PREPRINT UCRL-

Lawrence Livermore Laboratory

[illegible] for [illegible]

[illegible]

October [illegible], 197[illegible]

This paper was presented [illegible]

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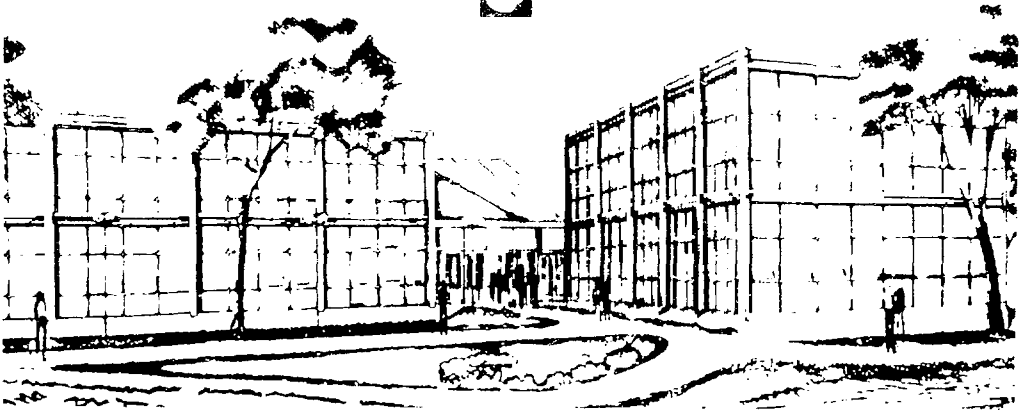

MASTER

[illegible] Talk, [illegible]
[illegible] October, [illegible]

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[illegible] economic position [illegible] independence and to our national security.

What I have to say tonight will not contribute directly to the solution of our immediate energy problems. But I hope it will help to put our present transition period in perspective, and therefore help clarify our thinking about it, by showing you that there is a solution to our energy problems that can be attained if we will but have the foresight (and the patience) to work and plan toward it.

In fact another title for this talk might have been "Our Energy Future" - with a subtitle "How to Beat the Numbers Game".

I will indeed be talking about a future source of energy - fusion energy (not to be confused with fission energy), and I will be talking about aspects of our energy requirements. Along the way I will be referring to some technical issues - but this will be mainly by way of making a point. That point is that our energy future - and by that I mean our children's, and our children's children - and countless generations after that - will involve a need for energy resources that are enormous compared to all the energy that man has used since the dawn of history. But that fact need not mean that the pessimists will come into their own - I claim that there is real reason to be optimistic about our energy future - provided we face the facts - the quantitative facts - of the energy problem with realism, and not instead kid ourselves about the numbers involved.

Aldous Huxley said "Facts do not cease to exist because they are ignored" - and that statement is certainly true about the whole energy/environment issue that we find ourselves involved in today. We are in some sense finding ourselves in a similar position to that of the king in the legendary story where he asks his wise man to name a reward for his services. The wise man makes a simple request: That the king should give him the number of grains of wheat that would be represented by putting one grain of wheat on the first square of a chessboard, twice that number on the second, and so on. The first [illegible] squares, were easy [illegible] the time he [illegible] to the 64th square he would have had to put up [illegible] world annual wheat harvest.

[illegible] compound interest. [illegible] that they wouldn't [illegible] 100 dollars [illegible] the American [illegible].

We are feeling the [illegible] compound interest" in the matter [illegible] ago, the world annual [illegible] grown at a steady rate [illegible] percent [illegible] times what it was [illegible] world [illegible] and the [illegible] transporting, refining, [illegible] time [illegible] that we [illegible] about the problem.

To repeat [illegible] there are two kinds of responses to this [illegible]. Both [illegible] as far as they go - but neither taken separately can solve the basic problem. The first response is conservation. Conservation buys time in the same way that a sound family budget conserves our money resources - but it does not itself solve the problem. The other solution is to look for new energy resources that can supply the increased demand without early depletion. - That solution is OK provided you eventually face up to controlling the demand to a level that the environment can sustain.

