# BEFORE THE

# SECRETARY OF ENERGY ADVISORY BOARD

# NATIONAL IGNITION FACILITY TASK FORCE REVIEW

# FIRST MEETING

November 16, 1999
Livermore, California USA
Day 2 of 2

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BEFORE THE

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NATIONAL IGNITION FACILITY TASK FORCE REVIEW

FIRST MEETING

Conference was held pursuant to Notice and Invitation Conference Room A, Building 123, Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, California, USA, commencing on the 15th day of November, 1999, at 8:30 a.m. PT; resuming on the 16th day of November, 1999.

TRANSCRIPT OF PROCEEDINGS

THE CHAIR: I, I guess we might as well get started. I think we had a good, broad overview yesterday to get us each oriented, and today we start getting more into the details of various systems, their performance requirements, and the, the development plans.

The first item this morning is, is on laser system performance requirements, and John Murray -- Is John here?

Hi, John.

-- will get us rolling.

LASER SYSTEM PERFORMANCE REQUIREMENTS AND ARCHITECTURE:

DR. MURRAY: Well, I'm going to go over

laser system performance requirements and some of the architecture of NIF, and necessarily this will cover many of the points, the same components that Ed talked about yesterday, and Ed English will shortly talk about. But we'll each give you sort of a different cut through the important components.

Now, NIF, the baseline design for NIF is to drive an indirect-drive X-ray target, 1.8 megajoules, 500 terawatts, and 350 nanometers. But we have a very large number of other uses.

Direct-drive targets, where the laser hits the target directly instead of giving you, used to generate x-rays; a lot of weapons physics and weapons effects experiments, which you heard about yesterday from George Miller; and some basic science, laboratory astrophysics, advanced hydrodynamics, et cetera.

Now, the use, for the users, all we are is a big power compressor. The neodymium absorbs light from xenon flashlamps, it amplifies li-, it stores energy for about 300 microseconds, amplifies light at 1 micron.

We can extract that and compress it into a volume less than a cubic centimeter and at fluxes of 10-to-the-14 to 10-to-the-16 watts per square centimeter. And it's the best available laboratory simulations of conditions in a nuclear explosion.

Now, we're pretty confident that NIF will work because of the scientific prototype we built, the Beamlet laser. And when I say "scientific" prototype as opposed to an engineering prototype, I mean this has all of the components in it, but they are not at exactly the same size, spaced in exactly the same positions, and put together the same way.

Ed English will show you some engineering prototypes later.

DR. BYER: John, is the --

DR. MURRAY: Yes.

DR. BYER: -- Beamlet laser still operating?

DR. MURRAY: The Beamlet laser, laser is being moved to the Sandia Corporation in Albuquerque. It's being reassembled down there where it will be used as a source for backlighting for some of the pulse-power experiments they have down there.

The sort of pulse we need to make for ignition targets is shown here. The actual pulse hitting the target is this blue line meant to indicate the fair harmonic.

There's a long, low pulse. Then there's some carefully tuned features here that drive shockwaves into the fusion capsule, and then we drive a final, massive sho-, shockwave that causes the, the major compression of the target.

These features have to be very carefully tuned based upon our knowledge of the equation of state of material in order to be able to get the target to implode at the, symmetrically at the minimum possible energy. Now, to generate this pulse in blue, the pulse, the laser has to generate in red, or the infrared, as it, as it looks like this.

You'll notice that out here it's a little bit more. There is, the ratio between these two is a little bit higher because at low density the frequency converters are not as efficient as they are at high.

Okay, so we have to generate that 1.8 megajoules, and now the question comes: How big does the laser have to be?

By the -- Before going into that, let me say that we're talking about that pulse, but we can actually operate over a much wider range in power versus energy space. We like to plot these as power versus energy because these lasers are scaled mostly as: How much power do you demand out of the lasers after you have extracted a certain energy? All right?

So we have this area here can be operated. We have this lighter green area out here you can oparate, but in that area you need to worry about things like exactly what is the pulse shape? What are the condition of the optics, et cetera?

And so if we can run peak powers up here in the range of 700 to 800 terawatts for short pulses, energies of a little over 2 megajoules out here for longer pulses.

Now, we have designed the laser to operate at a fluence of 8 joules per square centimeter in the ultraviolet. And this shows a, the damage histogram of a fused silica surface of a pretty good manufacturer, but several years old; probably not the best that can be done right now, compared to 8 joules per square centimeter.

And you can see that as you start running up the fluence, at around 11 to 12 joules per square centimeter you start seeing damage, and then it comes up and you get into the bulk damage properties of the surface.

Now, a surface is nothing but a mass of defects. You're going from a bulk material into air and subsequently all you have on the surface is defects.

The question is, does the finishing process produce benign defects or not so benign defects that damage at low effluence. We have two issues here with designing that at this point.

One is there is some intensity noise on the beam, and you don't want intensity noise on the beam to get up into this main distribution of defects.

The other issue we need to worry about is, this is a distribution. You know, there is always a tail, which comes down here to lower fluence.

And those defects are very rare, but if you damage them, you then have to worry about that. Let me say at this point that this has a character of another damage problem which we don't even talk about anymore, and that is the laser glass itself, as you know, is melted in platinum crucibles.

There is a little bit of dissolution of the platinum into the glass because molten glass is extremely corrosive, and under the proper, proper chemistry you can precipitate out very small platinum particles. All right, now the way we handle that is we do 100-percent inspection of all the laser slabs.

We scan across these slabs at 14 joules per square centimeter, and try to find something that will explode. If we find particles, and I think it's more than four or five per disk, we reject the disk.

Then if we find these four to five particles, we sit on those particles for a hundred shots, and if they grow to be bigger than 300 microns, then we throw out the disk. It's likely, in my opinion, that we're going to have to be doing that with UV optics also, even though that is an additional expense and people don't like to do that.

But anyway, having come to 8 joules per square centimeter, 1.8 megajoules at a fluence of less than 8 joules per square centimeter means the beam area is greater than 22 and a-half square meters, which is about the area of the wall of this room. So now we know what the total area is.

How are we going to divide it up? Larger individual beam area means fewer beams, and fewer beams, generally speaking, is cheaper.

You have less controls. You have less

assembly work. You have less mechanical parts, et cetera.

The, the Beamlet project demonstrated an amplifier at 39 centimeters and crystals at 37 centimeters. If you start getting too much bigger than that it becomes difficult to get optics.

There are very few manufacturers who will be, who will manufacture optics in that size, and the performance of amplifiers and crystals and such degrades, although fairly slowly, as you're going up in size. So for NIF we chose the aperture to be 40 centimeters and the effective beam area then comes out to be 1,250 square centimeters.

You may say, "All right, 40 centimeters squared is 1600. What happens here?"

First, the beam does not go straight through the amplifier. It's a multipass system. The beam moves a centimeter or so on the passes going through the system.

Second, we can never ensure that these amplifiers are exactly in the right place for the beam to go through. So you have to have an alignment tolerance around the outside to allow for misplacement and allow for alignment of the various different components.

And third, let's show what one of these beams look like. We have to roll the intensity of the beam smoothly to zero over a margin around the outside in order to prevent diffraction from bringing up intensity spikes on the edge of the beam as you propagate through the system.

And this is a matter of, oh, about one and a-half centimeters or so, and that cuts off the beam. Also, we have to round the corners to prevent diffraction spikes from coming in from the center.

So this is typically what a beam looks like from Beamlet, and a histogram of what the intensity distribution of that beam is.

And you can also see on here, although it's not the point I was trying to make with the slide, that if you model these things with a good propagation code, you can predict very well what the permanence is going to be.

Okay, now we know what size the beam is, and what we find is that 22 and a-half square meters of that area implies greater than 180 beams. Now, what are we going to do with the beams?

We're going to illuminate an indirect-drive target. And let me say all these beams are ultraviolets.

The color on here is simply for convenience in explaining the illumination geometry. Typically what these targets look like is they're a small metal cylinder about a centimeter long with a fusion capsule in the center.

And we want to illuminate three rings on the inside of that cylinder with roughly equal energy in each of those rings. Now, the way that we do that is we have two cones of illumination coming in from each end, an inner cone from both ends, the blue beams that illuminate this center ring, then an outer, a red cone that illuminates this ring, another green cone that illuminates this ring.

