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FUEL MANAGEMENT AND INVENTORY IN THE EBR-II FUEL CYCLE

by

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I. SUMMARY

A fuel management study has been made for the Second Experimental Breeder Reactor (EBR-II) with the objective of minimizing fuel inventory by pinpointing factors that strongly affect fuel inventory. Included in the various fuel-cycle operating parameters that were investigated were cooling time of discharged fuel, time required for processing and refabrication of the fuel (called, simply, processing time), time between reactor shutdowns for charging and discharging fuel (called reactor cycle time), and reactor power level. A burnup of 2 a/o of the heavy elements in all fuel discharged from the reactor was assumed for all calculations, but the general effect of degree of fuel burnup on the fuel inventory was discussed qualitatively.

The study indicates that an inventory of fuel about 40% greater than that in the reactor (an inventory factor of 1.4) should be sufficient. The required conditions are a total out-of-reactor time of 50 days or less (of which 15 days would be used for cooling the fuel), a reactor cycle time of 55 days or less, a reactor power level of 62 MW thermal, and 2 a/o burnup of the fuel. These reactor cycle, cooling, and processing times (<55, 15, and <35 days, respectively) are regarded as practical for routine operations of the reactor and the Fuel Cycle Facility located adjacent to the reactor and where fuel-recovery operations are performed. However, neither the 62-MW thermal power level nor the 2 a/o fuel burnup may be achieved for some time. Since these have opposite effects on fuel inventory (the fuel inventory decreasing with decrease in reactor power level but increasing with decrease in the burnup), the required fuel inventory should remain about 1.4 times the quantity of the fuel in the reactor.

The required fuel inventory includes a 15-day holdup of a small sidestream of fuel consisting largely of melt-refining crucible residues. These residues (known as "skull" material) must undergo special processing for recovery of the contained fissionable and fertile materials and purification of these materials from fission-product elements. The fuel inventory represented by a 15-day holdup of the residues is only 0.01 of the reactor charge. However, the equipment for recovery of these residues has not yet been installed in the Fuel Cycle Facility. Therefore, the residues, which should represent less than 10% of the total fuel throughput,

will be oxidized and stored until equipment for their recovery is in operation. For each 300 days of reactor operation at full power for which facilities are unavailable for recovery of the residues, an additional fuel inventory of about 20% of that in the reactor will be required.

The above inventory factors have been calculated for the hypothetical situation of "routine" operation of the EBR-II reactor and Fuel Cycle Facility. Neither facility is a production facility; both are experimental in nature. The reactor will be used to test potential fast-reactor fuels and to determine operational characteristics of a fast breeder reactor. Similarly, the Fuel Cycle Facility will be used to evaluate various fuel-recovery and refabrication steps. Some processes (for example, the residue recovery process mentioned above) may be operated only on a demonstration basis. Because of the experimental nature of the EBR-II complex, appreciable fuel may be tied up in samples, irradiated fuel specimens, fuel not amenable to processing by available procedures, and fuel residues. An extra inventory of fuel will have to be carried to compensate for fuel sidetracked in these ways.

Two schemes of fuel management in the reactor proper were also investigated: (1) movement of fuel directly to or from original positions in the reactor, and (2) movement of fuel from outer regions of the core to an inner region before discharge. Fuel inventory would not be affected by either of these schemes since a fixed fuel burnup was assumed before discharge of the fuel. However, there is considerable difference in the reactor shutdown times required. For a power level of 62 MW thermal and a reactor cycle of 20 days, a shutdown time of only 16 hr is required for direct in- or out-of-reactor fuel movement as compared with 41 hr for out-in movements of fuel within the reactor. The direct exchange of spent fuel with fresh or reconstituted fuel is concluded to be advantageous.

II. INTRODUCTION

The Second Experimental Breeder Reactor (EBR-II)(1) at the National Reactor Testing Station in Idaho was built to evaluate the technical and economic feasibilities of electrical power production by fast breeder reactors. The initial fuel for this reactor is a highly-enriched uranium-235 alloy (50 w/o U^{235}). Because of the relatively high, fissionable-material content of this fuel (and of fast-reactor fuels, in general), and because of the high value of the fissionable material, it is desirable to operate with as low a fuel inventory as practicable to avoid excessive inventory charges.

To accomplish this, pyrometallurgical processes, which have the ability to process high-burnup, short-cooled fuels, were chosen for the recovery and purification of discharged fuel materials. The recovery and refabrication processes have been incorporated in a reprocessing facility, known as the Fuel Cycle Facility,(2) at the reactor site. This facility will enable recovery of spent fuel and recycle of reconstituted fuel back to the reactor as rapidly as possible. Both the reactor and reprocessing facility are experimental in nature, having been designed to evaluate various reactor fuels and various fuel-recovery and refabrication procedures.

