klemenic, "Uranium Production Capability in the United States" Grand Junction Office Uranium Seminar, USDOE, October 1979.

7. "Uranium Production", Grand Junction Office Uranium Seminar, USDOE, October 1980.

8. Nuclear News, Volume 22, February 1979, pp71-76.

9. Additions to Generating Capacity 1979-1988, for the Contiguous United States, DOE-ERA-0020/1 (rev. 10 October 1979.

10. Enrichment Availability, International Nuclear Fuel Cycle Evaluation, Report of Working Group 2, Vienna, 1980.

11. DOE/NE-003/7, Fuel Cycle Facilities, January 1980.

12. License Application, Dated December 31, 1979 to U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Division of Fuel Cycle and Material Safety, Washington, D.C. 20555.

13. Electrical World, September 15, 1980.

14. 96th Congress, House of Representatives, Report No. 96-1070, Authorize Appropriations to the Nuclear Regulatory Commission, June 4, 1980.

Table 1

Existing Nuclear Capacity and Expected Additions

Year	Planned[1] Additions MWe	Construction Status[2] MWe	Construction Status[2] Av % Completion	Estimated Installed Capacity[3] Low	Estimated Installed Capacity[3] Medium	Estimated Installed Capacity[3] High
Present	53,744[4]	 (53,744)				
1980	5,034 (58,728)	8,180 (61,924)	97.7			
1981	11,850 (70,628)	9,704 (71,628)	85.2			
1982	8,850 (79,478)	6,727 (78,355)	75.9			
1983	11,900 (91,378)	9,014 (87,369)	63.0			
1984	11,931 (103,309)	5,845 (93,214)	55.0			
1985	10.995 (114,304)	5,695 (98,913)	45.1	 86,000	 98,000	 102,000
1986	12,197 (126,501)	9,842 (108,755)	35.4			
1987	5,366 (131,867)	6,757 (115,512)	24.7			
1988	7,723 (139,590)	10,811 (126,323)	14.2			
1989	1,067 (140,657)	13,931 (140,254)	5.4			
1990	0 (140,657)			 121,000	 128,000	 139,000

(1) Electrical World, September 15, 1980.

(2) Status of Reactor Construction, DOE/NE-0030/2(80), April 1, 1980.

(3) Statistical Data of the Uranium Industry, GJO-100(80), January 1, 1980.

(4) Electrical World, 1980 Statistical Report, March 15, 1980.

Table 2

U_3O_8 Requirements Annually for Reactor Fuel

Year	For Refueling MT	For Initial Cycle MT	Total MT	(Tons)
1980	9,350	2,380	11,730	(12,290)
1981	10.230	5,605	15,835	(17,420)
1982	12,290	4,180	16,470	(18,120)
1983	13,830	5,630	19,460	(21,405)
1984	15,900	5,645	21,545	(23,700)
1985	17,975	5,200	23,175	(25,490)
1986	19,890	5,770	25,660	(28,225)
1987	22,010	2,540	24,550	(27,005)
1988	22,945	3,650	25,595	(29,255)
1989	24,290	505	24,795	(27,275)
1990	24,475	-	24,475	(26,925)

Table 3

Enrichment and Fuel Fabrication Capacity and Apparent Demand

	USA (MSWU)	Demand From US Reactor (MSWU)	World (MSWU)	Fuel Fabrication Demand - USA (MTHM)
1980	10.5	7.0	20.9	1592
1981	14.7	8.5	28.4	2021
1982	21.6	9.5	37.5	2191
1983	21.6	11.0	38.4	2551
1984	23.5	12.4	39.9	2856
1985	25.6	13.8	43.1	3119
1986	25.6	15.2	46.6	3453
1987	25.6	15.7	50.2	3464
1988	26.5	16.6	55.3	3704
1989	28.4*	16.7	60.6	3609
1990	29.6*	16.6	65.7	3590
1995	34.4*	?	81.1	?

*Centrifuge Plant Additions

(MSWU) - Millions of Separative Work Units
(MTHM) - Metric Tons of Heavy Metal