So, if we look down there, we want twice as much energy in this red cone because it's illuminating one full ring as we do in this blue cone. Second thing we want is in order to get adequate symmetry on the target, we want at least eight groups of beams around this blue cone, all right?

So if you look through that quickly and you, and you see that if I go in groups of four beams, which is extremely convenient for the mechanical layout of the lasers, then I want eight around here, 16 around here, 24 on this end, 24 on that end, 48 times four is 192, and that is the first convenient number for doing this kind of illumination that's bigger than 180, and that's why it's 192 beams.

Now, we're using for NIF a mult-, a multipass system rather than a master os-, single-pass multi-oscillator power amplifier chain such as Nova used because it greatly reduces the number of parts, and thereby reduces the cost of the system. The master -- Ed mentioned this yesterday, so I won't spend too much time on it, but Nova, the beam is taken out at a size of a centimeter or so.

It's split up with beam splitters and puts down chains of amplifiers. It requires a lot of components. It also requires a lot of alignment in here.

In the case of NIF we have a master oscillator which is all fiber optics, goes over fiber optics distribution to a small preamplifier, and make multiple passes through cavity and switch it out, getting the effect of three amplifiers from this single large amplifier.

Now, let's see, or let's go in further. There are, as you see in here, those, those yellow telescopes. In the case of the multi- there are a lot of them. They look like they occupy about half the system.

And here they look like they occupy about, about half the system, and they really do. And here you can see in the NIF design, for example, here is one telescope, which is inside the laser cavity.

Here's another one, which we call the transport spatial filter, which is between the laser and the target chamber. And why were they so big?

Well, basically what we are doing is an image relay. In order to keep the beam uniform intensity and with no diffraction spikes on it, you want to go from image plane to image plane to image plane.

This is exactly the same technology that's used to take an image down a periscope to a submarine, all right? But we have an image in the amplifier where we want the beam to be uniform, and we want an image in the next pass through the amplifier or in the final optics.

Now, elementary optics will show you that if this, there's no beam expansion here and this spatial filter has a length of L, the distance between those images is 2L. You can slide them around.

You can push this one back here and then this one will push out. So you see, if I have a distance L from this, if I have a certain distance from this lens to the final optics assembly, for example, this lens is going to have to be about the same length as that distance from the final optics, and that's why those filters are so big.

The other thing we do in here is we attenuate high-spatial-frequencies noise on the beam by passing the beam through a small aperture. And that, it sounds very simple now.

Now, it has, however, some little complexities, because that intensity in this point is extremely high, so you have to worry quite a bit about what those small apertures look like.

Just as a digression, we've looked at several different varieties. You might think it was just a simple washer drill, drill a hole in a metal plate, but you generate plasma on the sides of this hole.

That plasma closes in and tends to block the tail end of the pulse when you're trying to run these long pulses that extend for 20 nanoseconds. Also you get some reflection on the front side of that washer, which is not good.

You can get away with a lot of this by staggering times so that the plasma does not stagnate on axis, but in fact you get a much better performance with a cone-shaped pin hole, a very shallow cone like this where you try to reflect and have grazing incidence on the sides of the cone.

These, these were actually designed using one of the laser target codes, so that illustrates that the codes are good for something. For, for NIF they get a little bigger, since that transport spatial filter is so long.

This happens to be one of them for the NIF transport spatial filter. If you'd like to take a look at it, it's very highly polished on the inside, and that's how they do it. So what looks like a simple pinhole is not always so simple.

Now, the NIF system, I think Ed showed you this picture yesterday. We have the master oscillator going over a fiber to the preamplifier.

We come through here, and we have the amplifier split into two parts with this spatial filter in between them. Now, you'll see what happens is on the last pass out through the amplifier I go through a section of amplifier to a spatial filter here, go through another section of amplifier and go on out.

Since I am attenuating the intensity noise at this point, it allows us to run a higher peak power than we could if we put all the amplifier in one place. And that's the reason that it's split into those two sections.

There's 11 slabs here, five here. There's been some discussion of adding two more here so you can get more energy with, about a half a megajoule more energy with long pulses, but we'll see. We haven't made a decision on that yet.

The path of the beam through here is that it comes in, reflects here, goes through the switch, hits this mirror, comes back, comes back through the switch we just fired off, and comes back out again and goes on through the target.

Now, what are the requirements on some of these components? Well, we have an injection laser system, a master oscillator, and 48 preamplifier modules.

The master oscillator provides temporally shaped, modulated, and precisely timed input pulses to this fiber distribution system. It also frequency modulates the pulse for beam smoothing and to suppress emulated Brillouin scattering. It's something we have to worry about.

Brillouin scattering is a scattering process where the light wave comes in, scatters from an acoustic wave in the material, and it scatters light sideways. It's also, by the way, it's also extremely important in these optical fibers communications networks.

So we have to frequency modulate the beam to prevent that from happening in the large optic. And we use hardware which is derived directly from the high-speed fiber-optics communications networks for this.

The beam then goes into the preamplifier module, which amplifies and spatially shapes the pulse in the fiber and provides about a joule input pulse to each of four NIF beams. Now, we, we make four passes through this.

And a question sometimes arises: Why is it four? You know, why is it not two? Why is it not six, or some larger number?

And the answer is: If I make four passes through this, I've driven that preamplifier size down to be about a joule. If I made only two passes through this system, which would be in some cases, in some ways easier to lay out, that preamplifier, has to be about 100 joules.

Therefore, that preamplifier gets much larger, more expensive. So going less than four passes is a problem.

Now, why don't we go more than four passes and drive this down even smaller? Well, first thing is, it doesn't get very much cheaper.

The second thing is that multipasses through a system like this have other problems. For example, when I read, when I go through this and I look at the distortions in all of these components, I'm reading them coherently on the multiple passes.

So, instead of adding in RNS sense, as they usually read, I read in an optical sense, system, they add lineally. At some point those get quite severe and they're hard to control.

Second, multiple passes in a system that stores a lot of energy and has a high gain is a dangerous situation. It's very difficult to control parasitics and stray light in such a system, for example, and that's one of the things that this switch has to do.

But, for example, here I have a cavity spatial filter, there's hardware down in here, and here I have a lot of gain. Well, suppose somebody misaligns a little baffle down there so it's close to being parallel to that mirror?

Well, you can do some serious metalworking that way, all right? Because this thing takes off as parasitic oscillations between that mirror and the baffle.

This one's from Beamlet. You can see it there. And that can be a problem.

Okay. The amplifier, what we have to do with the amplifier is store enough energy to allow about 20 joules per square centimeter to be extracted, and position the amplifier slabs to allow high-peak power operation. That's why they're in two groups, as I said before, have beam distortion consistent with NIF requirements, and allow one full system shot every eight hours.

And to do that we need 16 slabs of, of neodymium-doped phosphate glass. And you've seen what these amplifiers look like. And Ed English will show you in more detail, so I think I will not go through that.

We also have that pockel cell switch, which is a plasma electrode pockel cell. There is continuous plasma on both sides of the crystal which charge the surface of the crystal, and there's some sophistication as that is to go into this, too.

For example, I'm sure you know that when you have these plasmas, you get some sputtering of material from the electrodes. Well, if that sputtered material is metal, for example, and gets on crystal, it reduces the damage thresholds of the crystal.

And that's not desireable, so you have to be a little bit sophisticated about it. These cathodes and anodes are made of carbon.

The gas in here is helium plus a small amount of oxygen. And when you do that, anything that's sputtered comes off as carbon monoxide and CO2 and gets pumped out.

Now that switch has to rotate the beam polarization to switch the laser pulse out of the system at less than 100 nanoseconds. It has to block stray light propagation before and after the pulse to get around some of these stray light problems of the multipass.

It doesn't kill them all, but it gets a lot of them. And it has to be very high efficiency and high reliability.

And you know it's high reliability

because otherwise an engineer would never bring one down and put it in the lobby of a public meeting, right?  It's out there working now.

Oh, yeah, I just happen -- I had it in the wrong place here, but other stray light problems. Stray light is a big issue.

Ed mentioned the ghost beams.  We have, we spend hours and hours ghostbusting trying to find where all of these things go.

