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Feasibility Study of a Magnetic Fusion Production Reactor[1]

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A magnetic fusion reactor can produce 10.8 kg of tritium at a fusion power of only 400 MW—an order of magnitude lower power than that of a fission production reactor. Alternatively, the same fusion reactor can produce 995 kg of plutonium. Either a tokamak or a tandem mirror production plant can be used for this purpose; the cost is estimated at about $1.4 billion (1982 dollars) in either case. (The direct costs are estimated at $1.1 billion.) The production cost is calculated to be $22,000/g for tritium and $260/g for plutonium of quite high purity (1% ^{240}Pu). Because of the lack of demonstrated technology, such a plant could not be constructed today without significant risk. However, good progress is being made in fusion technology and, although success in magnetic fusion science and engineering is hard to predict with assurance, it seems possible that the physics basis and much of the needed technology could be demonstrated in facilities now under construction. Most of the remaining technology could be demonstrated in the early 1990s in a fusion test reactor of a few tens of megawatts. If the Magnetic Fusion Energy Program constructs a fusion test reactor of approximately 400 MW of fusion power as a next step in fusion power development, such a facility could be used later as a production reactor in a spinoff application. A construction decision in the late 1980s could result in an operating production reactor in the late 1990s. A magnetic fusion production reactor (MFPR) has four potential advantages over a fission production reactor: (1) no fissile material input is needed; (2) no fissioning exists in the tritium mode and very low fissioning exists in the plutonium mode thus avoiding the meltdown hazard; (3) the cost will probably be lower because of the smaller thermal power required; (4) and no reprocessing plant is needed in the tritium mode. The MFPR also has two disadvantages: (1) it will be more costly to operate because it consumes rather than sells electricity, and (2) there is a risk of not meeting the design goals.

KEY WORDS: Magnetic fusion production reactor; tritium production; fusion breeder.

INTRODUCTION

A very preliminary short study of the feasibility of producing special nuclear materials (SNM) in magnetic fusion reactors was carried out in 1980. This study showed that the reactor needed for the mission was about eight times lower in power (400 MW$_{fusion}$) than that considered commercial in the fusion program (3000 MW$_{fusion}$). A commitment to construct such a production reactor by the early 1990s would incur considerable risk. However, implementation in the late 1990s would result in lower risk of not meeting the design goals because the Magnetic Fusion Energy Program is independently heading toward such a facility.

In August 1981, we began our present study to determine the essential design parameters of produc-

[1]This paper represents work carried out from 1980 to 1982 and was in draft form in 1982. It was received for publication with only minor editing of its 1982 version, explaining the fact that some of the material is dated.

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tion reactors based on tandem-mirror-reactor and tokamak-fusion-reactor neutron sources. Cost estimates and an assessment of the technology requirements were carried out. The results of the study are provided in the companion papers in this issue.[1-6]

RATIONALE FOR A PRODUCTION REACTOR

The U.S. special nuclear materials production facilities are aging and becoming obsolete. To meet anticipated needs, old facilities must be renovated and new facilities constructed. New facilities can be brought into operation in the early 1990s and could be operational for 30 or more years. Since the replacement production reactors will be used that long, the choice of reactor must be considered carefully. Many types of production reactors—some of lower technological extrapolation than others—are being actively considered as replacements for the old reactors. One could select a modern version of a graphite-moderated, light-water-cooled reactor or a modern version of the D_2O-cooled-and-moderated reactor (the Savannah River Reactor). Other possibilities use more advanced technologies such as the helium-cooled graphite reactor. Although less experience with the technology exists, the helium-cooled reactor has clear advantages, such as better safety characteristics with respect to loss-of-cooling accidents. This reactor would also produce more revenue by the sale of electricity. Even more advanced technologies, such as accelerator and fusion neutron sources, can also be considered.

RATIONALE FOR A FUSION-PRODUCTION REACTOR

A fusion reactor is a candidate production reactor because of its well-known neutron-production capabilities. It can produce about eight times more excess tritium or plutonium than an equal thermal-power fission reactor. A fusion reactor also consumes no ^{235}U, whereas the fission reactors under consideration as replacements will consume more than one tonne of ^{235}U each year. Further, it has a safety advantage in that afterheat, and hence the potential for a loss-of-cooling accident, is minimized because very little fissioning is going on in the reactor. For the tritium production mode, no fissioning at all takes place, thus eliminating the need for a reprocessing plant for uranium and plutonium and a savings of over a billion dollars. Since no fissioning occurs, the risk of operating such a plant would be markedly lowered.

The objective of this study is to verify these advantages of fusion, as well as to consider the disadvantages. The principal disadvantage of fusion is that the technology has not yet been fully demonstrated. This research and development effort is funded at nearly $500 million/year. Great progress has already been achieved, and further significant progress is anticipated. From our study we conclude that, while technology is not ready to begin construction of a fusion production reactor now, it may be ready for such a start in five years. In 10 years it is possible that the fusion program will, for its own purposes, construct a similar size reactor for engineering development and materials testing.

A present disadvantage of fusion is the uncertainty in cost. We predict that the cost of a fusion production reactor and its facilities will, because of the lower power, be less than that of a fission production reactor. However, we have little experience to call on, and first-of-a-kind items may make costs high. The uncertainty in cost should decrease as fusion technologies are demonstrated in a wide variety of sizes and facilities around the world.

Both magnetic and inertial confinement fusion reactors are possible. This report, however, is restricted to magnetic fusion. Two approaches to magnetic confinement—the tokamak and the tandem mirror—are receiving considerable attention worldwide.

SUMMARY OF STUDY

Plant Description

For comparison, scale drawings depicting production reactors based on the tandem-mirror and tokamak configurations are shown in Fig. 1. The apparent larger size of the tandem mirror is deceptive, because each was estimated to cost close to $1.4 billion. The tandem mirror production reactor is compared in Fig. 2 to the Mirror Fusion Test Facility (MFTF-B). The tokamak production reactor and the Tokamak Fusion Test Reactor (TFTR) are compared in Fig. 3; a detailed drawing is shown in Fig. 4. A companion paper in this issue[1] provides more details on the plant and blanket design. Typical machine parameters are given in Tables I and II.

