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THE FUSION HYBRID REACTOR

MASTER

Sandia Colloquium by Hans A. Bethe
M. Moss (editor)

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THE FUSION HYBRID REACTOR

A Sandia Colloquium by Hans A. Bethe, September 19, 1980*

Dr. Sparks, Ladies and Gentlemen: I want to talk about the fusion hybrid. To begin with, let me say there are two types of this gadget. The purpose, of course, is to combine fusion and fission. The old idea of how to do this was to surround a fusion reactor (if such an animal ever works) with a blanket in which fissions take place so as to increase the energy produced by the reactor. The motive for that was, of course, that it was unlikely that fusion can be produced at the same cost per kilowatt hour as fission and, therefore, an enhancement of the energy seemed useful. The second version of the fusion hybrid is a fusion plant which produces fissile material which then serves as fuel for an ordinary fission reactor. The fusion reactor functions as a fuel factory, and whatever fissions are produced in the fusion reactor itself are secondary and, as I will show later on, probably harmful. I will only talk about the second type, mainly, where the fusion reactor is a fuel factory for ordinary fission-based power plants.

This is a good idea because the energy per fusion is only 17 MeV, and the energy per fission is 200 MeV. Of course, when I speak of fusion I always mean D-T (deuterium-tritium). The use of other types of fuel, like pure deuterium, is very far in the future, and it would be unrealistic to talk about it at the present time. The energy produced in one fission is eleven times greater than the energy produced in one fusion. The energy per neutron is many times larger in the fission reactor and, therefore, it is very sensible to use the neutrons of the fusion reaction to make fissile material.

*Transcribed from tape and edited by Marvin Moss, Div. 5824.

What are the advantages of such a hybrid scheme? First, of course, we need the performance of a fusion plant. The performance is commonly measured in terms of a quantity Q which is the ratio of the energy output to the energy input. The fusion reactors which are likely to operate during this decade are based on the idea of injecting neutral atoms of high energy (like 200 keV) into the fusion plant. This energy is much higher than the temperature (5 or 10 keV) to be achieved in the plasma. The atoms must be neutral; otherwise, they could not enter. The energy input is the energy required to provide these energetic atoms; the energy output is obtained from the nuclear reaction in the plasma.

In the first experimental fusion reactors, we probably will reach a Q which is much less than one, so that less energy comes out than was put in, in terms of energetic neutral atoms. Later we might reach a Q of one, and still later, much higher Q's like 10 or more. Only if we get to a value of Q of at least 5, let us say, does the fusion plant by itself make any economic sense. More energy must be produced than was put in, or it is of no use. On the other hand, for the fusion hybrid, a Q of one is ample, and that is what I am going to demonstrate as part of this talk. The hybrid makes less demands on the fusion reactor and, therefore, we can at an earlier time expect to have a fusion reactor which is suitable as a fuel factory.

The second point is that this would be a fuel factory for ordinary fission reactors. I'll discuss that in more detail soon, but the general idea is that sooner or later we will run out of U^{235}, and we will need some other way of making fissile fuel. The standard way, of course, is the breeder reactor, and, therefore, the fusion hybrid is its competitor.

The third point is that the fusion hybrid might help establish a system which is resistant to proliferation of nuclear weapons, and this is very important to President Carter. I'll come back to that also.

I want to mention that recent studies, which I will discuss in the second half of my talk, favor a minimum amount of fission in the blanket which reduces our problems. Let me first talk about the need for fuel for fission reactors. Our supply of uranium oxide (yellow cake) seems to be quite ample; it is estimated to be four million short tons of U_3O_8. One light-water reactor needs about 6000 tons of this material for its full life of 30 to 40 years. Even with no reprocessing, as is our present doctrine, the uranium ore which we have will, therefore, be enough for 700 light-water reactors. From the way the nuclear business is going, I estimate that by the year 2000 we will have no more than between 200 and 300 light-water reactors. We can easily fuel those for life without reprocessing, without breeders, and without the fusion hybrid. Only much later will we reach the 700 number. Other countries, of course, are much less fortunate. They have less uranium oxide available and they are more vigorous in pursuing nuclear power. Therefore, for other countries the manufacture of fuel will be important.