We get a lot of reflections back from things like the frequency converter out here.  That's an example of what happens if you, if you are not real careful with where some of those reflections go. That was from the Novette laser a few years ago.

Now, going to the frequency converter, we use plates of KDP crystal to convert the frequency to the ultraviolet.  The way that process works is we come in with the red light polarized horizontally into a crystal.

We convert by a phase-match frequency conversion two-thirds of that light into the green, the second harmonic of the crystal, which you adjust by how thick the crystal is and exactly what angle it's tipped at.  Then we go through a second crystal which mixes together the remaining red and the green to give this ultraviolet light.

And although that sounds like magic it does in fact work quite well, and we can get efficiencies up to about 80 percent for conversion to that third harmonic. And just a note here at the bottom to show that in large beams, 30 centimeter and 34 centimeter on Beamlet, we have done this at fluences of slightly over 8 joules per square centimeter.

These crystals for this bigger beam were not of this high crystal quality as for the smaller beam, so they didn't get up to high enough efficiency, but if you, that high efficiency, but if you have a little extra drive in the red part of the laser you can indeed push them up to the necessary fluence.

Now, the NIF final optics assembly, as shown here, has a vacuum window in the red beam because damage is much less of a problem in the red part of the spectrum than it is in the ultraviolet. It then has this frequency converter, a focus lens, a place to put some diffractive optics plates to do specialized science to this target spot, and I'll show you one of those in a minute.

And then it has a debris shield which

separates this clean environment of the third harmonic optics from the dirty environment of the target where the target is being evaporated and various metals, plastics, and whatever, are being deposited on the sides of the chamber.

Now, you notice over here it says, "Argon beam tube." We have to fill the beam tubes between the spacial filter and the target chamber with argon because at the intensities we're running, the the rotational Raman scattering at air is sufficiently severe that the beam won't go but about, oh, 75 or 100 feet, and we have to go further than that.

We, the physicists, would like helium, but the engineers don't like it. It's hard to keep helium in the tube.

So, anyway, we have this system here. This debris shield collects garbage from the target.

That is its purpose in life, and consequently this has to be changed frequently. We're planning on changing them about once a week.

Now, NIF, as I said, has to be very flexible to accommodate the needs of users. We've talked about energy and power, but we have users that want the smallest possible spot so they can do high temperature.

And you saw some of those experiments and talks yesterday. We want, we have users who want beam smoothing to give very uniform intensity on the spot so there are not a lot of spikes and intensity on the target.

They want very flexible pulse shaping, as you've seen from those ignition targets. They want to do direct-drive fusion targets, and there are a wide variety of other requests: placing targets substantially off-center in the target chamber for a Robitzsch-like experiments; putting big objects inside the target chamber, et cetera.

Now, we have demonstrated on Beamlet, and will install on NIF, adaptive optics, a deformable mirror, in order to get much higher beam quality than was typical for the Nova laser or earlier lasers. And this just shows a typical focal spot broken up into a large number of speckles here.

With the adaptive optics it looks much better. Now, I will have to say that what, these, these spots usually come out as what we call a "fried egg pattern."

There's a nice yolk in here, and you can sort of see that around the outside of it there is a thin, not-so-intense white of the egg. About half the energy is in that high-quality spot, or the spireo (phonetic) ratio is .4, for those who are interested in ultimate detail. And there is still some energy not in the high-quality spot.

We want -- We have users who want beam smoothing. Here's another one of those fairly ugly spots. That one is from the Nova laser.

We can put in a diffractive optics plate which breaks up the beam effectively into a lot of smaller beam areas, which then interfere with each other and give a speckled pattern which has uniform average intensity but a lot of high-frequency modulation on it.

We can then take that pattern and jiggle it sideways -- In time you can see where the lines and some intense speckles appear in there. -- and get very uniform intensity over the central region of the spot here.

That process is called "smoothing by spectral dispersion," if you see that term anywhere. And it gives us greater uniformity.

You can still see some structure here from the one-dimensional jiggle. And if you jiggle it in two dimensions you can get rid of that structure and get even smoother spots. And some users want to do that also.

Concerning the flexible pulse shaping, we did request, although we showed you a 1.8 megajoule ignition target pulse before, there are some more advanced target designs with slightly higher energy but longer pulse that give higher fusion yields to those ignition targets.

There are people who want to do very high temperature experiments, and to do very high temperature it's important that the pulse rocket up to its peak power in less than 200 picoseconds, and we also have been able to do that.

We also have people who want squarer pulses that are maybe 5 nanoseconds or 3 nanoseconds long who may want a pulse here, another pulse here, and then a pulse at the end, et cetera. And the pulse-shaping system has to be flexible enough to do that, and is flexible enough to do that.

But, we can't give everybody everything they want, so there are many, there are certain upgrades that we have designed the system so that they will be easy to implement but they're not included completely in the project.

For example, in the direct-drive

targets we have included ports in the right place on the target chamber to do that. We have included space for doing this two-dimensional beam smoothing, which they want.

We have included space for more complex frequency conversions which they, converters, which they may want, but what we have not done is actually buy the hardware as part of the project to fit in those spaces. And there are other cases for our weapons effects users and such where similar choices have been made.

Well, so where I'd like to leave you here, then, is that Beamlet has demonstrated that the NIF technology was ready for final engineering design. The large multipass laser will perform as designed.

Amplifiers, switches, and frequency converters are a few centimeters smaller than NIF at performance levels that are required for NIF have been demonstrated. The master oscillator and preamplifier technology proposed for NIF performs very well.

Adaptive optics can give us high beam quality. And the simulation codes which we use to predict the performance of the system can predict that performance very well.

And also many other features of the NIF design. I showed you some pinholes that are beam dumps that are important here.

If something goes wrong and you have to dump 20 kilojoules of light on, on a very small object, how do you do that safely? That's not proven.

Alignment for the system was tested. Diagnostics for the system, et cetera.

And now Ed English will tell you the state of that detailed engineering design. Are there any questions?

THE CHAIR: What's your biggest challenge at the moment?

DR. MURRAY: The biggest challenge. I would say the biggest technical challenge is damage to the third harmonic optics.

We can get there, but we have to be very careful with those optics, and we also have to be very careful to keep them clean.

DR. VOGT: Can I get something from you.

DR. MURRAY: Yes.

DR. VOGT: You mentioned here the

direct drive, what it included and didn't include. Does it mean you can do direct-drive things with a, with a first system? I mean, --

DR. MURRAY: What it means is that in order to do direct drive with the system you will have to install some additional hardware, and you would have to move some of the final optics and sundries, or buy new ones.

DR. VOGT: But you can do it in the existing target chamber; --

DR. MURRAY: You --

DR. VOGT: -- you don't need a new one?

DR. MURRAY: You can do it in the existing target chamber. You don't need a new one, right.

DR. VOGT: The, the other question I had is you mentioned the debris shield, you are planning on moving it about once a week. What number of shots does this assume?

DR. MURRAY: It assumes one shot every eigh hours for five or six days, so that's in the order of 20.

DR. WARNER: What, what, what spot size do you want out of NIF?

DR. MURRAY: Spot size? Well, for the

fusion targets they want a spot size of half a millimeter. For some of the high-temperature targets they want as small as possible.

DR. WARNER: So, so does the flexible mirror performance of beamlet meet those requirements? You talk about having, you know, so much of the intensity in the central spot and half the intensity outside of the central spot?

DR. MURRAY: I think the answer to that is that the better it is, the more capable experiments could be done. That is adequate to do highly capable experiments.

If it were better, they would use it. If it were worse, they would use that, too.

DR. WARNER: But I take it the performance you got for Beamlet, --

DR. MURRAY: Yes.

DR. WARNER: -- does that give you the specified target power?

DR. MURRAY: Yes, it is, it does.

DR. WARNER: And then I can ask another question about the -- Figure out my notes here. The doubling.

You had this, you showed that as you increase the power in your, in your frequency doubler, the efficiency went down?

DR. MURRAY: Yes. If you go to very high power, your efficiency turns over and goes down.

DR. WARNER: Where is the, the NIF power on that efficiency?