What I am going to be talking about is that second approach - the quest for a new source of energy, one that can easily sustain all our energy needs for millions of years to come, and yet if used prudently one which will not poison our environment or create unstable political or economic tensions in the way that the world petroleum situation is now doing. As I have already said, I am going to be talking about nuclear fusion - one of the ultimate energy sources that a kind God has provided for man to use.

Fusion energy really comes in two forms - natural and manmade - and in my talk I will concentrate on the manmade kind. These days we hear a lot about natural fusion energy - that is, solar energy. I think that solar energy will have some important uses, but I cannot agree with those who feel that solar energy can alone supply man's future energy needs. I do believe that it can help to conserve other energy sources when it is used for heating water, or for heating or cooling buildings, but I do not believe that it can turn the wheels of industry and of transportation in a world where we would hope that everyone will be able to share the good life that we here have known because we have in the past had abundant sources of energy.

So, at the risk of too quickly passing over one of our guaranteed long-term energy sources, I would like now to discuss manmade fusion as an ultimate energy source.

Nuclear fusion is nuclear combustion, that is it is the burning of a nuclear fuel consisting of a light element - in particular a special form of hydrogen. Nuclear combustion is accomplished by raising that

[illegible]

[illegible]

[illegible] would cost a few cents [illegible] energy, when converted to [illegible] with electricity [illegible].

Another way to put the potential of fusion in perspective is to consider [illegible] water [illegible] normal flow rate. If this stream of water was used as the feedstock for a heavy hydrogen separating plant, a trickle of heavy hydrogen would come out of the end of the plant. But this trickle would represent enough heavy hydrogen to supply <u>all</u> of the present day energy needs of the entire world. Contrast this "mining" problem with that for coal!

II) Fusion Basics

Granted that fusion could supply our future energy need, what do we have to do to achieve it? We have to accomplish on earth what the sun does - but on a bit smaller scale. Specifically, we have to take a small quantity of fusion fuel, heat it to its ignition temperature - 100,000,000° or more - and confine this heated fuel without allowing it to touch anything material (which would immediately quench the reaction) long enough for the fuel to release more energy from fusion than it took to heat up the fuel [illegible] in the first place. The key issues are therefore heating and confinement.

Again it is the huge numbers involved that represent both the promise of fusion and the problem of achieving it. - The payoff is tremendous, but so is the difficulty of achieving the quantitative goals required to obtain a release of fusion energy. Yet, in the [illegible] years since fusion research first began in earnest, we have seen progress on all fronts in solving the scientific and technological problems of fusion, to the point that most of us believe that the next 5 or so years will see the proof of the scientific feasibility of fusion, followed by a head-on attack on its engineering problems, which are probably equally as challenging as the scientific ones have been.

To put what I will be saying about our scientific progress in perspective, let me say that the search for fusion is now a major international research effort, with large and growing programs in Europe, the USSR and Japan (Japan has the most rapidly growing program of all, and has made fusion a national goal.).

To help explain some of the technical aspects of fusion I would like to use a few slides.

The first is one that I like, even though it has nothing directly to do with manmade fusion. It is a picture of the sun's corona, taken with [illegible] [illegible] [illegible] [illegible]

[illegible] [illegible] [illegible]

[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] that you get [illegible] already mentioned the need for high [illegible] fusion process, [illegible] nuclei are electrically charged, [illegible] order for two heavy hydrogen nuclei to be able to approach each other [illegible] reaction to take place they must have [illegible] the requirement for high kinetic temperatures. In terms of temperature this means hundreds of millions of degrees; in terms of physicists' units this means particle kinetic energies of 10 to 20 thousand electron volts. But since a fusion reaction, when it occurs, releases many *millions* of electron volts, there is an adequate margin of payoff to permit energetically self-sustaining reactions to take place, provided there are good solutions to the problems of heating and of confinement that I mentioned.

III) Approaches to Fusion

As we now see it there are two, and probably only two, approaches to fusion that could lead to practical fusion power plants. These are almost diametrically opposite in their [illegible] approach to the problems of heating and confinement. The names of these two approaches are:

1) Pellet fusion - which you might call the "[illegible] and [illegible]" approach, and

2) Magnetic fusion - which you might call the "[illegible] slow burn".