Because of the significant effect of inventory on fuel-cycle economics, this study was undertaken to determine the fuel inventory required for the EBR-II reactor and to investigate the effects of various operating parameters on fuel inventory. The parameters investigated include reactor cycle time, reactor power, cooling time for discharged fuel, and processing (which includes refabrication) time. The study was made for the EBR-II fuel cycle, but the results are generally applicable to any fuel cycle.

III. EBR-II FUEL CYCLE

The EBR-II reactor system will be the first in the U. S. to operate with a closed fuel cycle. Thus, it will be the first to provide information on the long-term effects of continued fuel recycle, particularly in regard to the buildup of heavy isotopes of uranium and plutonium.

Figure 1, a schematic diagram of the EBR-II fuel cycle, shows the major steps in returning the bulk of the core fuel to the reactor. Figure 2 illustrates how a process for blanket uranium and an auxiliary process for a portion of the core fuel will be integrated into the fuel cycle. The auxiliary process, known as the Skull Reclamation Process serves to reclaim and purify fissionable material contained in residues of the main-line melt-refining process. Fission products that must be removed from the fissionable material consist mainly of alkaline earths and rare earths that are concentrated in the melt-refining residues and the relatively noble fission products such as molybdenum, ruthenium, rhodium, palladium, and zirconium, which are not removed by the melt-refining process. These latter elements are collectively called fissium. Their removal from the small sidestream of material handled in the Skull Reclamation Process keeps their concentrations in the main fuel stream at equilibrium values.

Figure 1

SCHEMATIC DIAGRAM OF PROCESSING STEPS FOR EBR-II FUEL

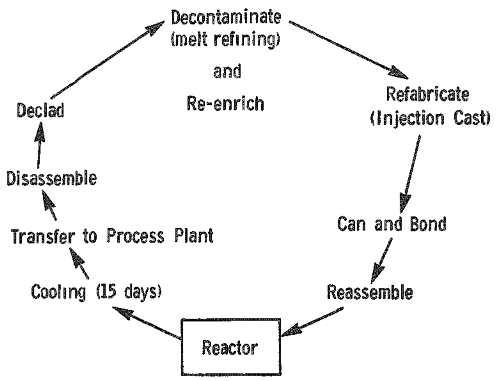

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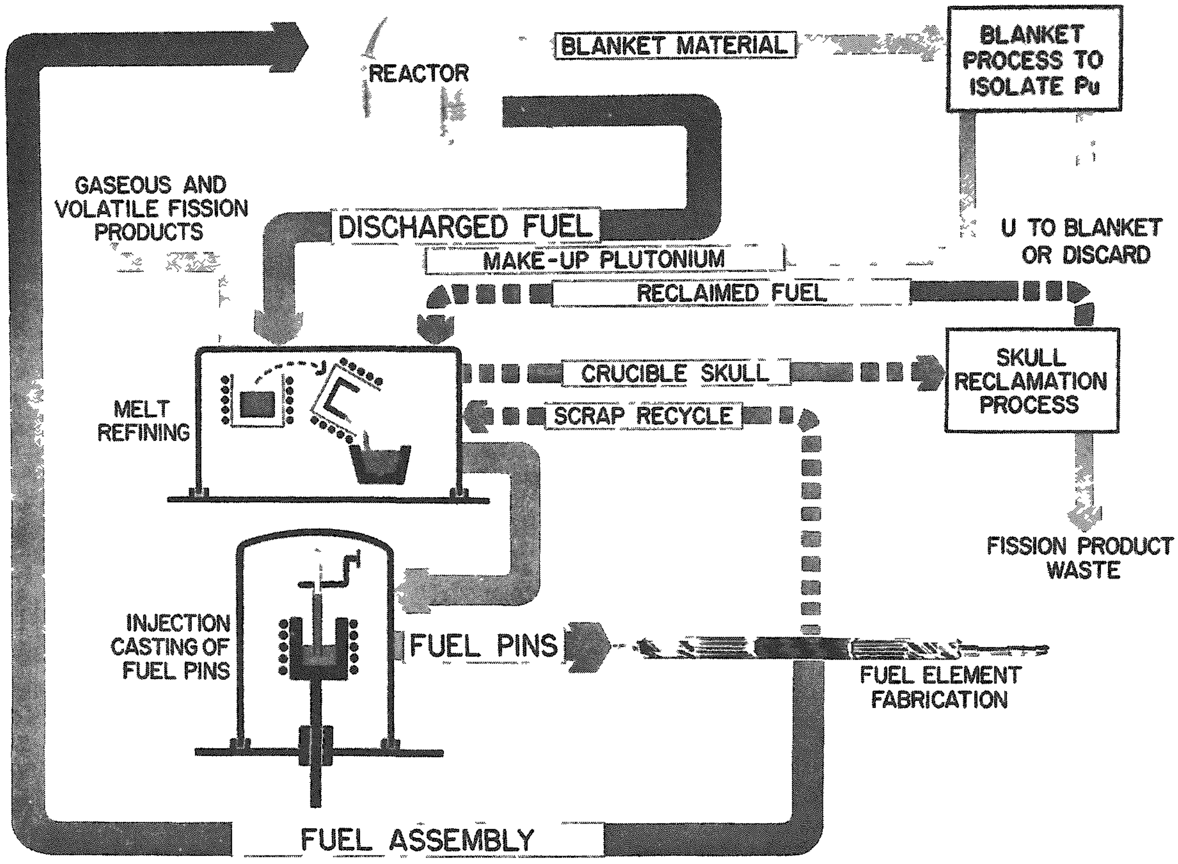
Figure 2