DR. MURRAY: Let me find it here a minute. Now, the, the NIF power, if you take one of those highly shaped pulses, of course it varies all over the map, but its peak is in three gigawatts per square centimeter.

Now, if you take other pulses and you take some of those shorter pulses, they may peak up out here at higher, around four gigawatts per square centimeter, or five. One thing which is not in this is that you can change the shape of these curves a little bit by slightly aligning these crys-, misaligning those crystals. So you can accommodate some of that.

DR. MOSES: Can I just add a little thing on that? Since at ignition pulse you start at very low energy for a long part of the pulse, you're down at the low margin of efficiency.

DR. MURRAY: Down in here.

DR. MOSES: Then as you go up to that 3 and a-half nanoseconds at peak, you move up to optimum, optimum conversion. So when John says, "It's all over the place," it means it's, depending on the exact pulse shape, you're moving instantaneously through that conversion efficiency rate.

DR. MURRAY: Yes, I'm sorry if it was not clear, that's precisely what I mean.

DR. MILLER: If you remember John's original viewgraph on the pulse shape, he showed a pulse shape at one at 1 Omega and a different pulse shape at 3 Omega. That's why the pulse shapes are different at 1 Omega.

You know the pulse shape you want at 3 Omega, and you procalculate what, actually all the way back to the master oscillator. So you propagate that pulse back through the system so you get the right thing at the end, taking all this into account.

DR. MURRAY: Yes, the, point, the point that I did not make on that viewgraph is if you go all the way back to the master oscillator, it, the pulse shape looks even very different from this because the system is saturating. You're extracting energy, so the gain in the system at the tail end of the pulse is very much less than the gain at the beginning.

And consequently the master oscillator pulse has to rise at the end to compensate for that. But this is the track they were talking about.

The conversion efficiency is low here. The conversion efficiency is high here.

DR. WARNER: I guess, I guess what I don't understand if you go going back to that other chart is that as you dropped, as you increase the power per square centimeter your conversion efficiencies dropped.

DR. MURRAY: Yes. In fact, --

DR. BYER: You're back-, --

DR. MURRAY: -- it does.

DR. BYER: -- you're back-converting on the harmonic process, Joe.

DR. MURRAY: It, it goes up -- It is a phase matched harmonic process. It converts over in theory fully --

DR. WARNER: And back.

DR. MURRAY: -- to the third harmonic, --

DR. WARNER: And goes back.

DR. MURRAY: -- and then it starts going back again. It sinusoidally varies if you go through there.

DR. MOSES: Actually it would go back to all --

DR. MURRAY: It would -- Yeah, it would --

DR. MOSES: All the way to 2 Omega, 1 Omega.

DR. MURRAY: -- all go back if you, if you, if you went the proper thickness through the crystal.

Now we tune the, the angles and the thickness to give the best dynamic range for the particular class of pulses that we're trying to run.

DR. MOSES: Yeah, actually this is another very interesting design issue. You know, if you were just designing a facility for a, high-temperature hohlraums or for ignition, you could pick, you know, a better, you know, more perfected optimization for that design.

But what John and the Laser Design Team has done is worked on a conversion that meets all of those needs nearly optimally.

DR. MURRAY: Yeah, this is, this is a compromise solution which is not -- I mean, if I wanted to make only pulses that ran exactly 4 gigawatts per square centimeter, the frequency converter would be different from this. It would be different thicknesses, different angles, et cetera.

But it could not perform as well when I get down to these low-end frequencies. And we need to have a compromise which is useful over the entire range of intensities we need to run. Okay?

THE CHAIR: Thank you.

DR. MURRAY: Thank you.

THE CHAIR: Now, Ed English.

LASER SYSTEM ELEMENTS: (9:13 a.m. PT)

DR. ENGLISH: Well, good morning. I'm Ed English.

I thought before I start into my talk I might say a few words about who I am. I have a Bachelor's Degree in Physics from Purdue University, and I received my Ph.D in optical engineering from the Institute of Optics at University Rochester in 1988.

Came to work here at the laboratory then 11 years ago working first in the Atlas Project for about four or five years where I was the optical design group leader. Then came over to the ICF-NIF Project, where I've been for the last five years, and have been with NIF since its inception, working first as the optical system engineer, then a manager for the optical mechanical systems, and now as the Associate Project Manager for the laser and optical system.

I'm going to talk about some of the equipment that is in that system, kind of a, a tour, if you will, of what some of these pieces of hardware look like that address the, the physicist's ideas about the laser system that we're trying to put together for the target experiments.

I'm going to principally talk about two subsystems.

Is there a pointer up here somewhere? There it is.

DR. MILLER: Yeah, it's right over here.

DR. ENGLISH: Ed talked about this a little bit I think yesterday when he talked about functional system descriptions. The two systems that I'm going to talk about are the laser system, which resides in the laser bay, -- There are two laser bays. -- and then the target optical system.

I'm going to walk you through first the, the main engines, I like to call them, of the laser system. That's the injection laser, the amplifier, and the final optics. These are the things that, that make the laser light, amplify it, and convert it.

Then I'm going to walk through some of the pieces of beam transport hardware, the, the elements that get light from one place of the building to another place and in the proper format.

One of the things that you've been seeing and heard about are line-replaceable units. Probably have seen this chart before.

There are roughly 4,000 line-replaceable units in the laser and optical system. This is a map of many of the large-aperture optomechanical systems.

These are the things that really are the, the laser system. Or I should be a little more accurate. These are the things that hold the things that are the laser system.

Just after I talk, Jeff Atherton -- This is after the break. -- is going to talk to you about the optical components. Those are the pieces of glass that actually touch and are the optical system.

So, the optomechanical systems, the mirror systems, lens systems, amplifier systems, pockel cells, final optics, those are the things that

I'm going to be talking about.

First I'm going to start with the, the laser at the front end. This is the injection laser.

It physically resides in two places. The oscillator is in t central core of the building, and the preamplifier modules reside under the transport spatial filter.

Now, yesterday I believe Ed showed you a demonstration unit of the, of the master oscillator. This is a slightly mocked-up version -- I think you saw this yesterday, right? -- of the, of the real master oscillator which is sort of about a foot by 2-foot-wide breadboard.

What you see here is an assembly that goes in a chassis that becomes mounted in a rack. So this is the chassis.

In fact, yesterday I was down in the basement of Building 381 where the, the team is putting this master oscillator together. This currently resides in the rack.

It's operating. There's a pump diode, about 100 milliwatts, that pumps a distributed feedback laser that produces the initial light for the laser. This is a CW system at this point.

After it leaves, leaves the master

oscillator it goes through a stage of amplification, phase modulation for both stimulated Brillouin scattering suppression and for smoothing by spectral dispersion, the initial 17 gigahertz for that.

The, the, the pulse is chopped into a 30-nanosecond basically square pulse, amplified, and fanned out to the preamplifier modules. This is where the actual pulse shape is generated.

John showed you the, a couple of the pulse shapes. I just wanted to show you some experimental data using the actual pulse-shaping system for NIF to show that we can generate the kinds of pulses, and have demonstrated that we can, can actually generate these, these pulses, and they meet, they meet the requirements for both the, the indirect-drive pulse, the short pulses, sort of, this is a programmable computer-controlled system.

I should emphasize, this is all based on -- And maybe you can sort of tell from the, the model and from the pictures. It's really standard telecommunications fiberoptic technology.

We've customized it to our particular wavelength, so the doping is a little bit different, but it's, it's the same kind of thing that you buy if you're putting up fiber optics to run under the ocean or across the country.

In fact, the amplifier for the oscillator comes in a kit from a company, and you put it together with the amplifiers, the pump diodes, the, the couplers and things like that.

It won't look like oscillators in, in past ICF systems. It's really a rack-mounted thing, as, as Ed described.

So this single master oscillator is split out, fanned out into 48 separate inputs which feed preamplifier modules located underneath of the transport spatial filter, 48 which will later be split four ways each to get to the 192. The output energy delivered to a preamplifier module is sort of an order of nanojoule, so it's a very low-energy pulse, but with the right spectral and temporal characteristics.

The preamplifier module is going to multiply that energy by a factor of ten to the tenth. There are cer-, to major subsystems to the preamplifier module.

One is on the back side of this photograph. It's called the regenerative amplifier.