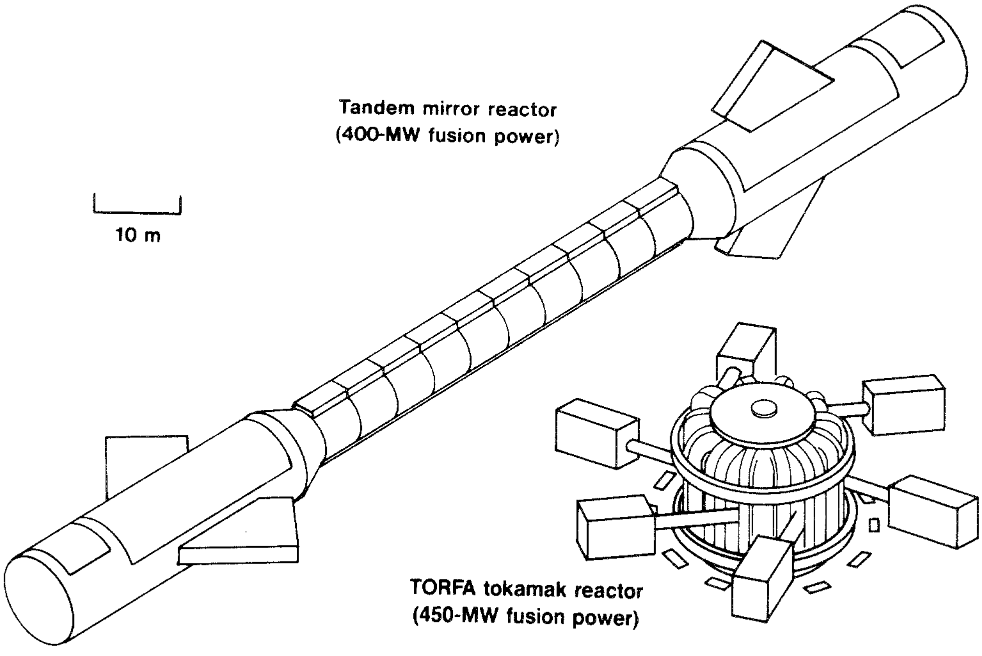

Fig. 1. Comparison of tandem-mirror and tokamak production reactors, which have similar costs.

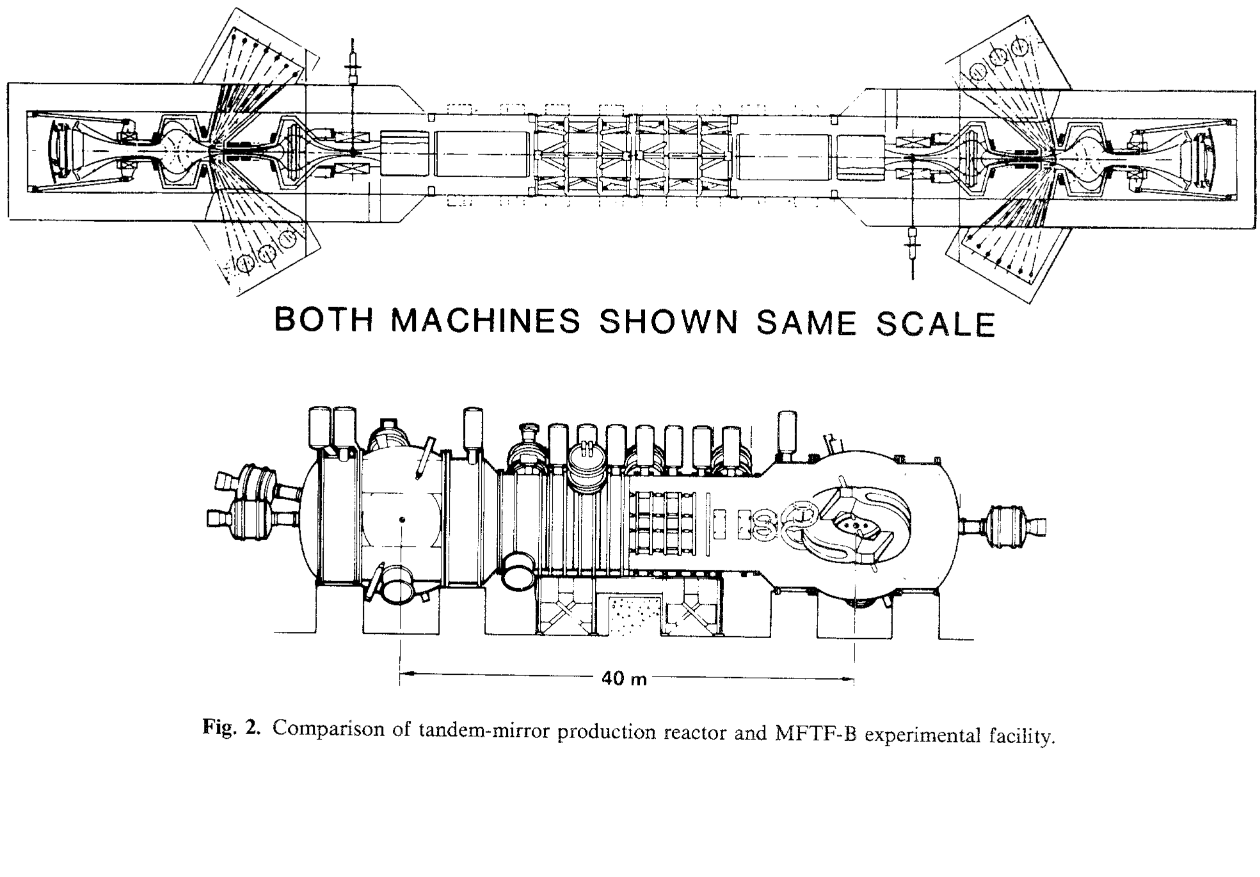

Fig. 2. Comparison of tandem-mirror production reactor and MFTF-B experimental facility.