EBR-II FUEL CYCLE



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The melt-refining process is in operation in the Fuel Cycle Facility. Equipment for the processing of blanket material and recovery of fissionable material from melt-refining residues has not yet been installed in the Fuel Cycle Facility. Plant equipment for these processes is currently being developed and tested and will be installed in the facility at a future date.

The composition of the first core alloy is 43 a/o U^{235}, 46 a/o U^{238}, and 11 a/o fissium.* It is hoped that a fuel burnup of 2 a/o can be achieved with this fuel. At full-design power level of the reactor (62 MW thermal),

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*Concentrations of the individual fissium elements in the first core loading are: 5.87 a/o Mo, 4.33 a/o Ru, 0.56 a/o Rh, 0.39 a/o Pd, 0.25 a/o Zr, and 0.02 a/o Nb. These are calculated equilibrium concentrations.

this burnup would be reached in an average of about 136 days and would result in an average required fuel processing rate of 3.1 kg of fuel per day. The processing rate would be increased by discharge of fuel at a lower burnup and decreased by operation of the reactor at lower average power levels. Because the reactor is experimental in nature, both of these factors will be operative and will greatly affect the fuel processing rate, as well as required fuel inventories.

Future core loadings of the EBR-II will probably contain plutonium as the fissionable material. The fuel cycle would not be materially changed for a plutonium-based fuel, although some modification in the pyrometallurgical processes will be required.

IV. VARIABLES INVESTIGATED

The effects of the following variables on fuel inventory were investigated in this study:

1. Reactor Cycle Time (time between reactor shutdowns for charging and discharging fuel). Calculations were made for reactor cycle times of 10, 15, 20, 25, 30, and 40 days. As the cycle time is increased, more fuel subassemblies are removed and replaced during shutdown.

2. Average Reactor Power. Since a constant burnup of 2 a/o was assumed, the time to achieve this burnup is directly proportional to the average power level. Two power levels were investigated: (1) the fuel design power level of 62 MW thermal, and (2) 80% of the fuel design power level, or 49 MW thermal.

3. Cooling Time for Discharged Fuel. A cooling time of at least 15 days is required before processing the fuel. However, because subassemblies are handled and processed one at a time, average cooling times may be considerably longer than 15 days. For this study, cooling time was varied within the range of 9 to 30 days. (Fuel subassemblies will be stored in the reactor for about 15 days to allow fission-product decay heating to decrease sufficiently so that a subassembly may be safely transported to the Fuel Cycle Facility, but this time could be reduced if the rate of fuel burnup is reduced.)

4. Processing Time.* It is estimated that between 15 and 27 days will be required for processing the fuel. In initial operations, sufficient fresh fuel must be available to replace that removed from the reactor, but after about 45 days, reprocessed material will become available.

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*In this report, the term "processing" includes both chemical recovery and refabrication of the fuel.

Actual fuel losses in the EBR-II fuel cycle are expected to range between 0.5 and 1.0% of the fuel discharged from the reactor. About 10% of the charge to melt refining will remain in the melt-refining crucible. These crucible residues (skull material) are to be recovered by the Skull Reclamation Process, the development of which is not yet complete. Therefore, the crucible residues will be oxidized, to permit their removal from the crucible, and stored. Extra fuel will have to be carried in inventory to make up for the stored crucible residues. Equipment installed for the Skull Reclamation Process may not be operated routinely, but only on a demonstration basis. If this equipment were put into routine operation, about 15 days would be required to process the small sidestream of fuel going through it. Fuel inventories were calculated for the equilibrium situation, i.e., Skull Reclamation Process in operation.

V. THEORY

To enable interpolation and extrapolation of calculations presented in this report, theoretical expressions have been developed for the minimum equilibrium inventory factors for two cases:

1. The sum of the cooling time and processing time is less than the reactor cycle time (time between reactor shutdowns).
2. The sum of the cooling time and processing time is greater than the reactor cycle time.

Both cases are covered by the following theoretical expression:

$$IF = 1 + T_r/T_b + x\ T_r/T_b, \tag{1}$$

where

$$IF = \text{equilibrium inventory factor} = \frac{\text{total fuel}}{\text{fuel in reactor}} \text{ or}$$

$$= \frac{\text{fuel in one reactor core charge + fuel in cooling and processing}}{\text{fuel in one reactor core charge}};$$

T_r = time between shutdowns (cycle time), days;

T_b = time to achieve desired burnup, days;

and

x = additional inventory fraction for material held up in processing, and is given by the equation

$$x = \frac{(T_p + T_c) - T_r}{T_r}, \tag{2}$$

where

T_p = processing time, days;

and

T_c = cooling time, days.