I think in computer-aided model yesterday you saw a pulse going back and forth 30 or

40 or 50 times. The regenerative amplifier has a gain of about ten to the seventh.

It takes the pulse from a nanojoule up to about 10 millijoules. Then that three- or four-millimeter diameter Galoisian beam is expanded up to the proper format for the preamplifier module.

The multipass amplifier here, there's a four-pass amplifier here based on Nova rod amplifier technologies, a five-centimeter rod. This unit is about, sort of 3-foot by 14-foot long.

It weighs about what a car weighs. It's a line-replaceable unit.

This complex electro-optical system is aligned off-line, tested, evaluated, and then gets installed into what's called the PAS, which is a preamplifier support structure, underneath of the transport spatial filter.

The output from the preamplifier module then is about 10 to 20 joules. Remember, this is going to feed four beam lines.

The indirect-drive requirement is about a joule per beam line. There are losses in the transport system after this.

And another feature of the preamplifier system is to shape the pulse spatially. And you'll be able to see why this is when I talk about the amplifier, the main amplifier in a moment.

So the preamplifier module, a prototype of which was built and tested a year ago, was shown to meet its requirements in terms of the energy performance. The stated specification was 17 joules.

And here's a photograph of the near field of radiance profile. It's about a 30-millimeter beam.

And one thing you should note here is that it's slightly more intense on the edges than in the center. So the, the input pulse to the main laser is shaped in its irradiance profile.

And that addresses some nonuniformities in the gain of the main laser amplifier. I'll show you that in just a few moments.

The, the principal activity in the preamplifier module at this point in time is readying a procurement package to go out for acquisition from an integrated, what we call an integrated contractor. We're pursuing a path, and we've been developing this for, I think, about the last six months or so, to having an outside vendor, essentially, provide to us a working preamplifier module.

So, working through this strategy, in

the last few months we have formally surveyed and selected, down-selected to 13 possible suppliers, based on a number of criteria. Have they built large electro-optical optomechanical systems before? Do.

They have optics neutrology capabilities? Do they have systems to manage the material that will go into that?

In August we held a prebidders' conference inviting those suppliers here for a discussion. Presented a draft statement of work.

Got some very good feedback from that which is being incorporated both into our strategy and into the preparation of the documentation. And so the engineering and documentation teams are doing that right now.

There's a rigorous internal review of what our documentation package is. This is drawings, tolerances, specifications, test procedures, and so forth.

And our goal is to issue requests for proposal for this, for, for the first articles of this module in the next few months, with those articles being received then about a year later, so that would be early 2001.

DR. VOGT: What would be the size of

such a contract, roughly?

DR. ENGLISH: For the first articles, I should mention our strategy right now is to award two contracts for our first articles, so we would have two vendors. Those, that would sort of be of an order of a $1-million-type contract, maybe a little more, because for the initial article there's some nonrecurring engineering and so forth.

DR. VOGT: And after that?

DR. ENGLISH: The, the estimates for production costs on these units range from sort of $500,000 to $1 million. So there will be 48 of these preamplifier modules for the NIF laser.

Okay, so that's the first engine that I'd like to talk about, the injection laser system providing the initial pulse injected into the transport spatial filter. Now I want to talk about the main laser amplifier system.

Amplifiers here and here. Capacitor bays, there are four.

Injected pulse, sort of about a joule per beam line, amplified up to about 16 or 18 kilojoules in the, in the main laser system at 1 micron. This is the, an engineering picture of what the basic building block of the amplifier is.

This gives me a couple of opportunities to talk about the NIF laser architecture from an engineering standpoint. See that slabs in this case, laser slabs are stacked four high and two wide.

That's a basic unit that we call a "bundle," a 4-by-2. And in NIF there are 24 bundles, so that's sort of the basic laser increment.

You'll notice here that these are packed relatively close together. That's for efficiency and cost.

We're trying to pack this gain into a relatively small volume for a couple of reasons. One, the flashlamps, which are on the outer side and in the interior, -- And by the way, on the back table is, is a flashlamp. -- by packing these slabs close together, the flashlamps don't have to be as long.

That causes a number of mechanical engineering problems not only in this assembly, but actually throughout the laser system. And I think you'll see that as I talk about some of the other optomechanical components. The pieces of glass are very close together.

DR. MOSES: Ed, I can't help it. I think people really have to look at --

DR. ENGLISH: Yeah, you got to take

this --

DR. MOSES: -- what a flashlamp looks like.

DR. ENGLISH: This is a flashlamp.

DR. MOSES: I was thinking about -- and about how many of them are there?

DR. ENGLISH: There are 7,680 flashlamps.

THE CHAIR: All right. And of course they're not, they're in the vertical configuration, right?

DR. ENGLISH: Right.

DR. MOSES: This is, this is the size.

DR. ENGLISH: It's inside --

DR. MOSES: It's inside the --

DR. ENGLISH: It's inside the holder. Yeah, actually it's inside the Lexan tube here.

DR. MOSES: Yeah. But I'm just saying, this height gives you the size.

DR. ENGLISH: Yeah, it's about, about six, about, a little bit over six feet, counting the -- It's six, it's six feet from sort of here to here.

THE CHAIR: Who manufactures them?

DR. ENGLISH: EG&G and IOC. There's

been a consolidation.

DR. BYER: There's one company now, EG&G.

DR. ENGLISH: One company, EG&G, for, for -- And they are the flashlamp vendor for NIF. The, the award of the contract for the flashlamps was, was made in the last month or so for the first half of the flashlamps for NIF.

THE CHAIR: What's their life expected to be?

DR. ENGLISH: Flashlamps? I believe, I believe it's the facility lifetime, 20,000 shots.

DR. WARLAUMONT: Will you explain the gas flow a little bit?

DR. ENGLISH: I'll try. This is not my area of expertise, but flash-, the flashlamps need to be cooled in order to achieve the short turnaround time that's a requirement of the facility. That's the eight-hour shot time.

So I won't get this right on this picture, but nitrogen is flowed into a flashlamp cavity and up through the adjacent one. And that's repeated for this module.

And in the main laser there were 11 slabs in a row, so there were six of these there and three of these modules, these 4-by-2-by-2 modules in the power amplifier, so that the gas system delivers through this --

This is also an electrical insulator. It has a, cavities for the gas plenum as well as for attaching the, making the electrical connections to the flashlamps.

I don't know. That's probably about as good as I can do right here. If you, if you want some more detail I can certainly get it.

DR. WARLAUMONT: That's good.

DR. ENGLISH: So, in, in, in one of these modules there are 40 flashlamps, 16 laser slabs. The next viewgraph, we've already shown you the flashlamp itself.

These are, these are about 13-times-larger flashlamps than were used on, on Nova.

Let me talk about the power conditioning system for just a moment. Let's bring you back to geography here.

Capacitor Bays 1, 2, 3, and 4, these are where the power conditioning modules reside. These provide the electrical energy which drive the flashlamps.

Now, working with Sandia, in fact Sandia National Laboratories designed, built, and tested a first-article NIF transmission module. That's what this is a photograph of.

There are 192 of these modules in NIF. There are eight per bundle.

Contains 20 capacitors. There are capacitors on either end here.

Fired through a, a discharge switch up into 20 transmission lines which connect to 40 lamps. Each transmission line is connected to two lamps in series.

So this first article test, this prototype, again built by, by Sandia in collaboration with, with Livermore and industry, you know, proved out that the NIF design would meet the requirements of the power conditioning system.

I should mention at this point the capacitors for the power conditioning system, the contract has been awarded for the first half of those capacitors, and we're currently looking at -- I'll skip ahead here maybe just one viewgraph.

We're currently developing a strategy for acquiring the power conditioning system, which again would use an outside integrated contractor to build, assemble, test, and ultimately install these power conditioning modules in the capacitor bays.

Okay, we're just going to talk a little bit more about the performance of the amplifier system. We built a facility called "Amp. Lab" where we were able to put together some of the modules of an amplifier and fire the flashlamps, measure gain, measure wavefront, measure performance of the system.

So here are some test results from those gain measurements. And here you can see the gain rolloff across the aperture of an amplifier.