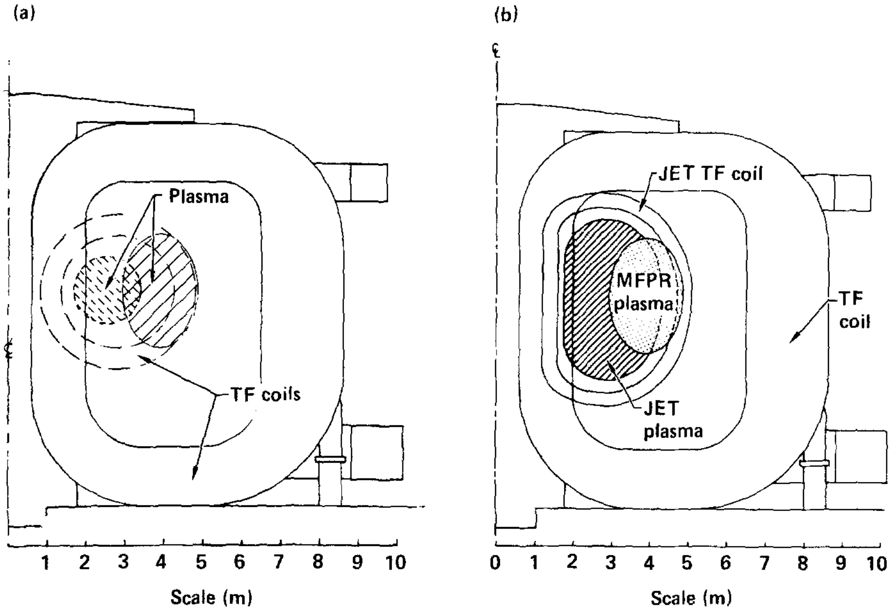

Fig. 3. Size comparison of the tokamak MFPR and (a) TFTR experimental facility shown by dashed lines, and (b) JET facility. The toroidal field (TF) coils and plasma are shown as an overlay.

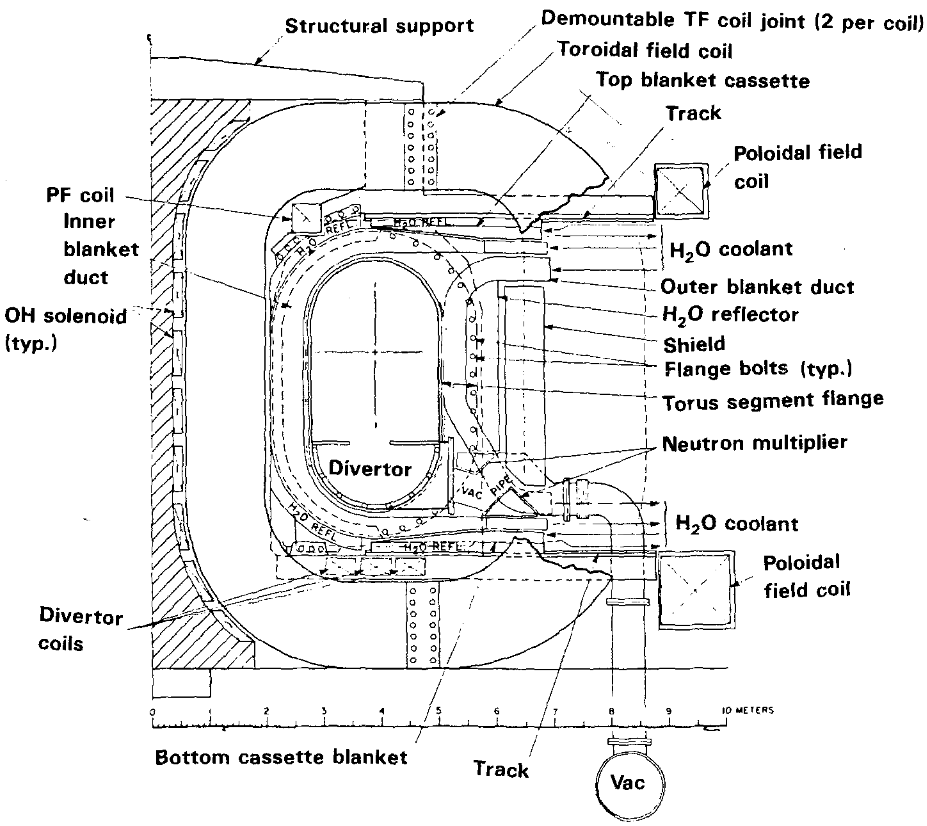

Fig. 4. Cross section of tokamak production reactor, showing breeding blankets, demountable copper magnets, and vacuum components.

Table I. Parameters for the Tandem Mirror Production Reactor (TMPR)[a]

Parameter	TMPR	MFTF-B	FPD-II
L_c (m)	50.0	16.5	75.0
B_c (T)	5.0	1.0	4.7
B_{max} (T)	20.0	12.0	20.0
β_c	0.4	0.5	0.7
$T_{e,c}$ (keV)	30.0	9.0	32.0
n_c (cm^{-3})	3×10^{14}	4.8×10^{13}	4×10^{14}
$(n\tau)_c$ (s/cm^3)	3×10^{14}	5×10^{13}	4.5×10^{14}
$E_{inj,max}$ (keV)	475.0	80.0	475.0
f_{max} (GHz)	70–100	56.0	70–100
Γ (MW/m^2)	1.9	0.004	1.75
P_{fus} (MW)	400.0	0.126 (equivalent D–T)	400.0
Q	4.0	0.4 (equivalent D–T)	4.75

[a]Parameters for MFTF-B and the fusion power demonstration (FPD-II) are shown for comparison.

Blanket Design

The blanket design is based on the use of aluminum, lithium–aluminum (Li–Al) alloy, and beryllium with water cooling below 100°C. The design is shown schematically in Fig. 5. Beryllium, the only material with which there is no extensive experience at Savannah River, has been used extensively in the reactors at Idaho National Engineering Laboratory and elsewhere. The design would use hot-pressed blocks about 10 cm on a side, as shown in Fig. 6. The Li–Al fuel-slug design is shown in Fig. 7. We expect

Table II. Parameters for the Tokamak Production Reactor (or TORFA-D2)[a]

Parameter	TFTR, mid-1980s	JET, mid-1980s[b]	FED-R, early 1990s	Tokamak production reactor (TORFA-D2), late 1990s
Major radius (m)	2.5	2.95	3.5	3.9
Minor radius (m)	0.85	1.25×2.00	0.85×1.3	0.95×1.45
Maximum B at coil (T)	9.2		7.0[c] 8.8[d]	9.8
Maximum B at plasma axis (T)	5.2	3.4	4.0[c] 5.0[d]	5.0
Plasma current (MA)	3.0	5.0	3.6[c]	5.0
Neutral beam energy (keV)	120.0	160.0	150.0[c]	250.0
Neutral beam power (MW)	30.0	25.0	50.0[c]	150.0
$\bar{n}_e\tau_E$ (cm^{-3}/s)	$\sim1\times10^{13}$	$\sim3\times10^{13}$	$\sim2\times10^{13}$	$\gtrsim3\times10^{13}$
$\langle\beta\rangle$ = plasma pressure/ field pressure (%)	3.0	5.0	5[e]	6[e]
Pulse length (s)	~2.0	15.0	≥1000.0	Steady-state[f]
Duty factor	0.003	0.01	0.25	0.90
Fusion gain, Q_p	~1.0	~2.0	1.5[c]	3.0
Fusion power (MW)	20.0	50.0	75.0[c]	450.0
Uncollided neutron wall loading (MW/m^2)	0.2	0.3	0.4(outboard)[c]	1.4
Electrical power consumption (MW)	660.0 (short pulse)		370[c]	575.0