For case (1), $x = 0$ in Equation (1), and the equation becomes

$$IF = 1 + T_r/T_b. \tag{3}$$

For case (2), the last two terms in Equation (1) can be combined to give

$$IF = 1 + (1+x)\ T_r/T_b. \tag{4}$$

Now

$$1 + x = (T_p + T_c)/T_r, \tag{5}$$

and

$$(1+x)\ T_r/T_b = (T_p + T_c)/T_b. \tag{6}$$

This leads to the final form of the equation for case (2):

$$IF = 1 + (T_p + T_c)/T_b. \tag{7}$$

Equation (7) shows that the minimum, theoretical, equilibrium inventory factor depends only on the sum of cooling time plus processing time, and on the time to achieve the desired burnup. It is independent of the time between shutdowns. Realization of the theoretical minimum inventories requires that the reactor cycle time (or reactor shutdown time) be in phase with the processing cycle, that is, that the out-of-reactor time $(T_p + T_c)$ divided by the reactor cycle time, T_r, be an integer. To the extent that these times are not in phase, the required fuel inventory will be increased. When the mismatch is greatest, a complete extra fuel charge, T_r/T_b, must be carried in inventory. Thus, the maximum required fuel inventory is given by the equation:

$$IF = 1 + (T_p + T_c + T_r)/T_b. \tag{8}$$

The degree of fuel burnup and the reactor power level are implicitly contained in the term, T_b, the time to achieve the desired burnup, since T_b varies directly with burnup and indirectly with reactor power level.

VI. RESULTS

The results of calculations of simulated operation of the EBR-II reactor at 49- and 62-MW average power levels are presented in Table I. The method of calculation is illustrated in Figure 3. The required rate of removal of subassemblies was rounded off to the nearest half subassembly, a condition achieved in practice by alternating the number of subassemblies removed in successive shutdowns between one-half greater and one-half less subassembly than the theoretical requirement. Because removal of fractions of subassemblies was not considered, except for the case of one-half of a subassembly, calculated inventory factors do not always agree exactly with theoretical factors.

Table I

CALCULATED FUEL INVENTORY FACTORS[a] FOR VARIOUS EBR-II FUEL CYCLES

(for direct in- or out-of-reactor fuel movement)

		Calculated Inventory Factors											
Reactor Cycle Time[b] (days):		10		15		20		25		30		40	
Reactor Power Level (MW):		49	62	49	62	49	62	49	62	49	62	49	62
Out-of-reactor Time (days)													
Cooling	Processing												
9	15	1.18	1.22	1.19	1.24	1.25	1.31	1.16	1.19	1.19	1.24	1.26	1.32
9	18	1.18	1.22	1.19	1.24	1.25	1.31	1.30	1.37	1.19	1.24	1.26	1.32
9	21	1.24	1.31	1.27	1.36	1.25	1.31	1.30	1.37	1.37	1.45	1.26	1.32
9	27	1.24	1.31	1.27	1.36	1.25	1.31	1.30	1.37	1.37	1.45	1.26	1.32
12	15	1.18	1.22	1.19	1.24	1.25	1.31	1.30	1.37	1.19	1.24	1.26	1.32
12	18	1.24	1.31	1.27	1.36	1.25	1.31	1.30	1.37	1.37	1.45	1.26	1.32
12	21	1.24	1.31	1.27	1.36	1.25	1.31	1.30	1.37	1.37	1.45	1.26	1.32
12	27	1.24	1.31	1.27	1.36	1.25	1.31	1.30	1.37	1.37	1.45	1.26	1.32
15	15	1.24	1.31	1.27	1.36	1.25	1.31	1.30	1.37	1.37	1.45	1.26	1.32
15	18	1.24	1.31	1.27	1.36	1.25	1.31	1.30	1.37	1.37	1.45	1.26	1.32
15	21	1.24	1.31	1.27	1.36	1.25	1.31	1.30	1.37	1.37	1.45	1.26	1.32
15	27	1.29	1.37	1.27	1.36	1.38	1.45	1.30	1.37	1.37	1.45	1.50	1.60
30	15	1.29	1.37	1.37	1.47	1.38	1.45	1.30	1.37	1.37	1.45	1.50	1.60
30	18	1.29	1.37	1.37	1.47	1.38	1.45	1.30	1.37	1.37	1.45	1.50	1.60
30	21	1.29	1.37	1.37	1.47	1.38	1.45	1.47	1.55	1.37	1.45	1.50	1.60
30	27	1.29	1.37	1.37	1.47	1.38	1.45	1.47	1.55	1.37	1.45	1.50	1.60
Fuel Assemblies Removed per Cycle		3½[c]	4½	5½	7	7½	9	9	11	11	13½	15	18

[a] $\text{Equilibrium Inventory Factor} = \frac{\text{Fuel in one reactor core charge} + \text{Inventory in processing and cooling}}{\text{Fuel in one reactor core charge}}$

[b] This assumes no shutdown time for fuel movement, maintenance, or other reasons during the stated operating period.