Slide No. 1 is due to investigations of Dr. C. E. Till at Argonne and Dr. P. R. Kasten at Oak Ridge National Laboratory. This slide shows how many reactors can be supplied by different procedures if four million tons of uranium oxide are used. With the light-water reactor there is the possibility of 670 reactors. With recycled uranium, but not plutonium, it is 870. With the high-temperature graphite reactor, it is about the same without recycling; with recycling, the number is a little over 1000. If a really powerful converter is used (it would probably have to be the heavy-water reactor, but Dr. Kasten believes that it can also be the high-temperature graphite reactor) it is 1500.

Now that is a goodly number, but at some point the uranium supply will come to an end. With the reuse of plutonium we get a little over 2000, and the Argonne people estimate quite a lot more for the heavy-water reactor with a conversion ratio of 0.9.

Slide No. 2 assumes we have breeders in which some excess fissile material is produced which is then used in converters, that is, light- or heavy-water reactors. If we have a breeder with plutonium oxide, and use the light-water reactor as a converter, and uranium for the fertile material so that plutonium is produced in the breeder, we can calculate the ratio of converters, that is thermal neutron reactors, to the number of breeders. That ratio is interesting economically, because it is almost certain that a breeder will be more expensive per kilowatt than a converter reactor, and therefore, the more converter reactors there are per breeder, the better. Unfortunately, the number is deplorable -- only two converter reactors for three breeders. With our uranium supply we could reach an equilibrium of 1000 reactors (some breeders and some converters) which seems to be a good number. (A reactor in my slides always means a gigawatt reactor.) It would be better if, for the converter, we use a heavy-water reactor like the CANDU, and for the fertile material, thorium, which is converted by neutrons to U^{233}. U^{233} is a much better material for a thermal reactor than plutonium and, therefore, there would be almost three converters for each breeder, which would be a great advantage.

In addition, there is the proliferation argument. This was first published by T. B. Taylor and H. A. Feiveson of Princeton in the December 1976 Bulletin of the Atomic Scientists in which they assumed that there are, indeed, producer and burner reactors. They were worried that if breeder reactors, especially, were given to non-nuclear countries, those countries would be tempted to remove the fuel and convert the plutonium into bombs. That, of course, is something we want to avoid; we want to reduce the possibilities for proliferation of nuclear weapons by means of reactor fuel.

The trouble with this is, at least as long as we use light-water reactors, it simply doesn't work. The breeders would be located in the nuclear countries -- United States, England, France -- and the converters in the non-nuclear countries. Then surely in the long run the demand for power in the non-nuclear countries will be much higher than in the nuclear countries. Therefore, if there is only two-thirds of a converter reactor for one breeder, it just doesn't work, since one couldn't sell the electricity in the breeder countries, and there wouldn't be enough in the converter countries. We must also consider the conclusion arrived at by the International Nuclear Fuel Cycle Evaluation (INFCE) group: it is very difficult to distinguish between different reactors as to their proliferation dangers. The idea is still useful and I am going to continue talking about it. Because of the proliferation possibility, I will emphasize the thorium cycle which makes U^{233} which can be mixed with ordinary natural uranium to get a mixture which cannot be used to make bombs without isotope separation.

Slide No. 3 goes through the actual functioning of a hybrid. I assume that the fusion reactor is surrounded by a blanket whose main ingredient is thorium. There must, of course, also be some lithium to reproduce the tritium, but I focus particularly on the thorium. Out of the fusion reactor come neutrons of 14 MeV. For low-energy neutrons (below about 7 MeV), most of the neutrons would be inelastically scattered (indicated by n', the lower-energy neutron) and a few of them would make fission. Above 7 MeV we get a very probable reaction where one neutron makes two, and both of these will then be available for capture in the thorium blanket. That is one big advantage of, instead of one 14 MeV neutron, getting two of lesser energy. Once the neutron energy is as high as 14 MeV, there is even some chance of getting three neutrons from the collision. This, therefore, multiplies the neutrons in the blanket, which increases the chances of getting fissile material from it.