[a]Parameters for TFTR and FED-R are shown for comparison. Because of the demountable copper coils, the FED-R can be upgraded from 75 to 250 MW of fusion power.
[b]Joint European Torus.
[c]Values given are for Stage 1 operation.
[d]Stage II operation, projected for late 1990s.
[e]Approximately two-thirds of pressure is in bulk plasma and one-third is in superthermal (injected) ions.
[f]Assuming steady-state, noninductive current drive is feasible.

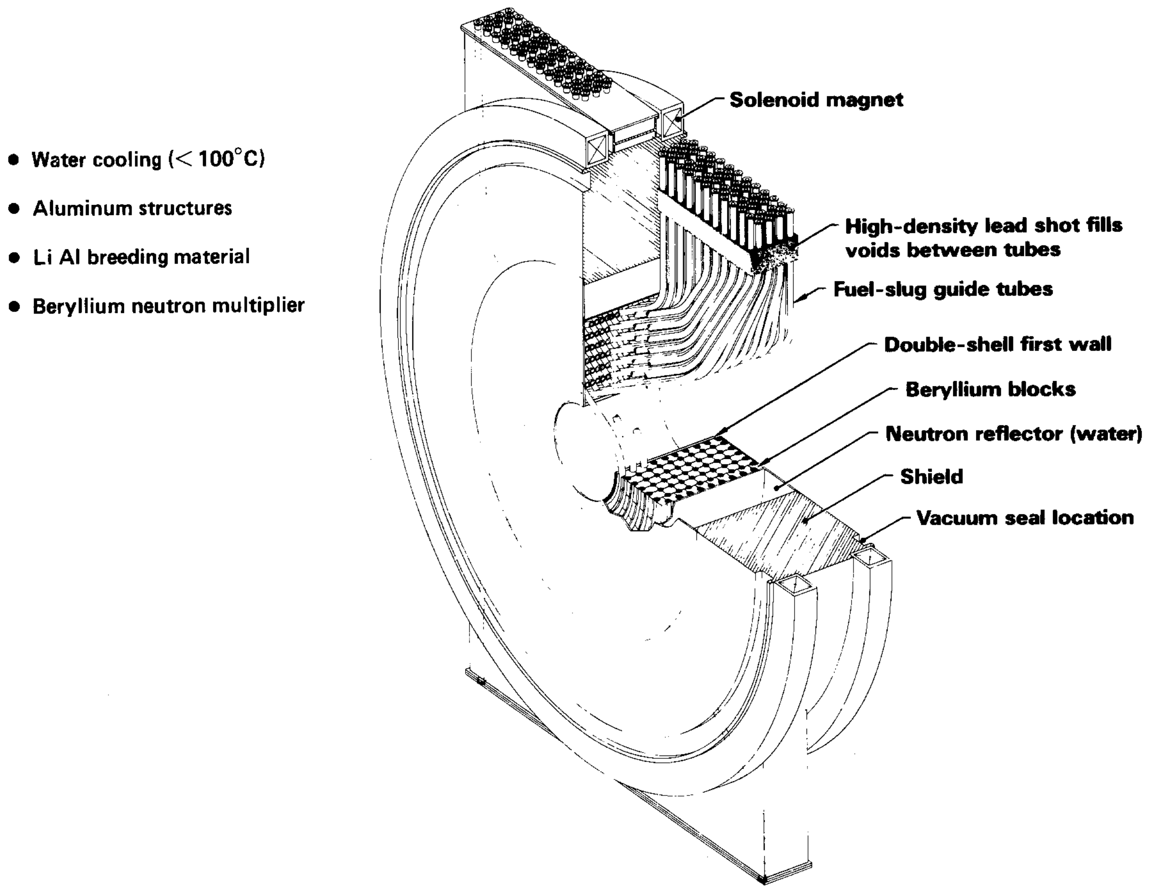

Fig. 5. Cross section of breeding blanket for tandem mirror production reactor.

no major issues with this blanket design other than those due to radiation damage resulting from the hard spectrum of fusion neutrons. Both beryllium and aluminum are predicted to become brittle and eventually crack. Because beryllium is not used as a structural material, careful design practice to accommodate considerable cracking should be possible. When the aluminum structural material loses its ductility and leaks develop as a result of cracking, we would replace the blanket with a new one. The double first wall is designed to allow for the detection of leaks due to small cracks before the leaks force shutdown of the reactor. The peak fluence of neutrons seen by the aluminum and beryllium after 5 years is 8×10^{22} n/cm^2; for energies over 1 MeV, the fluence is one-third this value. We have allowed for 5-year replacement (3.5 full-power years) of all the blankets. The tokamak production reactor (Fig. 4) uses the same blanket.

Fuel-Cycle Description

We have studied fuel-cycle characteristics for a magnetic fusion production reactor and considered two modes of operation—*T*MODE and *P*MODE—for a fusion power of 427 MW. *T*MODE produces a net tritium product of 10.8 kg/year, whereas *P*MODE produces a net weapons-grade plutonium product of 995 kg/year.

In *T*MODE the uranium stream and associated fissioning are eliminated from the system. The capital and operating costs for *T*MODE fuel-cycle facilities are estimated at $124 and $41 million/year, respectively.