[c] Alternate removal of three and four fuel subassemblies; e.g., three fuel subassemblies at ten days, four fuel subassemblies at twenty days, etc.

Figure 3

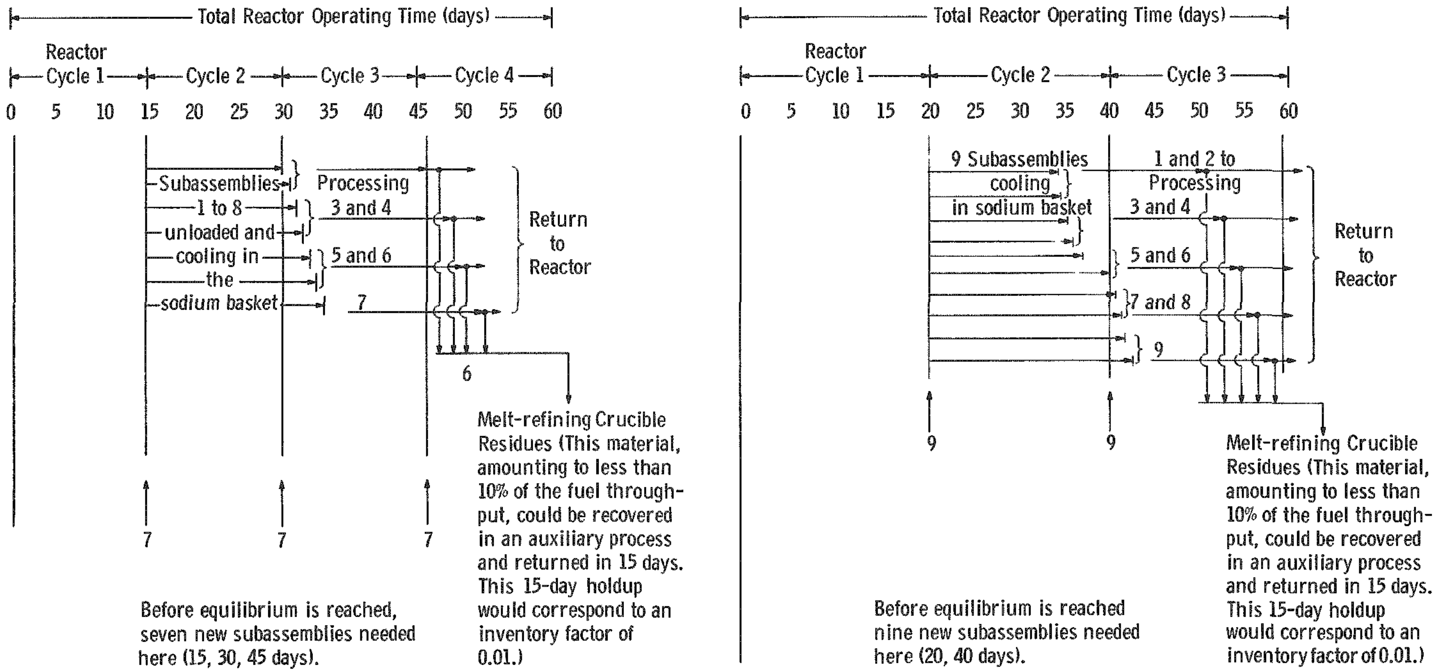
INVENTORY CALCULATIONS FOR TWO EBR-II FUEL CYCLES

15-day Reactor Cycle

15-day Reactor Cycle (Continuous Reactor Operating Period between Shutdowns)
15-day Cooling Period
21-day Processing Time
62-MW Power Level
Seven Fuel Subassemblies Removed per Cycle (2% burnup)
Inventory Factory = 1.36

20-day Reactor Cycle

20-day Reactor Cycle
15-day Cooling Period
21-day Processing Time
62-MW Power Level
Nine Fuel Subassemblies Removed per Cycle (2% burnup)
Inventory Factor = 1.31



Melt-refining Crucible Residues (This material, amounting to less than 10% of the fuel throughput, could be recovered in an auxiliary process and returned in 15 days. This 15-day holdup would correspond to an inventory factor of 0.01.)

Before equilibrium is reached, seven new subassemblies needed here (15, 30, 45 days).

Melt-refining Crucible Residues (This material, amounting to less than 10% of the fuel throughput, could be recovered in an auxiliary process and returned in 15 days. This 15-day holdup would correspond to an inventory factor of 0.01.)