People have made calculations (especially at Livermore, but also at other places) which indicate (Slide No. 4) that for each fusion neutron there is produced about 0.6 U^{233} atom. If we use uranium in the blanket, the amount of plutonium we get is somewhat greater than that of U^{233} from thorium, but we will soon see that this doesn't do much good. It is always assumed that, at the same time, something like 1.1 atoms of tritium are produced for every fusion reaction, because the tritium is needed to keep the fusion going. Some people have wondered: If so many neutrons are used to make tritium, what about the D-D reaction? The answer is two-fold; one is that the D-D reaction is far in the future, and the second is that in the D-D reaction we get neutrons of about 3 MeV instead of 14 MeV, and therefore, there is no multiplication of the neutrons in the blanket. Therefore, we are no better off with the D-D reaction than with the D-T.

The important quantity is G, the number of U^{233}'s produced for each T-D fusion. But then we must consider that there are fissions in the blanket (I showed the curve of the fission cross section), and each of these fissions makes a lot of energy. Therefore, we must also consider M, the total amount of power divided by the amount of fusion power. All power must be dissipated, both that from fusion and from fission. Dissipation of power, whether it is used afterwards or not, is expensive. What really counts is not the number of U^{233}'s which are made per unit of fusion power, but the number made per unit of total power. Therefore, the ratio G/M is very important, which is clear from this slide. If we use uranium in the blanket instead of thorium, or make the blanket entirely of uranium, then we obtain a higher G, but also a higher M and, in fact, the two just compensate; G/M is about the same as it was with thorium. Therefore, there really is no advantage in using uranium/plutonium. The thorium has the advantage that U^{233} is the best fuel for a thermal reactor, which is what we want to feed. With all of these assumptions, a standard fusion reactor of 3000 MW thermal power will produce 1500 kg of fissile material per year, in addition to reproducing the tritium. This takes into account that there are holes in the blanket which let some of the neutrons escape, and that the plant works only about 75% of the time.

Slide No. 5 shows what is required by a standard light-water reactor, also at 3000 MW thermal and 1000 MW electrical. It needs approximately 400 kg a year if it is fed with plutonium. We can make 1500 kg of fissile material in a fusion plant of the same power. If U^{233} is made, we need only 300 kg of feed. Therefore, five light-water reactors can be fed with a single fusion fuel factory. With an advanced converter (the heavy-water reactor), these numbers are divided by three. This is assuming a 70% plant factor for the fission reactor, and I mentioned before that the fusion reactor has holes which let some of the neutrons escape.

The main attraction then of the fusion hybrid compared with a breeder is that one fusion hybrid supports quite a number of normal light-water reactors. Slide No. 6 gives this number. The hybrid with a thorium blanket will support 5 light-water reactors and permanently produce the fuel for them, or 15 advanced reactors. A breeder will only support 0.7 light-water reactor or 2.7 advanced reactors. Therefore, the fusion hybrid is at least five times as efficient in breeding fuel as a breeder. Then the Feiveson-Taylor proposal can be carried out. Very few fuel factories can be located in countries which already have nuclear weapons (they might be put under international control, if we like), and the user or burner reactors would be all over the world. The fusion hybrid would serve only as a fuel factory and rather few of them would be needed. This could be used for a proliferation-resistant nuclear fuel cycle. The fusion hybrids would be associated with chemical reprocessing plants, and possibly plants to fabricate nuclear fuel. The fusion hybrid, therefore, is an existence proof for the establishment of a proliferation-resistant scheme. The U^{233} can be mixed with depleted uranium so that it is even less attractive as a bomb material. The support ratio which I have given here does not depend on the cost of the fusion hybrid. Cost has not come into the consideration at all; no matter how expensive the fusion hybrid, this support ratio will hold.

Now I come to the new development at Lawrence Livermore Laboratories where they have worked very hard on these problems. Two papers by J. D. Lee and R. W. Moir embody the idea of producing as few fissions as possible in a blanket, which has two advantages. One is that it minimizes the total energy of the fusion device per fusion, with the multiplication ratio M going down to just a little over one. This, therefore, reduces the cost of the fissile material produced. Second, it minimizes the radioactivity in the blanket. One of the troubles with the hybrid that the fusion people object to is that their pure gadget gets dirtied by the fissions in the blanket. If fission is minimized, so is the radioactivity. This also improves the safety of the device because it reduces the after-heat if and when the fusion plant is shut down.