In *P*MODE, the heavy metal throughput is only 142 Mg/year for a high-quality (1% ^{240}Pu) product. This low throughput may negate the need for a dedicated fuel reprocessing plant. The overall capital and operating costs for *P*MODE fuel-cycle facilities

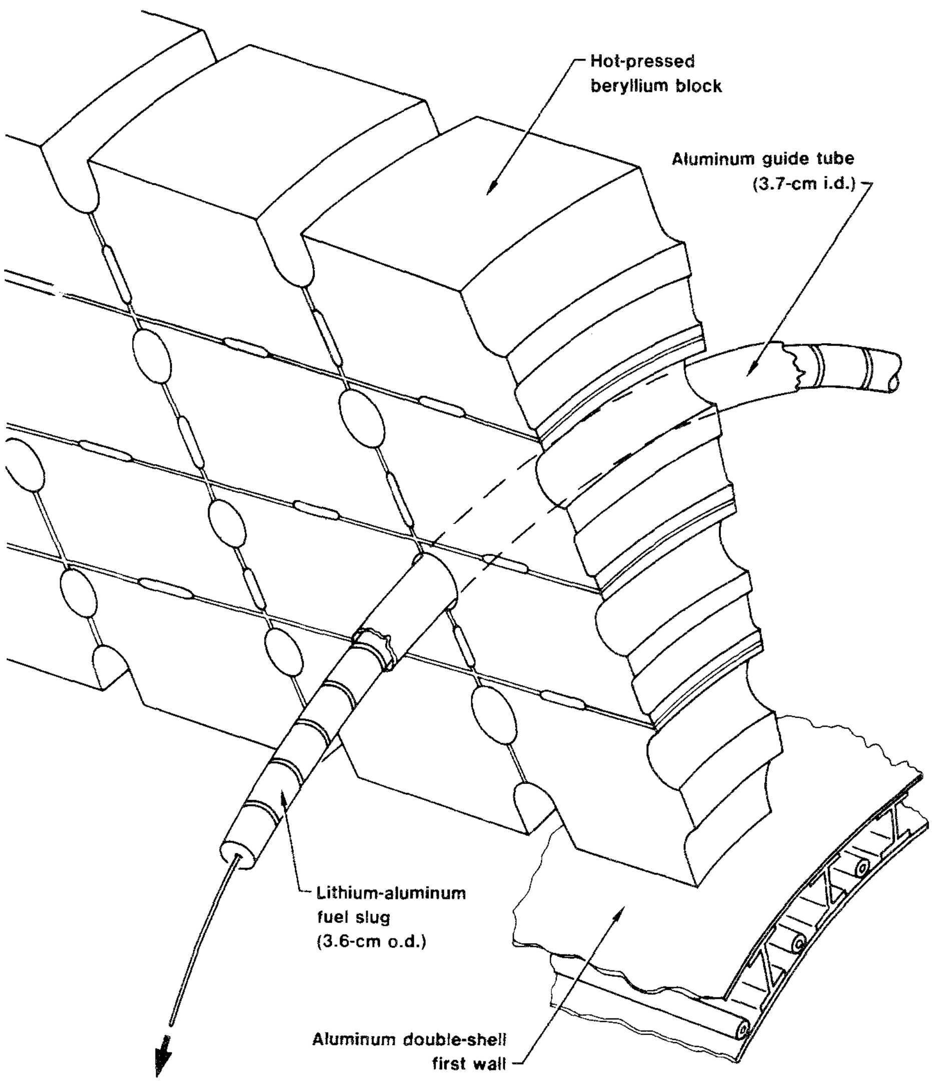

Fig. 6. Internal details of production blanket. The beryllium blocks are about 10 cm on a side. The double first wall is designed to provide early crack detection and thus enhance reliability.

are estimated at \$104 and \$67 million/year, respectively.

The selected fuel forms for both modes are similar to the aluminum-clad Li–Al and uranium metal targets employed in existing production reactors at Savannah River Laboratories and have a low developmental risk. Neither mode requires any fissile feed material whatsoever.

Cost Estimate

The cost of a fusion production reactor is highly uncertain because fusion technology has not reached the demonstration stage. At this time we can only make cost estimates of preconceptual designs. However, we expect the cost to be lower than that for a fission production reactor for three reasons: (1) the thermal or nuclear power is four to six times lower; (2) the power conversion and balance of plant systems run on cold water and do not employ any electricity-generation equipment; and (3) fewer fuel-cycle facilities will be needed, especially in *T*MODE, where we have no fissile or fertile material.

The cost breakdown by major components for the tandem mirror production plant is given in Table III. The cost for the tokamak (see Ref. 1) is only a

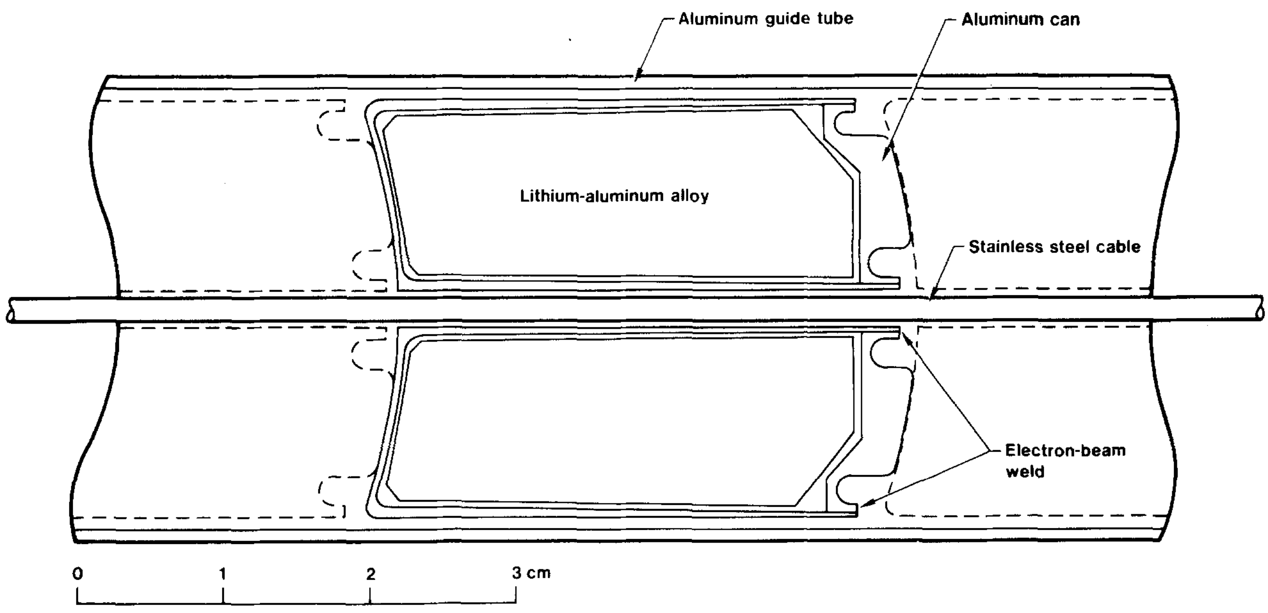

Fig. 7. Tritium breeding-fuel slug. In *P*MODE, a fraction of the slugs will have uranium metal in place of the Li–Al alloy.

few percentages higher. The capital cost of the reactor plus fuel-cycle facilities is given in Table IV, and the operating costs in Table V. The low indirect cost and low capital charge rates shown in Table V should be revised upward. The effect of increasing the size from the reference value on the cost of producing tritium is shown in Fig. 8.