Before equilibrium is reached nine new subassemblies needed here (20, 40 days).

A. Variables Affecting Fuel Inventory

The effects of the various parameters on fuel inventory factors are as follows:

1. Reactor Cycle Time. The effect of reactor cycle time (T_r) is shown in Figure 4 for a total out-of-reactor time (cooling + processing) of 42 days. Up to a reactor cycle time of 42 days, the minimum inventory factor is 1.31 and is independent of cycle time. The maximum inventory factor is greater than the minimum by the amount, T_r/T_b. As shown in Figure 4, the theoretically required inventory factor oscillates between the maximum and minimum inventory factors along lines that successively have slopes $2\ T_r/T_b$, $3\ T_r/T_b$, $4\ T_r/T_b$, etc. The minimum inventory factor is realized when, at reactor shutdown, preparation of a batch of fuel subassemblies required to replace the fuel being discharged from the reactor has just been completed in the Fuel Cycle Facility. If none of the replacement batch were available, it would be necessary to carry in inventory an extra batch of subassemblies (equivalent to T_r/T_b times the number of subassemblies in the reactor). For example, a total processing and cooling time of 42 days, in conjunction with a reactor cycle time of 10 days, would result in a completed batch of fuel on the 42nd day for exchange with spent fuel. This is 8 days before the next reactor shutdown and 2 days after the previous shutdown when the subassemblies, had they been available, could have been returned immediately to the reactor. Probably some, if not most, of the subassemblies in this batch would have been available for return to the reactor, in which case the actual required

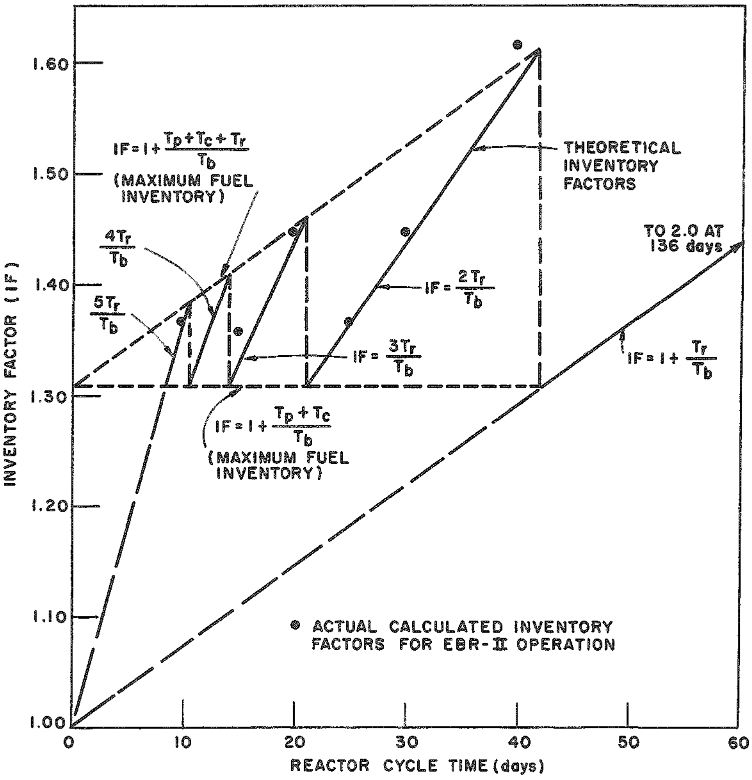


Figure 4

EFFECT OF CYCLE TIME ON FUEL INVENTORY FACTOR

T_p = 27 days
T_c = 15 days
T_b = 136 days
Power Level = 62 MW Thermal

inventory would lie somewhere between the theoretical and minimum inventory factors. Nevertheless, the 8-day mismatch would result in a higher inventory requirement than the minimum. The minimum factor could have been realized with a reactor cycle of 14 days, for which cycle time the necessary replacement fuel would become available in coincidence with reactor shutdowns. Thus, from a fuel inventory standpoint, it is important that reactor shutdown cycles match out-of-reactor time cycles.

The data points in Figure 4 are calculated inventory factors given in Table I for actual EBR-II operation. The agreement between the theoretical and calculated factors is good.