Minimum blanket fission is achieved by having an inner blanket made of beryllium. Beryllium is a nice substance; it has an n,2n reaction and a neutron binding energy of less than 2 MeV so that many neutrons are able to make a second neutron in it. Beryllium, of course, does not create any radioactivity and still it multiplies the neutrons. Outside the inner blanket there is another one which contains the thorium and lithium. The lithium makes tritium and the thorium makes U^{233}. The beryllium slows the neutrons so that only very few of them can produce fissions in thorium.

In doing all this, Lee and Moir can achieve a performance similar to that with a pure thorium blanket; that is, the number of fissile atoms produced per fusion reaction is the same. Now they go one step further; they eliminate the U^{233} from the blanket. The U^{233}, once it accumulates will, of course, fission when hit by neutrons, and will contribute to what we want to avoid -- energy production in the blanket. This difficulty would increase the longer the reactor works. To avoid this they proposed a circulating molten salt for the thorium blanket, one composed of lithium fluoride and thorium fluoride. Outside the blanket the salt would pass through a chemical reprocessor which would remove the uranium and the fission products. This chemical process is possible. A similar idea involving molten salt was proposed and developed at the Oak Ridge National Laboratory for a thermal neutron breeder. In that role it never was any better than marginal, because the breeding ratio was something like 1.04, which is a miserable number. There were also other difficulties.

In the present application I think it is a very good idea. The salt is circulated to extract the uranium; if the fission products are extracted at the same time, so much the better, but it isn't absolutely necessary. Furthermore, now only abundant materials, namely thorium and lithium, are circulated. Fissile material is not circulated to any appreciable extent; this is, in fact, what you take out in the chemical reprocessing. Finally (and to me the most important difference between the Oak Ridge molten-salt proposal and this one), in the Oak Ridge plan all this had to be done in an energy-producing utility. Therefore, the utility would have been saddled with a chemical plant, and no utility wants that. Here, instead, there are very few plants of this type. They would be run by a contractor for the government, and I will soon show how few we shall need. It is totally reasonable to have a chemical plant within the factory for nuclear fuel. Another advantage of this idea is that it keeps the power in the blanket constant during the life of the system because the U^{233} has been eliminated, and, therefore, we don't get any appreciable number of fissions from it. With the pure thorium blanket the power in the blanket would increase, and provision would have to be made for getting rid of it.

Slide No. 7 shows the basic device which Livermore has developed for a fusion plant; this is not yet a hybrid. In Livermore, fusion is achieved by a so-called "mirror device" which has both a maximum B-field and a minimum B-field in succession. At one end the maximum B-field reflects the ions and electrons which go through the plasma. In the middle there is a long cylinder, and at the other end another mirror device. This is called a tandem mirror. It has worked on relatively modest power, and in my opinion it is a very promising device. These curves show the magnetic field and electric potential at various points. The cylindrical main part of this is, of course, ideal for being surrounded by a blanket. This is why it is so suitable for a hybrid.

Slide No. 8 gives the parameters for the hybrid. It is a big installation of about 6 m diameter and about 100 m long. The wall will be loaded at 2 MW/m^2 which is very tolerable. It keeps the neutron damage to the inner wall well in bounds. Shown are the length, the radius, the blanket thickness, the wall load and the capital cost. In each case, for the thorium blanket as well as for the beryllium blanket, the plant has a total thermal power of 4000 MW. It is, of course, more expensive with the molten salt because there is a larger amount of fusion power which is more expensive to produce, and one needs the chemical plant as well.

Slide No. 9 compares the two blankets. The fissile breeding is 0.8 atom per thermonuclear reaction. The energy multiplication is much smaller for the beryllium-molten salt blanket as I have explained (only 1.6 compared to 5.2) and therefore, the manufacture of fissile material per unit energy is much better in the Lee-Moir device. The fusion power is 2700 MW versus 800 MW, and the remainder is fission power up to 4000 MW. The net electric power which is extracted is substantial in the case of the thorium blanket which is cooled by helium, and is very small in the case of the beryllium-molten salt blanket. This doesn't matter very much as the produced electric power is not a major part in the economy because, as I have said, so few of these devices would exist in an equilibrium economy. The aim of having low fission would have been achieved.