Now, this is because amplified spontaneous, spontaneous emission depletes the gain near the edges of the slab, and so that actually affects the reflector design where we try to direct more of the flashlamp light towards the edges of the slabs to partially compensate for this.

This profile, combined with the profile injected from the front end, then produced the flat top irradiance profile that John showed. We did this on Beamlet, and we were able to, in amp. lab, show that we did, that, that our models and predictions of what that gain uniformity would be were actually borne out by the, by the design.

So I want to go back to the, the

amplifier schematic for just a moment. The, the amplifier, a, a part of the amplifier system is very tightly coupled with the building and the infrastructure.

That part is the frame assembly unit and these gas plenums. These are installed as part of the facility, for all intents and purposes.

The LRUs are the slab cassettes and flashlamp cassettes. Those come along later to be installed.

But the frame assembly units are part of the beam enclosure, part of the beam line. And this is an area that is, is actively moving ahead in terms of construction, fabrication, and assembly.

So, for the frame assembly units, these are being fabricated and precision cleaned by contractors. That's actually happening right now.

They will be finally assembled in a clean room here at Livermore, transported over to the laser bays for installation by the infrastructure contractors. Again, just to give you a little feeling here, the frame assembly units are on, are, are on order.

The gas plenum and top plate electrical isolator award is, is ready to happen. The facility where this assembly will happen is being prepared.

Here's a photograph from a few months ago. This is actually the, the Beamlet high bay without the Beamlet laser in it.

It's a Class 100 clean room. There it's sort of getting ready a few months back.

A little more recent picture showing the support structures on which the amplifier frame assembly units will be assembled. I should maybe say a little bit about alignment of these assembly units now, because that will come up in a number of, a number of cases.

These are assembled in exactly the same mechanical configuration in which they will be mounted in the facility. So they, they hang from these structures.

And that's important in terms of achieving the alignment tolerances for where these amplifier slabs ultimately get positioned in the laser. John talked about the uncertainty with which you place components in the beam line.

For these particular components, for amplifier slabs, that tolerance the plus or minus three millimeters. So that means in the amplifier slab, that 400-millimeter aperature, there's a few millimeters around the outside edge which is there because we cannot locate the slabs with infinite precision in this large facility.

That actually comes up in a number of cases when we talk about LRUs, that alignment precision. The, a couple of things that really come through here are glass close together, literally sort of an inch or less between edge of glass to edge of glass, which drives the mechanical engineers kind of crazy. They like to grab onto things and there's no, no room to grab onto it.

And then in this laser bay the, the length of the laser in that laser system is 123 meters. We have sort of millimeter-type tolerances on positioning in these optical components.

The reason why we try for a millimeter is looser than that we give up aperture, which means we give up gain. Tighter than that I don't think we can achieve.

So it's sort of a millimeter-class alignment in a 150 meter-long facility, or pardon, 10 to the fifth. That's a, that's what we're shooting for.

Okay, the third part of the laser engine, so far it's been near infrared, is the final optics assembly here where the light's converted to the ultraviolet. I think yesterday you saw a photograph or two of the target chamber, this 10-meter-diameter sphere.

It is the mounting structure for the final optics assembly. Where you see these plates, these are where the final optics assemblies will be installed.

And just to follow up on the question about direct drive, these ports here are where you would install the direct-drive final optics assemblies. So the target chamber has the ports in the proper location for that.

Okay, John showed you a schematic of the optical system inside a final optics assembly, one beam line. Here is the engineering prototype of the final optics assembly.

There are four laser beams that, that come into one of these assemblies. They go through these modules here, one, two, three, four.

Inside this housing here then are the optics that John was, John was describing. The frequency converter and focusing lens are about here.

The debris shield comes in and out through this slot here. So this actually gives me a chance to talk a little bit about how the engineering responded to some of the physics and operational requirements.

A couple of people have asked in the last day or two about changing out debris shields. We estimate that that's something you'll have to do every week, probably on a maintenance day.

On Nova that was always on Monday. So you'd have to change out 192 debris shields every week.

This is an LRU here, this, this housing, but so is this, the thing that goes in this slot. There's a cassette, sort of like a kitchen drawer -- Weighs a little bit more than the fully loaded silverware drawer. -- that has to be installed through this slot onto precision slides into this, this module.

This can happen on, on the beam line. Let me jump to my next picture to give you a little sense of what some of the engineering challenges are.

Okay, this is a similated picture. We took the final optics assembly photographs and pasted them onto here to give you a little sense of what, what, what operators are going to deal with in dealing with some of these operations.

You'll notice we've only put every other one on. So these are relatively close together. You access these by various floors in the target building.

So this debris shield change-out, which we think will happen once a week for all 192 beams, involves about a 15- to 30-minute operation of actual exchange. Two people would remove the debris shield from the previous week's shot and install a new debris shield.

There are a couple of cleanliness aspects that factor into this design. You can't just open up the interior of the beam line to the laser bay or target bay, because they're not clean rooms.

So, in, in the design, it's not shown on this photograph, but there's sort of a local clean room, clean hood over this area that blows clean air across the opening allowing you to slide in a plate allowing you to cover up the optics on this side.

A plate also goes against the debris shield cassette. You extract that cassette.

So here's the plate on the expensive optics. You slide in the new debris shield cassette.

These double plates go together, and then you extract that, maintaining the cleanliness.

And this is very challenging engineering because the pieces of glass, again, are very close together.

In this case it's longitudinally, and so the space requirements really drive the, the engineering detail and the design.

A couple of things John didn't tell you about the magic of frequency conversion was just how hard this magic is to achieve.  It's very sensitive to angular and, and, and positional tolerances.

The frequency conversion process, the Type I/Type II configuration is sensitive to tolerances on the order of ten micro-radiance.  Now, how do you hold the crystals in the lens to those type of tolerations and give yourself the ability to tip and tilt it to do the frequency conversion and get the performance that John described?

Now, in Type I/Type II, the doubler is sensitive to tilt in one axis, and the tripler in the other axis.  It's actually convenient, and we took advantage of that in the optomechanical design, because both the doubler and tripler are in the same optical mount, which then turns in one axis to tune the doubler, and the other axis to, to tune the tripler.

In that same mount is also the lens,

all in close proximity, about 20 to 30 millimeters apart.

The crystals are thin. They're sort of about a centimeter in thickness, and about 40, well, they're 41 centimeters square.

They're kind of floppy types of things. And the frequency conversion processes cares about the local variations of the crystal's axis. And that local axis can be distorted by strain, gravity, mounting pressures, and so forth.

So this cell, which was manufactured using relatively conventional machining techniques, was able to achieve the flatness requirements on these mounting services, which are two to three microns, for both the doubler, tripler, and lens surface.

And this particular cell, this was a photograph of the cell that was tested as part of the Beamlet frequency conversion campaign. So we actually put 37-centimeter crystals and lens into a cell, put it onto Beamlet.

Okay, that sort of walks you very, very quickly, I know, through the, as I said, the, the engines of the laser system. I'm going to go back now and talk about beam transport, how we get the light through the laser system, and what some of that hardware looks, looks like.

I'm going to talk just very briefly, I think, about the deformable mirror, because you've seen a few of those results. I'm going to talk about spatial filters, and talk about mirror mounts. And I'll also talk about the pockel cell for, for just a moment, too.

So, one of the things that, that is very central to the performance of the laser system is, is the adaptive optic. The deformable mirror corrects primarily the thermal distortions in the amplifier slabs.

As Ed mentioned yesterday, when you fire these flashlamps, a tremendous amount of heat is actually deposited in the laser slabs. They distort in a very quick sense during the pulse, and also there's heat that resides in those slabs for a long period of time, and that distorts the optics.

But in addition to those aberrations, there are aberrations due to fabrication of optical elements; installation, lenses don't go in exactly the angle that you'd like them to go in.

There are some low-order distortions in the nitrogen environment. The adaptive optic, which has 39 actuators, is designed to address those low-order, relatively low-order aberrations.

So it can do sort of third-order and a little bit into fourth-ordertypes of correction, which turns out to be exactly what's needed from the amplifier distortion. The amplifier distortion has sort of this "M" shape to it.

It's kind of a third- or fourth-order type effect. The optical aberrations due to mounting and installation are, are generally a second-order and a fourth-order.