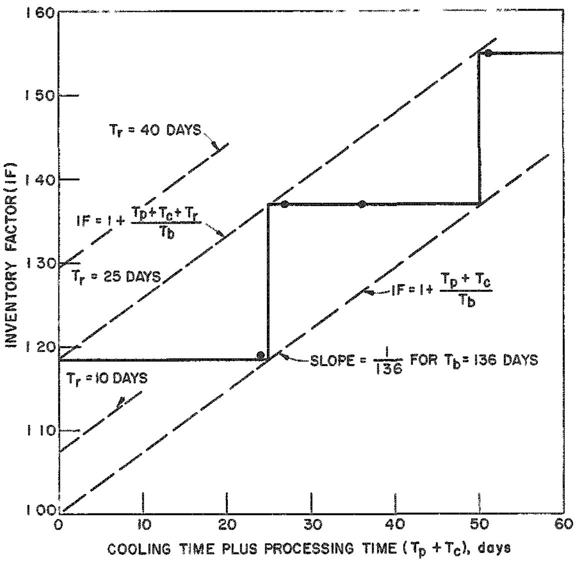
At cycle times of greater than $(T_p + T_c)$ (42 days in Figure 4), the required inventory factor increases only with reactor cycle time at a rate of $1/T_b$; i.e., it is independent of $(T_p + T_c)$. The resulting line has a relatively low slope, and an inventory factor of 1.4 is not reached until the reactor cycle time has been increased to 55 days. Thus, an attractive reactor cycle time is one that is slightly longer than the out-of-reactor time. There is little, if any, advantage in employing reactor cycle times less than the out-of-reactor cycle time.

2. Out-of-reactor Time (Cooling and Processing). In Figure 5, the required fuel inventory is seen to increase stepwise with out-of-reactor time $(T_p + T_c)$. The step positions occur at times when $(T_p + T_c)$ is an integral multiple of the cycle time. The height of each step is equivalent to the fraction of fuel in the reactor removed each time the reactor is shutdown, namely, T_r/T_b. For a reactor cycle of 25 days, for total processing and cooling times of less than 25 days, the inventory factor is 1.185; between 25 and 50 days, it is 1.37; between 25 and 75 days, it is 1.55; etc.

Figure 5

EFFECT OF TOTAL OUT-OF-REACTOR TIME ON FUEL INVENTORY FACTOR

Power Level = 62 MW Thermal
T_b = 136 days



3. Time (T_b) to Achieve Desired Burnup of Fuel. In Figure 5, the inventory factor is seen to increase generally at a rate of $1/T_b$, the slope of the lines connecting corresponding points of the stairstep. Since T_b is directly proportional to the achievable fuel burnup and inversely proportional to reactor power level, fuel inventories would be decreased with increase in the fuel

burnup and increased with increase in the reactor power level. Thus, with cooling and processing times being constant,

$$IF = 1 + C \times \left(\frac{\text{reactor power level}}{\text{fuel burnup}}\right),$$

where C = a constant.

The effect of time of the fuel in the reactor on the fuel inventory factor is plotted in Figure 6. Fuel residence times in a reactor are generally greater than 100 days, at which times fuel inventory requirements change slowly with fuel residence time.

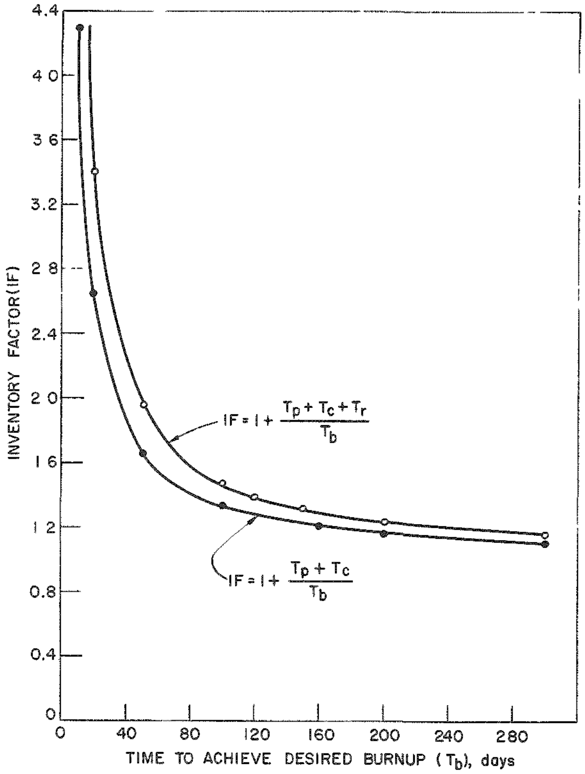


Figure 6

EFFECT OF TIME TO ACHIEVE DESIRED BURNUP* ON THE FUEL INVENTORY FACTOR

Cooling Time (T_c) = 15 days
Processing Time (T_p) = 18 days
Reactor Cycle Time (T_r) = 15 days

*The time to achieve desired burnup is inversely proportional to reactor power level and directly proportional to the permissible fuel burnup. Therefore, curves of inventory factor versus fuel burnup would have the same shape as those on this figure.

In general, fuel inventories are increased by longer cooling, processing, and reactor cycle times and are decreased by reduction in the reactor power level or increase in fuel burnup, both of which have the effect of increasing the time required to reach a desired burnup.