Slide No. 10 is the most important as it gives the actual performance of the hybrid. The number of greatest importance is the fissile production in kilograms per year. In the old design it was only 1500 kg/yr, but with the Lee-Moir design we get a fissile production of over 9000 kg/yr. Therefore, we have a simply wonderful support ratio. An enormous number of ordinary light-water fission reactors, namely 23, can be supported with a single fusion hybrid. That is the reason very few hybrids will be needed. Therefore, it doesn't matter if they are very expensive, and they may be combined with the nonproliferation idea of Feiveson and Taylor. A single fusion hybrid can support 70 advanced heavy-water reactors, if they were used.

The next line gives the cost of the fissile material: $60 per gram for the beryllium-molten salt reactor. We now can calculate the cost of electricity from the light-water reactors. This is a much lower number than I usually use because the two gentlemen from Livermore have chosen a capital charge of 6.74%, whereas I choose 16% which is appropriate for present interest rates. They argue, quite correctly, that one should do accounting always in constant dollars, and when you do so you should use interest rates which correspond to constant dollars (which my banker son says is about 3% per year). The 6.74% is not as unreasonable as it sounds at first.

The total cost of light-water reactor electricity will be 2¢/kWh, which includes the cost of the fuel. For comparison, at present it costs 6¢/kWh for the oil in an oil-fired plant; this does not include anything for maintenance or amortization. The last item gives the fraction of the cost which goes into making the fissile material. It is one sixth; that is, most of the cost is in the light-water reactors, and only 17% is in making the fuel.

Still more significant, perhaps, is the question, "When do you break even?" At present we use uranium from the mine, and do isotope separation. The cost of uranium from the mine used to be $8/lb and is now about $40/lb. When it goes to $90/lb, the uranium from the mine would be just as expensive as getting the fissile material from the hybrid. With this low fission-fusion hybrid it would not be necessary to use advanced heavy-water reactors. In fact, it is believed that the heavy-water reactors or graphite reactors are more expensive than light-water reactors by about 20%. Therefore, if the fuel represents such a small fraction of the total cost, and remains so even when we exhaust the presently available fissile material, then there is essentially no point to the heavy-water reactor from the standpoint of cost.

Slide No. 11 refers to fast breeders making the fissile material, and I again assume an economy in which there are fast breeders and light-water reactors. The total cost of electricity production -- and here, of course, some of the electricity is produced by the fast breeders themselves -- is about 1.33 times the cost of running the light-water reactors alone. That is to say, the production of the fissile material in the fast breeder adds 33% to the cost of just building and running the light-water reactor. This is based on the pessimistic assumption of a light-water reactor with a conversion ratio of 0.6, and a fast breeder with a breeding ratio of 1.2. What I want to show is that with the expected cost of a fast breeder, which is assumed to be 1.5 times the cost per installed kilowatt of a light-water reactor, the fusion hybrid does better than the fast breeder -- not greatly so, but noticeably.

Finally, what is the role of the hybrid in the fusion system itself?

1. Many people are worried about keeping fusion pure and not getting involved in the fight over fission power, and I can sympathize. It is an important consideration, and this argues against using any type of fusion hybrid. The Soviets have no such qualms as they see great demand for nuclear fuel everywhere, and they want to satisfy it by using fusion hybrids.
2. The hybrid promises a much earlier commercial reward for fusion, and this is important for keeping money supplied for fusion development. Congress may get tired of appropriating funds for fusion if the goal of economic power is many decades in the future; this would bring the rewards very soon.
3. The hybrid need not distort the progress of pure fusion development. It is true that the tandem mirror is not the preferred and best fusion device now known. It is behind the tokamak, but we can use a breeding blanket around the tokamak, too; this has been investigated by Westinghouse. It is not as good as with the tandem mirror, but it is good enough.
4. The hybrid would provide engineering and operating experience in fusion reactors.
5. When fusion reactors are first built they will be very unreliable. They may work, perhaps, only 20% of the time, which is useless for a power station, but still very useful for making fissile material. Fissile material is made whenever the device runs; steady operation is not needed.
6. To supply enough fissile material for fission reactors we need very few fusion hybrids, perhaps a total of 10 to 50 for the United States. The investment and time scale for this is quite moderate compared with a

buildup of a pure fusion economy for which the investment and, therefore, the time scale would be enormously long.