So the mirror is very well-suited to the aberrations of our system. This is a, a mirror that was tested on, on the Beamlet system, and I think you've seen this picture maybe, this is the third time now, of test results from, from the Beamlet laser system.

One, one thing that maybe hasn't come forth yet. There's another operational advantage to having a deformable mirror.

Because you have this heat in the laser system, and you're basically waiting for the laser to cool down before you can fire again, that means there are periods of time when you can't align and can't do anything with the laser system. The adaptive optic actually gives you the ability to start that alignment process earlier, before the system has completely cooled down.

And the adaptive optic is not really moving very far. It has a 15-wave peak-to-valley system requirement, but light bounces off of it twice, and it's a mirror.

So that means we're actually only pushing and pulling on the mirror's surface a few microns, three or four microns. Now that's a big number in optical sense, but small mechanical, small mechanical movement.

And this is another opportunity for me to say what we're doing with, where we are in, in, in, in this acquisition. We're currently in the process, beginning the process of transferring the technology for assembling these mirrors to the University of Rochester Laboratory for Laser Energetics.

So our current strategy would have them building up and testing these mirrors for us, transporting them here to be integrated into the actual mount, and installed in the, in the laser system.

THE CHAIR: That thing that's two-fold

symmetry, right?

DR. ENGLISH: In this axis and in this axis? Is that what you're referring to?

THE CHAIR: Yeah, the horizontal and vertical are not identical.

DR. ENGLISH: That's correct. Actually there's a, there's a couple of details here.

You, for alignment purposes you actually need to be able to see through this mirror. The actuators on the edge are actually just outside of the aperture of the mirror, but they're needed to control how the edges sort of flap around.

But there are, but there are 39 actuators. The place where the symmetry's broken, perhaps, is what you're referring to, is right here in the center. If you took these two out.

THE CHAIR: Yeah, there's --

DR. ENGLISH: Okay, the pockel cell is the next thing I'd like the talk about, and after I speak, I understand there's a, a short break, so that might be a good opportunity to step out in the lobby where we have a prototype of a, a 2-by-1, so-called 2-by-1 version of the pockel cell. For NIF you need a 4-by-1 version.

If I go back to the amplifier

configuration, the amplifier configuration really drives the bundle geometry. Four apertures high by two wide.

Most LRUs in the laser bay that hold large-aperture optics are four, four high, one wide, so there are two LRUs per bundle. So this is the pockel cell.

Four apertures, but electrically it's really like two of the units that you see in the lobby. It's two 2-by-1s.

A number of challenges in, in this engineering task. Some of those were addressed in Beamlet, where we built a single-aperture pockel cell.

Some of the things that we looked at for NIF, again getting towards sort of manufacturing and engineering, going away from a polyethylene insulating housing to an aluminum housing, aluminum being able to offer the structural stability that we needed with thinner walls.

Again, remember, things are closer together so we need to, to look at thinning up the walls of things. However, the aluminum does not electrically isolate the cathodes and anodes, so it's annodized to provide that insulation.

That's one of the technology engineering developments that had to be proven for the NIF design, again, responding to these optical spacing requirements, as well as trying to generate the uniform plasma across all of these apertures. And the pockel cell is really one of our, I think, greatest success stories, not only from a technology standpoint, but, but an engineering standpoint, because it works.

The requirement is that the, that the average transmission be greater than 90 percent, 99 percent, with no point in that aperture less than 98 percent.  This is extinction ratio, or switching efficiency, if you will.

The prototype exceeded those requirements, 99 percent.  And principally the, the losses are due to strain in the windows that bound the, the pockel cell environment.

Okay, one of the things I was involved with quite a bit in the early preliminary design of the, the NIF system was the tran-, the spatial filters, how they were laid out, how long they had to be, some of the optical imaging and relaying requirements.

This spatial filter here is 23 and

a-half meters long. This one is 60 meters long.

The length from the front surface of the deformable mirror to the output lens here is 123 meters. So it's actually a little more than half of the length of, of the, the laser system is, is this evacuated space for spatial filters.

What drives this length is the length of the cavity, which is twice that length, as John says, or the cavity is 47 meters. And to get to the 47 meters we had to think about things like: How are we going to install and maintain these line-replaceable units?

How much space do we need between mirrors and amplifiers and lenses to be able to do those insertions and removals and those maintenance activities?

That actually drives the cavity a little longer than the way a physicist would think of it. But it's, it's got to be a facility.

It's, I like to call this a "light factory." It's got to work day-in, day-out. So we have to accommodate that in the design here.

The transport spacial filter length is principally driven by the length of the path from the output to the target chamber. These different beam paths range in length from sort of 60 to 70 meters, and that ostensibly sets the length of the transport spacial filter.

It's not just a simple geometric optics problem, because we're talking about a high-peak power laser where there are nonlinear effects. So the, the uniform irradiant distribution that you like here actually happens over a several-meter length, and it's a fairly shallow minimum.

But that's what sets the length of this transport spatial filter.

Now, on Nova the longest spatial filter was 13 meters. This is a picture of a Nova Spacial Filter Number 5. This one's actually nine meters.

A round lens here, a round lens here, tapered beam tubes to a pinhole assembly in the center.

On NIF, the optics are square, and that's basically a packing fraction reason. We have to put things close together, and that's what drives the design of the optomechanical hardware, being able to pack these square apertures relatively close together.

And a couple of years ago there were fairly heated discussions between the mechanical engineers on one side, and the optical engineers on the other side, the optical engineers wanting the glass to be a little bit bigger for manufacturing purposes, the mechanical engineers wanting it to be a little smaller so they can have a few more millimeters to put the aluminum and stainless steel around to hold onto it.

But this is Spatial Filter Lens Number 4, which actually has a lens and a diagnostic beam splitter.  Real NIF glass is not orange.  This is a, a surrogate that's used for the prototype testing.

But again, you see the sort of familiar LRU hardware geometry stacked four high by one wide. And if you're not sort of cal-, to kind of calibrate you, if you hold your hands out like that, that's about how big the NIF laser beam is.

That's sort of about 16 inches, which is the size of a NIF laser beam.  So that gives you a sense for the, the scale on these spatial filter cassettes.

Again, just point out one of the engineering aspects that, that came into this particular task.  Traditionally for these vacuum spatial filters lenses the barrier, this is the barrier between vacuum and, and atmosphere of pressure, we've used O-rings to seal between those two.

Now, the NIF lens design is equiconvex, so it's cured on both sides, and it's square. So when you trace out that profile, you get this sort of pillow shape.

You can machine into the, the bezel that shape for an O-ring. It's fairly expensive.

We have 192 beams, each having four spatial filters. So the engineers working in this area had the idea to try and use a shaped or formed gasket which would be mounted on a flat surface, so a cheaper manufacturing process than putting on a gasket which actually has that shape.

That's not something you would do when you're building one or two or three or four, but when you're building lens mounts for 800 lenses, that becomes an economical thing to do. So that's one of the kind of engineering tasks that was proven out in the last couple of years.

Let me talk about mirror mounts for a little bit here. In the laser bay it's this bundle geometry, four high by two wide.

When we get into the switchyard we have to split that grouping so that half of the beams go to the top of the chamber and half go to the bottom. That happens right here at the first mirror in the switchyard.

Four of the beams are directed up and four of the beams are directed down. Now, remember, the amplifier drives this spacing, both horizontally and vertically, and that derives, again, some of the mechanical engineering aspects for some unique and, and new places.

Here's a, a photograph of the, of a mirror being tested. And I want you to observe in this photograph how the mirror is being held.

It's being held from the back. There isn't enough room on the side to grab onto the mirror.

And if there were, because of gravity pulling down, or in the other case, the mirrors facing up, the distortions of the front surface would be larger than we would like. So part of the mechanical engineering design was figuring out how to hold onto the mirror from the back.

There are 1-inch diameter holes drilled into the mirror. A mandril's inserted in there, expanded to hold onto the mirror.

And they're positioned in such a manner

so as to minimize the distortion due to gravity. So, this mirror was tested, this mirror mount design developed here at Livermore.

A flecture-based kinematic mount design was shown to meet the requirements of sort of a quarter-wave peak-to-valley distortion as mounted. You can actually see, so you have to, you have to look at the scale here.