Operating costs for the magnetic fusion production reactor are high because of the requirement to purchase electricity. The fusion reactor will consume 250 MW-years of electricity annually (400 MW-years for the tokamak), while the same production reactor candidate might sell about 500 MW-years of electricity each year. At a sales price of 23 mill/kWh and a purchase of 28 mill/kWh, the fusion case requires a \$60 million/year expense and the fission case benefits from revenues of about \$100

Table III. Direct Costs for a Magnetic Fusion Production Reactor[a]

Fusion components	878
Magnet systems (includes shielding)	
End cells	198
Central cell	84
Neutral beam systems	200
Microwave systems	100
Direct converter system	6
Blanket	86
Vacuum systems	20
Instrumentation and control	40
Tritium system	45
Remote fueling and maintenance equipment	74
Balance of plant	239
Buildings	
Containment	80
Auxiliary	50
Cooling system	65
Electrical system	44
Total direct cost	1117

[a]In millions of dollars, assuming a tandem mirror base case, *T*MODE operation, and a production rate of 10.8 kg/year at a 70% capacity factor.

Table IV. Total Capital Cost Summary for a Fusion Production Reactor[a]

Reactor and facilities	*T*MODE	*P*MODE
Reactor	1.4	1.4
Lithium target fabrication	0.04	0.02
Tritium processing	0.09	0.06
Uranium target fabrication	0.0	0.03
Purex reprocessing	0.0	0.0[b]
Totals	1.53	1.51

[a]In billions of dollars.
[b]We assume an existing reprocessing plant would be used because the throughput would be five times lower than the capacity of the Savannah River Plant.

Table V. Total Capital and Annual Costs ($millions) for a Magnetic Fusion Production Plant[a]

Capital plant costs ($M)		
Direct cost of plant	1115	
Indirect cost of plant	268	
Total cost of reactor plant	1383	
Total cost of Li–Al process plant	119	
Total plant cost	1502	
Annual plant costs		
Capital (6.5% of total plant cost)	97.6	(41%)
Reactor O & M[b] (2% of total reactor cost)	27.7	(11%)
Li–Al process plant O & M	38.0	(16%)
Blanket replacement (20% per year)	17.2	(7%)
Electricity (at 28 mill/kW hr)	59.2	(25%)
Total	239.7	

$$\text{Tritium production cost} = \frac{239.7\times10^6\$}{10{,}800\ \text{g}} = 22{,}200\ \$/\text{g}$$

[a]This assumes a tandem mirror base case and *T*MODE operation, where $P_{\text{fusion}} = 427$ MW, $T_{\text{net}} = 10.8$ kg/year, and electric power consumption = 355 MW. All costs are in 1982 dollars.
[b]Operation and maintenance.

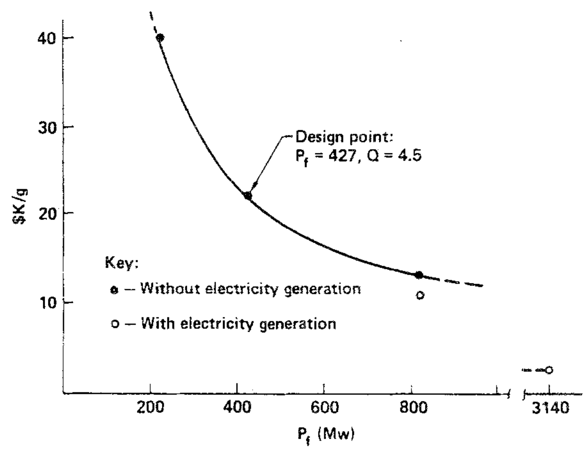

Fig. 8. Tritium production costs vs fusion power level, P_f (MW).

million/year. On a per-gram basis, the price differential is $16,000/g of tritium. However, the fission reactor cost for fuel purchase, fabrication, and reprocessing is expected to more than offset the electricity sales advantage. For example, Purex fuel reprocessing plants required for fission production reactors typically cost around one billion dollars. This cost component alone translates to around $65 million/year at a 6.5%/year cost of capital. See Ref. 2 for a discussion of economics.

Nuclear Analysis

The tritium breeding ratios[3] for the tandem-mirror-based and tokamak-based MFPRs are calculated to be 1.67 and 1.56, respectively. The blanket energy multiplication[4] is 1.3 in both cases. When the reactor is operating in the plutonium production mode, the plutonium plus tritium breeding ratio is 1.74. Blanket energy multiplication for the plutonium mode is 2.4, with a plutonium to uranium ratio of 0.7% and a uranium volume fraction of 3%.

[3]Breeding ratio is defined as atoms bred per fusion reaction, including one atom of tritium per fusion required to sustain the fusion reaction.

[4]Blanket energy multiplication is defined as blanket energy deposited divided by 14.06 MeV.

The breeding estimates for the tandem mirror take into account the leakage of neutrons out the ends, the tritium burned in the end cell where there are no breeding blankets to use the resulting neutrons, and various heterogeneous effects discussed in Ref. 3. The results of the calculations are given in Table VI.

Isotopic Purity

The isotopic composition of the plutonium produced in *P*MODE is given, in percent, below

^{236}Pu	0.0002
^{238}Pu	0.04
^{239}Pu	98.9
^{240}Pu	1.0
^{241}Pu	0.06

Safety

The main safety issue is the containment of radionuclides. In *T*MODE there are no fission products or actinides. The principal radionuclides will be activated structural material (mostly aluminum) and tritium. Since aluminum is a low-activation material, we expect discarded blankets to be disposed of on site in shallow burial. The bred tritium in the breeding blanket will be well contained in aluminum-canned Li–Al slugs similar to the form used successfully in the Savannah River reactors. The tritium in the fusion fuel cycle will be located on cryopanels (~100/g inventory) and cryogenic columnar isotopic separators (~100/g inventory) as well as in the plasma chamber, neutral beam injectors, and

Table VI. Neutronics Summary of Effective Breeding Ratios $(BR)^a$

	TMODE	T + PMODE
$T + F_{net}{}^b$	1.93	2.00
Corrections for		
Fuel slugs (−6%)[b]	−0.12	−0.12
Inlet/outlet plena[c]	−0.03	−0.03
Module ends[c]	−0.02	−0.02
Total corrections	−0.17	−0.17
Inleakage[b]	0.014	0.014
Blanket coverage (P_f blanket/P_f total)	0.937	0.937
T' (tritium consumption)	1.02	1.02

[a] $BR_{eff} = [(T + F_{net}) + \text{corrections}] \times (1 + \text{inleakage}) \times \text{blanket coverage}$. NET $BR = BR_{eff} - T'$. BR_{eff} equals 1.67 and 1.74, respectively. NET BR equals 0.65 and 0.72, respectively.
[b] Calculated with TARTNP.
[c] Geometrical estimate.

walls (<10/g inventory). The average tritium inventory in the fuel slugs is approximately 22 kg.