Pellet fusion is the newer of the two approaches (about 20 years old) and is conceptually the simpler one - but it is technically very demanding. For it the problem of heating is the key issue, and the problem of confinement then solves itself.

Magnetic fusion is the older of the two. For it the key problem is confinement, and heating is a secondary problem, one for which good solutions already exist.

To be less cryptic and more specific, the idea of pellet fusion is to take a tiny pellet of solid fusion fuel, to heat it and compress it extremely rapidly - that is within less than a billionth of a second - to fusion temperatures, and then rely on its own inertia to keep it together long enough for fusion reactions to take place and release energy in excess of that required to heat it up in the first place. The main way that this feat is now being attempted is through the use of focused beams of [illegible] from [illegible] powerful lasers. However, it also appears that focused beams of high-energy particles might also be used, with some considerable practical advantages. I will come back to the pellet fusion [illegible] approach, now under [illegible].

In magnetic [illegible] enclosure [illegible] low [illegible] of the [illegible], at which point the fuel [illegible] is broken apart into its constituent [illegible] nuclei. This ionized gas, or "plasma" [illegible] is then held, free from contact with the [illegible] walls, by specially-shaped magnetic [illegible]. The magnetic field here acts somewhat like a [illegible] "[illegible]" to protect - not the walls but the plasma from [illegible] the walls. [illegible] the kinetic temperature of the plasma [illegible], its density is correspondingly low, so that its total heat content is small. The heat content of all the plasma in a magnetic fusion power plant would be about enough to boil a few quarts of water - or to raise the temperature of the chamber wall a few degrees if it dumped into the wall. The real purpose of the magnetic field is to prevent the plasma from being cooled by contact with solid material, which would instantly quench the fusion reactions. The problem is that the confinement must be good enough to hold in the randomly flying fuel nuclei for about 1 second - that is for a long enough time for them to have a reasonable probability of hitting another nucleus and fusing. But because they are moving so rapidly, during one second's time these nuclei will have traversed a distance of the order of 1000 miles. It is the job of the magnetic field to localize the region in which these can move to lie within the chamber. Solving this problem is what has taken the ingenuity and the time that it has been required to get us to where we now are.

IV) Pellet Fusion

To return to the pellet fusion idea, the next slide shows how conceptually simple the idea is: drop in a pellet about once a second and zap it in flight, absorbing the released fusion energy in the chamber walls as heat to make steam, and then electricity, some of which is fed back to the laser to keep the cycle going.

At Livermore we happen to have the largest laser system in the world for the study of pellet fusion. Recently the SHIVA laser was brought on line and experiments with it are now commencing. The next slide shows a model of SHIVA to give you the scale - note the size of the man!

The next slide is again a model - in this case showing the laser support structure and the target chamber. Because of the extreme precision required in focusing the beams to all converge onto a timing pellet, this structure must be extremely rigid and must be housed in a temperature-controlled room.

The next slide shows a photo of SHIVA as it exists today.

The next slide shows a picture of a target chamber for SHIVA within which the pellet is irradiated. Most of the gadgets hung on the sphere are for instruments that measure the results of the experiments.

As it presently stands, the SHIVA laser system is capable of delivering a focused burst of laser light at a power rate which is 5[illegible] times the total electrical power output of the United States [illegible] maintained only for a fraction of a billionth of a second. What is the target that this enormous burst of energy is focused on?

The next slide shows one of the hollow glass [illegible] spheres, [illegible] with pressurized deuterium and tritium gas, that are being used in the experiments.

The next slide may give you [illegible] of the scale of things. This shows a similar microsphere [illegible] head of a pin!

Steady progress has been made in the pellet fusion program, and the physics issues involved are by now [illegible] understood. [illegible] it will involve several years' work and still further major increases in laser power before the so-called "scientific breakeven" point can be reached, where the fusion release equals light energy input. Beyond that lies with the need to achieve the "practical" breakeven point (as opposed to scientific breakeven), where the laser energy exceeds the electrical input, including the inefficiency of the laser itself. Beyond that lie engineering and economic issues.