I have given you a sales talk. I don't mean to imply that I want the United States to go immediately into fusion hybrids. I do mean that the fusion hybrid should be considered as a very important option along with pure fusion and pure fission.

Supplementary reading:

H. A. Bethe, Nuclear News 21 No. 7, 41 (May 1978).

H. A. Bethe, Physics Today 32 No. 5, 44 (May 1979).

J. D. Lee, Lawrence Livermore Laboratories Report No. UCRL-84018 (preprint, April 1980).

J. D. Lee and R. W. Moir, Lawrence Livermore Laboratories Report No. UCRL-84104 (preprint, April 1980).

NUMBER OF REACTORS WHICH CAN BE SUPPLIED WITH FUEL USING 4 MILLION TONS OF U_3O_8

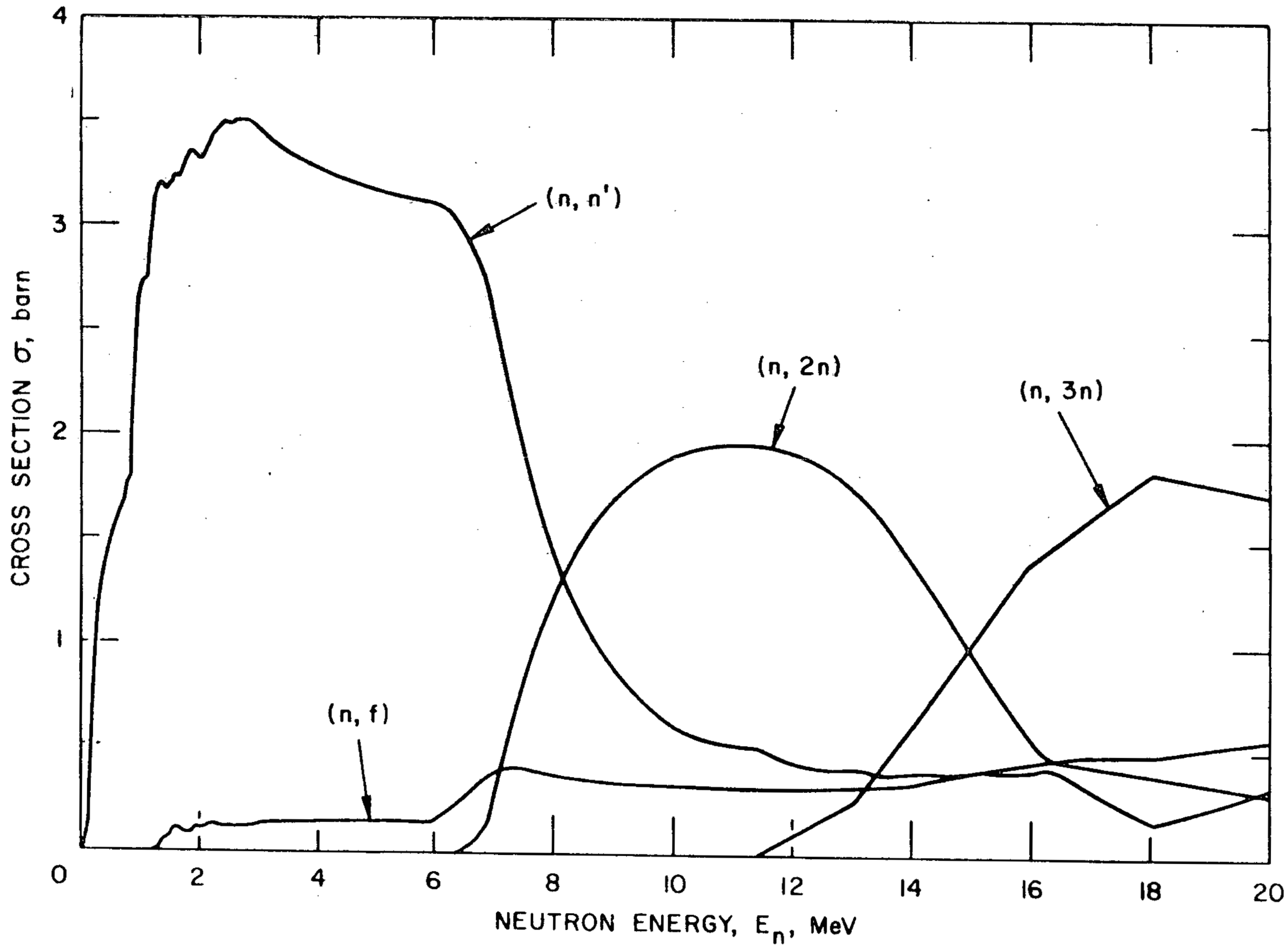
	ORNL	ANL
LWR ONCE THROUGH		670
LWR, U RECYCLE	870	
HTGR (0.66) ONCE THROUGH	895	
HTGR, RECYCLE	1,060	
HWR OR HTGR (0.90)	1,470	2,520
WITH REUSE OF PU		2,070