B. Additional Variables Pertinent to EBR-II Operation

For startup of the EBR-II reactor, that fraction of the fuel inventory factor above 1.00 would have to be on hand for approach to the equilibrium state, i.e., to replace fuel discharged initially from the reactor and used to fill the cooling and processing channels. Extra fuel will have to be on hand or subsequently obtained to replace what will be stored as oxidized melt-refining residues. It is estimated that additional inventory factors of 0.17 and 0.22 will be required to replace fuel diverted to storage as oxidized crucible residues for each 300 days of reactor operation at average power levels of 49 and 62 MW, respectively. These residues may be recovered when the Skull Reclamation Process is put into operation, but it is possible that this process will be operated on only a demonstration basis. The fuel inventory required to replace processing losses, which is expected to be about 1% of the total fuel throughput, has not been included in calculations of the inventory factor. An additional increment of fuel inventory will have to be carried to replace fuel losses and to serve as a precautionary measure against breakdown of the fuel processing and refabrication equipment.

VII. FUEL MANAGEMENT SCHEMES WITHIN THE REACTOR

Benedict and co-workers at MIT(3,4,5) have reported that the optimum burnup pattern and minimum fuel cost for a power reactor results from an out-in fuel movement within the reactor core. The data of Benedict(5) indicate also that direct-out-of-the-reactor movement might give a less uniform burnup than the out-in scheme. Comparing this scheme with the direct-out-of-reactor scheme proposed for EBR-II seemed desirable. Since inventory calculations in this report were based on discharging fuel when a 2 a/o burnup has been achieved, fuel inventory would not be affected by the method of fuel management within the reactor. However, there may be operational reasons for using a particular fuel management scheme.

A. Description of Fuel Management Schemes

1. Direct Movement of Fuel in and out of Reactor

The first fuel management scheme considered here involves direct removal of subassemblies from the various zones (see paragraph 2 below for explanation of zones) of the reactor core, immediate replacement of subassemblies with reprocessed or new subassemblies, followed by processing of the discharged fuel. It is estimated that 60-70 core fuel rods will be required to achieve criticality. For simplicity of calculations, exactly 61 fuel rods were assumed to be required since this leads to four zones (four annuli) containing 7, 12, 18, and 24 fuel rods, respectively. The 7 fuel rods are in the center of the core, 12 in the next hexagonal ring, etc.

2. Out-in-internal Core Movement Scheme

In the out-in-internal core movement scheme, the reactor core is divided into several zones. When the required burnup is obtained in the central zone, a certain number of subassemblies are removed from the central zone. Fuel subassemblies are then moved inward from outer zones in a preset pattern. New or reprocessed fuel is then charged to the outer zone. The principal calculations for the present out-in fuel movement were made on the IBM-704 computer using a CYCLE code supplied by the Argonne Reactor Engineering Division. In this code, three equal-volume fuel zones containing 55 core fuel subassemblies were assumed, surrounded by a fourth zone containing 12 control rods. Fuel movement was assumed to occur only in the three central zones.

B. Comparison of Shutdown Times

The following times were used to estimate the total shutdown time required for fuel movements:

One subassembly from the core to the sodium basket:	1 hr
Movement of one subassembly within the core:	20 min
One subassembly from the sodium basket to the core:	1 hr

Startup and shutdown of the reactor was estimated to require 6 hr. Shutdown times were calculated for power levels of 49 and 62 MW. At 49 MW, an average of 170 days is required to achieve a fuel burnup of 2 a/o. At 62 MW, the time is reduced to 136 days.

Shutdown times for both methods of fuel management and for operation at the two power levels are listed in Table II. It is seen that considerably less shutdown time, by a factor of about 3, is required for the direct movement of fuel in and out of the reactor than is required for the out-in-internal core-movement scheme. It is concluded that complicated internal fuel movements have no advantage.

Table II

SHUTDOWN TIMES REQUIRED FOR OUT-IN AND DIRECT OUT-OF-REACTOR FUEL MANAGEMENT SCHEMES

Cycle Time, days	10		15		20		30	
Power Level, MW	49	62	49	62	49	62	49	62
Fuel Assemblies Removed/ Cycle	3-4	4-5	5-6	7	7-8	9	11	13-14
Out-in Cycle Shutdown Time, hr	30	32	33	36	36	41	43	49
Direct Out-of-reactor Cycle Shutdown Time, hr	9-10	11	11-12	13	13	16	17	21

VIII. CONCLUSIONS

The following conclusions are evident from the information in this report:

1. Fuel inventory factors (total fuel/fuel in reactor) vary directly with cooling, processing, and reactor cycle times and with reactor power level, and indirectly with degree of fuel burnup.

2. From the standpoints of both reactor operation and inventory, a reactor cycle time slightly longer than the out-of-reactor time would be advantageous.

3. For the EBR-II reactor, a fuel inventory factor of about 1.4 (i.e., 1.4 times that in a reactor charge, the excess 40% being held up in cooling, processing, and refabrication) will suffice if fuel discharged from the reactor can be made available for return to the reactor in about 40 days.

4. Intermediate movement of fuel within the reactor before discharge offers no advantage over direct exchange of spent fuel with newly-fabricated fuel.

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