The large afterheat due to fission products in the fission production reactors could lead to a meltdown and release of fission products and actinides. However, in the TMODE case, both the afterheat and the large inventory of radionuclides other than tritium are absent. The result is that the safety problem is not only dramatically reduced, but different in quality. This greatly enhanced safety should result in a substantially reduced risk of adverse environmental effects, as well as a reduced risk to capital investment.

To a great extent, the above safety arguments still hold in PMODE because fission is suppressed and no fissile material is fed to the reactor; however, containment of the smaller but still significant inventory of fission products and actinides is required. Further design work is needed to adequately address this issue.

Construction Schedule

In our previous study of the MFPR we considered two developmental sequences that included a high-average-power fusion test reactor in which components could be tested for lifetime. The first sequence, which called for a test reactor of under 100 MW fusion power followed by construction of the 400-MW_{fusion} production reactor, placed great urgency on getting the test reactor started soon (we would now move the projected 1985 start date to 1986–1987). The risk of operating the production reactor at its design point would be lower than had been postulated, but its operating date would probably be delayed until about the year 2000. The second sequence employed a phased construction schedule, the first phase of which would check out the physics and then proceed to the burning of tritium and the production of blankets. The development and testing of components, especially blankets, would then be carried out by the machine itself. After a 3-year testing program, we envisage that full production could commence. Figure 9 shows the events that would lead to a full-production start date of 1996 in the second sequence. Although this sequence would

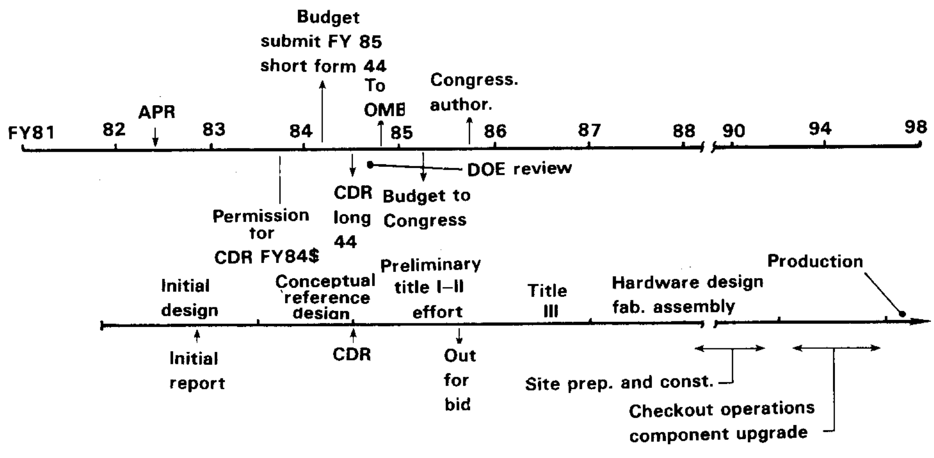

Fig. 9. Phased construction sequence leading to a production reactor that can operate in 1996 without a separate fusion test reactor.

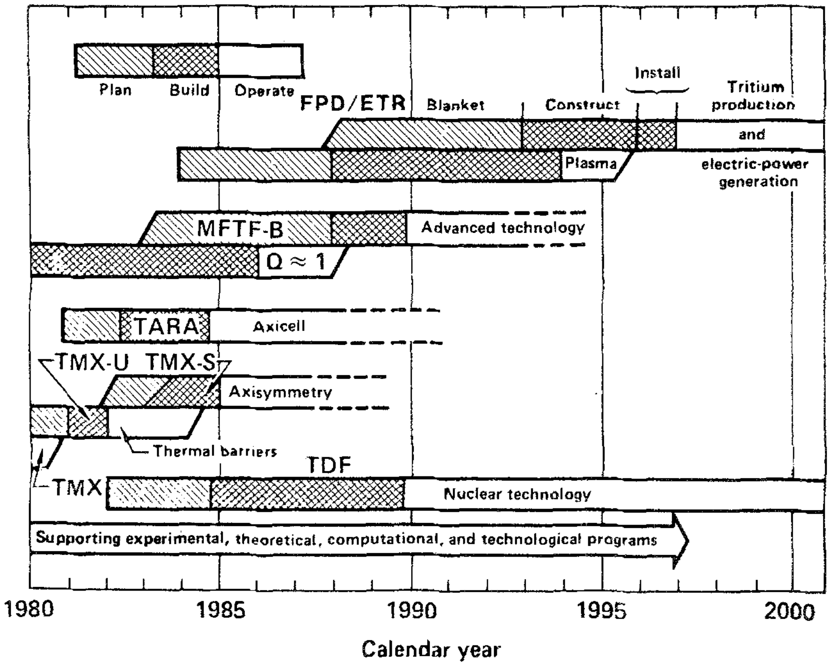

Fig. 10. Tandem mirror main-line sequence, showing (in order) the tandem mirror experiment (TMX), its upgrade (TMX-U), a symmetric-coil-set modified version (TMX-S), the Massachusetts Institute of Technology's TARA, the mirror fusion test facility (MFTF-B), and the fusion power demonstration (FPD), or engineering test reactor (ETR). The technology demonstration facility (TDF) could be built in parallel with the main-line sequence for engineering testing.

minimize both time and funds, there is a risk of possible nonperformance as a result of the early freezing of some parameters without adequate testing.

While both of the above sequences appear feasible, we prefer the sequence shown in Fig. 9. It seems clear, however, that the advantages offered by the MFPR over fission reactor options are not compelling enough for the Nuclear Materials Production Program to risk embarking on either construction sequence at this time. Within the Magnetic Fusion Energy Program itself, however, there is strong motivation to embark on one of these construction sequences as a separate mission within the next few years. Plans now being studied in both the tandem-mirror (Fig. 10) and tokamak (Fig. 11) programs are remarkably similar to a sequence that would lead to an operating MFPR in the late 1990s.