SLIDE 1

BREEDERS & CONVERTERS

BREEDER	CONVERTER	NO. OF CONVERTERS / NO. OF BREEDERS
OXIDE	LWR, U	0.67
OXIDE	HWR, TH	2.75
CARBIDE	LWR, TH	1.12

SLIDE 2



Reaction cross sections of Th^{232} as given in ENDF/B-V.

SLIDE 3

PERFORMANCE OF FUSION HYBRID

G = NO. OF U-233 PRODUCED PER TD FUSION

$$M = \frac{P_T}{P_F} = \frac{\text{TOTAL POWER OF HYBRID}}{\text{FUSION POWER}}$$

1.2 ATOMS T PRODUCED PER TD FUSION

FOR TH BLANKET: $G \approx 0.6$, $M \approx 2$

IF U INCLUDED, BOTH G AND M ARE HIGHER.

SLIDE 4

PRODUCTION AND CONSUMPTION

STANDARD PLANT OF 3000 MWE

HYBRID PRODUCES ABOUT 1500 KG FISSILE

NET CONSUMPTION (REQUIRED MAKEUP) OF FISSILE:

	U-233	Pu-239	
ADVANCED CONVERTER	100	150	KG
LWR	300	400	

ASSUMING 70% PLANT FACTOR

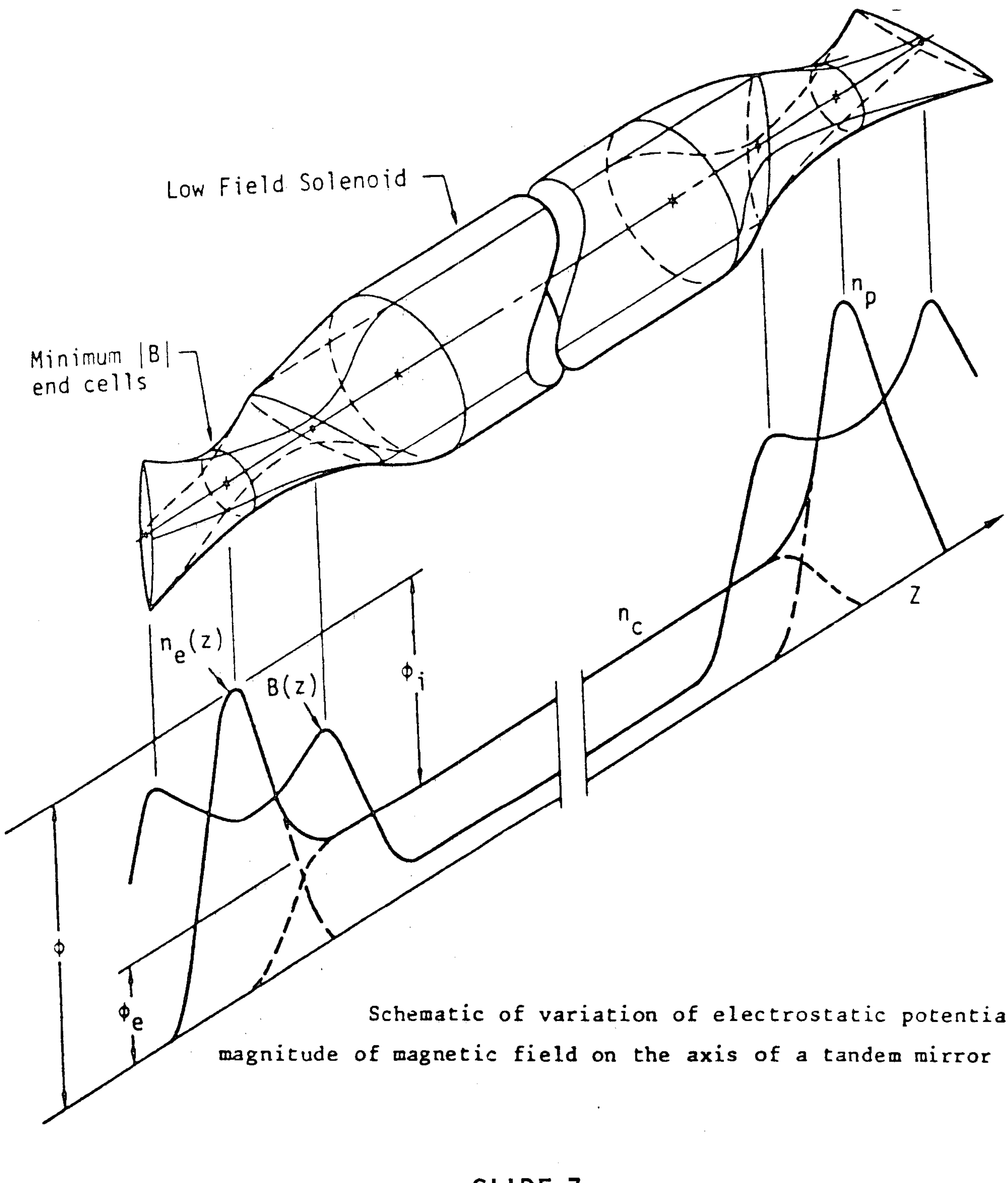
70% GEOMETRIC COVERAGE OF HYBRID

SLIDE 5

SUPPORT RATIO

Converter:	LWR	Advanced
Hybrid with Th	5	15
Hybrid with U	3.75	10
Fast Breeder	0.7	2.7

SLIDE 6



Schematic of variation of electrostatic potential and magnitude of magnetic field on the axis of a tandem mirror device.

SLIDE 7

Hybrid Parameters

Blanket	Th + Li_2O	Be
Coolant	He	Molten Salt LiF + ThF_4
Length (m)	35	80
Radius (m)	2.0	2.1
Blanket thickness	0.6	0.8
Wall load (MW/m^2)	1.5	2.0