V. Magnetic Fusion

Although the idea of magnetic fusion is conceptually more difficult to explain than pellet fusion, what we are attempting to do is much more closely related to our usual picture of how energy is obtained by burning a fuel - for example burning natural gas in a furnace. In such a furnace fuel is continuously fed in, heated to its ignition point, burned with the release of energy and its combustion products are carried away. In magnetic fusion we are carrying out exactly the same processes, except that our fuel density is a hundred thousand times lower than that in an ordinary gas furnace, and the fuel temperature is roughly one hundred thousand times hotter. The reason the fuel density is so low is that even at this low a density the energy yield from fusion is as large as we need for practical power generation - a cubic meter of hot fusion fuel plasma would release fusion energy at the rate of about 10 to 100 million watts, so that a relatively few cubic meters would be all that we would need for a large electric power plant.

As I mentioned earlier, in magnetic fusion the magnetic field is needed to act as a non-material container to protect the hot fusion plasma from being cooled by contact with the chamber walls. The trick is to find those configurations of magnetic field that can hold in the plasma without its either leaking out too rapidly, or without allowing it to break into unstable turbulent motions that disrupt its confinement. Finding these special configurations and understanding the complicated physics issues involved is what has taken the lion's share of the time in magnetic fusion research.

There are two basic forms that magnetic fusion systems can take - sometimes called "closed" or "open" systems - because of the way the magnetic field is configured. Each has its own advantages and its own problems.

As I mentioned, the progress that has been made in magnetic fusion is the result of years of effort in many laboratories throughout the world. I will try to compress that effort into two or three slides by showing you pictures of two of the most successful of these experiments - the PLT tokamak toroidal device at Princeton University, and the 2XIIB magnetic mirror system at Livermore, and the follow-on experiments which are now authorized and under construction at Princeton and Livermore.

The next slide is a photograph of PLT. You may have read a recent press release concerning the success in the device in achieving temperatures of 50 million degrees - the highest yet achieved in that kind of device.

The next slide shows the new TFTR tokamak under construction at Princeton for completion in 1981. This experiment should be capable of proving the scientific principles of the tokamak idea up to energy breakeven. It will not be a fusion power plant, however.

The next slide shows a drawing of our 2XIIB mirror experiment at Livermore. In it we have achieved the highest sustained plasma temperatures in any fusion device in the world - 200 million degrees.

The next slide shows a new large mirror experiment, MFTF, under construction at Livermore for completion in 1981-82. We expect to achieve temperatures in excess of 600 million degrees in this device, sustained for periods of about 1 second - or 100 times longer than in 2XIIB.

Finally, in the fusion program we are beginning to consider what fusion power plants might look like, and how much power generated by them might cost. The next slide is an artist's concept of what a large magnetic mirror power plant might look like.

Through these studies we have become aware of the fact that there will be some very difficult engineering problems to be tackled after the physics issues are solved. We also have gained a rough idea of what the cost of power generated by magnetic fusion will be. We believe that it will be competitive with conventional means, such as coal, but the cost mix will be very different: [illegible] essentially zero, but capital [illegible] higher than that for conventional plants. It is [illegible], however, [illegible] that simplifying principles will [illegible] that will affect the capital and maintenance costs in a favorable way.

Environmentally, we believe that fusion will prove to be a very safe and non polluting source of power, and we will [illegible] better and better systems as time goes on.

VI) Conclusions

One of the general conclusions that we can reach about our energy situation today is that we have come a long way from the era when our energy sources consisted of wood for the fireplace and hay for the horse in the barn. Some people would like us all to go back to that kind of an era, thinking that this would solve all our problems. I suggest that they should read again Edwin Markham's famous poem "The Man with the Hoe" (Markham was an Oregon boy, you know. . It is conceivable that a greatly reduced world population could exist at a subsistence level with dwindling and limited sources of energy - but I would not wish that kind of world on my great-grandchildren or anybody else's. What I have been saying tonight is that even though we are passing through a transition period during which there will be difficult short range problems to solve, that there will in time exist at least one answer to our long term energy needs. That answer is nuclear fusion. And fusion represents not only an environmentally desirable solution, but one for which we will no longer have any concern that it will run out. Just knowing that this is true should give us the courage to steer our way through the energy problems of the coming next decades. Don't believe the pessimists - they are wrong.