The tandem-mirror plan shows a phased construction program called Fusion Power Demonstration (FPD), which would lead to an operating reactor of 400 MW_{fusion} by 1994, with tritium production starting in 1997. The plan also shows the earlier and partially parallel construction of a small facility called the baseline Technology Demonstration Facility (TDF). The TDF (20 MW_{fusion}) has a direct cost of approximately $0.78 billion, while the direct cost of the FPD (400 MW_{fusion}) is significantly higher.

After the FPD plasma has been successfully operated starting in 1994, further risk should be minimal. The machine could be designed and constructed in the second phase as both a production and test reactor. For example, 5 of the 50 modules would be dedicated to long-time testing while the other 45 modules would be dedicated to the production of SNM. Of course, a host of test samples could ride "piggyback" as long as they didn't interfere significantly in SNM production. This sharing of facilities would lower both the capital investment of the Magnetic Fusion Energy and Nuclear Materials Production Programs and the operating cost of the Magnetic Fusion Test Program.

The tokamak program is looking for construction options before deciding what device to build next. A well-studied option called the baseline Fusion Engineering Device (FED) is not favored be-

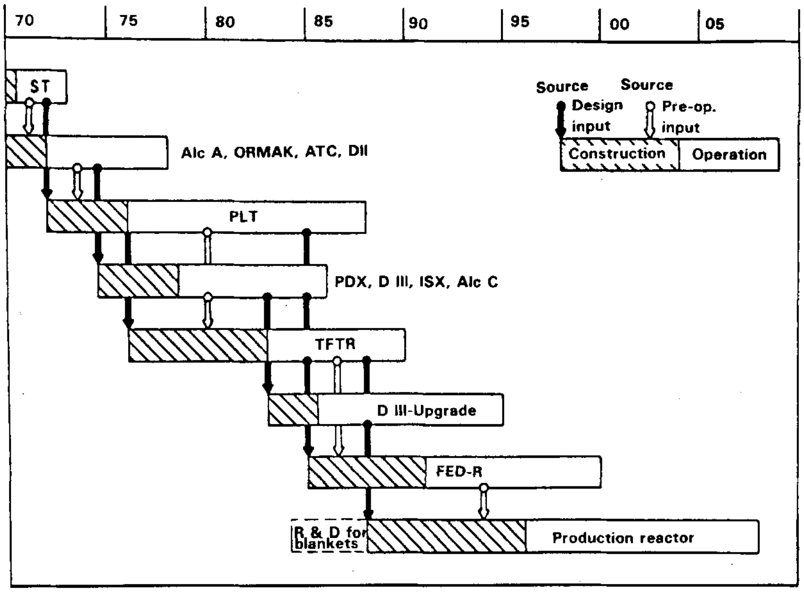

Fig. 11. Tokamak main-line sequence planned to result in a production reactor.

cause of its high cost (~ $2 billion) and high risk. Further FED studies were undertaken at the Fusion Engineering Design Center in Oak Ridge, Tennessee, on a resistive-magnet (rather than superconducting) version of FED, called FED-R.[7] The FED-R has a 3.5-m major radius, whereas our tokamak production reactor, which is essentially the same machine, has a 3.9-m major radius. The FED-R (75 MW_{fusion}) could be constructed in stages, as shown in Fig. 10, to turn it into a smaller production reactor (250 MW_{fusion}); with a moderate design change for Stage I, the FED-R could be upgraded to 400 MW_{fusion} in the second stage.

Present Department of Energy (DOE)/Office of Fusion Energy design efforts are concentrated on small ignition test reactors (ITRs). These devices would have short pulses and no nuclear test capability. Almost all current designs feature resistive demountable toroidal field coils, as in the tokamak MFPR. An ITR appropriately designed could be similarly upgraded to a tokamak MFPR.

The two conclusions of our construction schedule studies are (1) that fusion technology is predicted to be ready for late 1990s production of SNM, and (2) that possible next steps in the Magnetic Fusion program bear close resemblance to the production reactor, leading one to speculate that the next machine could be used first for fusion technology and later as a spinoff for the production of SNM.

Development Requirements and Status of Technology

The tandem mirror and tokamak technology development requirements for a materials production reactor that could be implemented in the 1990s are discussed in Ref. 4. The performance characteristics of the fusion plasma and the major technological subsystems for these two fusion drivers are compared with the present state of the art. The corresponding development needs are identified, and technology program requirements in addition to those now being supported by DOE are pointed out. The tandem-mirror and tokamak fusion drivers are also compared with regard to their required advancements in plasma performance and technology development.

Tandem Mirror Vs Tokamak

A magnetic fusion reactor can produce SNM using either the tandem-mirror or tokamak configuration. The tokamak MFPR consumes approximately 200 MW_e more than the tandem-mirror MFPR because of its resistive copper toroidal magnets. The blankets for the tokamak are also more complicated to service for fuel-handling operations. If we had a choice of configuration, we would choose the tandem mirror for the fact that its simpler blankets are easier to maintain, and the tokamak for its better physics performance to date. Although the configuration whose technology is demonstrated in a timely way will be preferred, either configuration appears workable.

CONCLUSIONS AND RECOMMENDATIONS

The tandem-mirror reactor may have enhanced scientific feasibility as a result of the TMX-U experiments in 1983. The scientific feasibility of the tokamak approach has been enhanced by large-scale experiments in TFTR and JET starting in 1984. We recommend that studies continue until significant scientific results from advanced machines are available. At that time, the program should be expanded to include a thorough study leading to a demonstration of the technology in a prototype reactor operating in the mid-1990s.

We should continue to evaluate the magnetic fusion approach to breeding because it is a better technology for production reactors of the next century.[5] This is because (1) no fissile fuel is needed, (2) the capital cost is probably lower than the cost of a new fission production facility, and (3) it is safer to operate because there are no fission products in the tritium production mode and minimal fission products and afterheat in the plutonium mode.

[5]The next-generation production reactor may, on the basis of present experience, be operating until the year 2040.

We recommend that the close resemblance between possible next steps in the Magnetic Fusion program and the MFPR be studied. This resemblance suggests that one facility could permit both fusion research and development and the production of SNM, saving both programs large sums of money and resulting in a superior production reactor.

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