Capital Cost (M$)	2000	4125

SLIDE 8

FUSION HYBRIDS

BLANKET	TH/HE	BE/MS
FISSILE BREEDING	0.83	0.81
ENERGY MULTIPLICATION	5.2	1.58
PLASMA Q	2.0	2.2
FUSION POWER (MW)	810	2730
NET ELECTRIC POWER	890	360

SLIDE 9

Hybrid Performance

Blanket	Th/He	Be/MS
Fissile production (kg/y)	2910	9550
Support ratio (LWR/hybrid)	7.2	23
(HWR/hybrid)	22	70
Hybrid fissile ($/g)	70	60
LWR electricity (c/kWh) total*	2.1	2.0
Fissile fraction (%)	20	17

*6.74% capital charge

SLIDE 10

Cost Relative to LWR

	Fast Breeder		Fresh U_3O_8
Breeding Ratio	1.2	1.4	\$200/lb
LWR, C = 0.6	1.33	1.25	1.355
C = 0.7	1.30	1.22	--
Advanced, C = 0.9	1.33	1.30	1.35

NOTE : The total cost is given for a burning reactor, including its fuel supply, relative to the cost of an LWR without fuel. The first two columns consider a fast breeder with two different breeding ratios, the last column considers that fresh U_3O_8 has to be bought at a cost of $200/lb. Three different converter reactors are considered, an LWR with a conversion ratio of 0.6 (about the present) and 0.7 which might be achieved with U-233 fuel, and an advanced reactor (presumably heavy water) with a conversion ratio of 0.9.

SLIDE 11

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