This is in 100 nanometers minus 100 nanometers, so these are sort of 50- to 100-nanometer depressions. These were actually where the, the, the attachment points are.

And because they expand out, that actually pulls, by a plasmon effect, pulls the front surface down slightly. This, however, meets our requirements for, for beam transport to the final optics, for frequency conversion, and then focusing down on the target.

Okay, so that's kind of a very quick tour of LRUs in the system. The last topic that I'd like to just briefly address is the assembly of these LRUs.

You've heard discussed some of the aspects of the cleanliness and what happens in the amplifier, or actually in any optical element where you get a little bit of contamination at these high peak powers and high energies.

So the optics assembly building, which is down here, contains an 8,000-square-foot Class 100 clean room. And for the most part, that's where these large optical elements were mated to their mechanical and electrical systems.

So amplifiers, pockel cells, lens cassettes, mirror mounts, those are assembled in this assembly building, which is just about ready to be turned over to the program to operate as a, as a clean room. And in fact, in my areas we've got a few people getting ready to install equipment on those isolation pads.

Those are essen-, essentially the equipment that will be used for doing this assembly, the alignments, fixtures, and so forth.

The final topic that is what I sometimes think of as an extension of the optics assembly building, is how you get these LRUs from this clean environment, through the laser bay, and then installed in the clean beam line.

We have these transportable clean rooms, essentially, that, that match the environment into which the optic's going to be inserted. So it's, for the most part it's a nitrogen environment in the main laser cavity, except for, of course, the, the vacuum in the spatial filter.

We have a large, essentially automated guided forklift that carries the canister inside of which is a line-replaceable unit. The line-replaceable unit is placed in the canister in the optics assembly building, closed off.

The transporter picks it up, carries it down the aisleway to the appropriate location in laser beam line, docks to the laser. Remember, the laser is over your head. Docks to that.

There are a pair of these covers then that remove, push the LRU up into the beam line, where, by kinematic mounts, it's positioned onto its, its mounting position. Again, the tolerances for where that optic ends up when you're done with this operation is a millimeter. Some cases it's three millimeters.

And you have to think about that in the context of this large laser bay which starts from concrete, concrete pedestals, structures, a beam path, beam tubes, mounts inside of that, and this LRU being essentially precision positioned to kind of a millimeter tolerance.

A millimeter's kind of a big number to a mechanical engineer, but again I remind you of the scale. It's ten, it's one part in ten to the fifth of the whole facility.

So a lot of activity has been happening in the last couple of years with the engineering design, and in many of the areas I've described, the design is complete and, and we are either in procurement phase or, or rapidly moving into that.

The master oscillator, it is being built right now. The preamplifier module, as I mentioned, we're preparing the procurement documentation to have that acquired as an integrated unit from an outside vendor.

In the frame assembly units for the, in the amplifier, those enclosures, they'e being fabricated now. The assembly facility is being prepared. Starting in the spring we'll begin those assembly operations.

Capacitors and flashlamps, they're on order. As I mentioned, we're developing an acquisition strategy for the power conditioning system which would have an outside contractor build, assemble, test, and install these 192 modules into the facility.

Some LRUs, like the pockel cell, have their final documentation package being prepared for procurement. In almost all cases where the LRU touches the infrastructure there's some mounting hardware. Those procurement packages, some of them are out. Some of them are being prepared now. Some of them are out in the next couple months.

The deformable mirror technology is being transferred to the Laboratory for Laser Energetics. They will do the assembly and testing of these mirrors for us.

I didn't dwell on this at all, but the final optics assembly contains a large vacuum isolation valve to separate those four beam lines from the target chamber. That contract was awarded in July, and the housing upon which the integrated optics modules mount, that contract is also out.

And as you saw from the photograph, the, the installation vehicle is actually being tested, programmed for use right now.

So just to wrap up, again, a couple of the challenges that, that the engineers have faced in, in designing this hardware is meeting the performance requirements. I like to say that the engineer's job is to make the physicist's dreams come true.

They talk about the magic of amplification, the magic of frequency conversion, the magic of switching from a pockel cell. Someone's actually got to manufacture that hardware and have it meet those performance requirements in an operable, maintainable, cost-effective manner.

And that's, that's really the, the engineering challenge. We've tried to, in some cases, especially like the master oscillator, design things in such a way that we can incorporate new technologies as they become available.

I think that's a, a prudent thing to do when you're talking about a facility that will operate for 20 or 30 years. This has been a big aspect of many of the engineering discussions.

It's not just, "Can you build it?" but, "Can you build 192 of them? Can you manufacture it?"

So the discussion's about casting something versus machining it. If you're building a protective, building a one off, you'd probably just machine it so that it worked.

But again, for the quantities of roughly 200, you start to look at other technologies that are more cost-effective from a manufacturing standpoint. This, of course, is an activity that has been engaged fairly extensively in the last six months especially.

How are we going to buy this stuff? How are we going to get it here?

How are we going to manage and know what's where, quality control of that? And ultimately, how are we going to assemble that and install it into the, into the facility?

Those were my prepared remarks. I'm happy to answer, try to answer any questions that you might have.

THE CHAIR: Thank you.

Any questions?

DR. VOGT: What are your problem areas?

DR. ENGLISH: Well, I think there's a couple of ways I can answer that question. We have some parts of our, of our system which are in final detail design.

They're, for the areas that I'm responsible there are about 8,000 mechanical drawings. We have about 6,500 of those complete.

So one area that, you know, I'm actively engaged in is: Who are the engineering teams? Are they sufficiently organized to be able to finish out the designs of the LRU equipment, and in a more urgent sense specifically the hardware that has to be provided to the infrastructure, the mounting hardware and so forth.

So things like frame assembly units, kinematic mounts, I don't know if they're so much problem areas, but they're the areas that, that I pay very close attention to. I think by and large the optomechanical system I feel pretty good about.

We've got, you know, problems at all kinds of different levels, sometimes problems that come up each week, and you, you work on those. We're, we're looking at designs in a couple of areas to see if they are robust enough.

DR. VOGT: But nothing which requires R&D?

DR. ENGLISH: I think predominantly no, not, not really R&D. Now there may be some technology-driven responses.

For example, we talked a little bit about 3-Omega damage. There may be some this about 3-Omega damage and how you have a laser system that operates for the lifetime that you'd like it to that would factor into the, the engineering aspects.

But they tend to, the, the technology

related things from an engineering standpoint tend to be much more sort of detailed, like: Is this material acceptable in this environment?

Can it be cleaned? Does this manufacturing process yield a, a product that meets the other requirements? Very sort of engineering -- I, I don't really think of those as R&D types of things.

THE CHAIR: Any others?

(Whereupon, no response was had.)

THE CHAIR: Thank you very much.

DR. ENGLISH: As I mentioned, during the break I'll be out in the lobby if you want to ask some questions about pockel cells or that flashlamp that's back there.

THE CHAIR: All right. Thanks.

We reconvene at 10:30.

(Whereupon, at 10:12 a.m. PT the members took a brief recess and returned at 10:30 a.m. PT, after which the following occurred:)

THE CHAIR: Now we're up to the cleanup hitter. Jeff Atherton is here to talk about optics development.

OPTICS DEVELOPMENT PLAN AND REQUIREMENTS:

DR. ATHERTON: As John said, my name is

Jeff Atherton. I'll take the next little bit of time to try to get you up to speed with where we are on optics development, our plan and requirements.

Here's a summary outline of my talk. What I'll go through up front is just the scope and approach that we're using for the large optics production. That's to get the roughly 7,500 large optics that we need for NIF.

Then I'll go through the status of our optics manufacturing technologies and the facilities. And what you'll see very much is that we're transitioning from this pilot production phase into main production. You'll see that in a lot of different ways.

And then I'm going to wrap up with the plans for on-site optics processing, which is cleaning and applying the silica gel antireflection coatings in the optics processing development laboratory.

Just to give you a little historical perspective, supplying precision optics for ICF lasers is a decades-long endeavor. And I summarize for you, going back into the early '70s, the Janus laser, which you saw laser glass yesterday from Ed Moses, and I'll show you again today in a little bit, going from Janus up through Beamlet, we've built and operated a series of lasers, each one having larger aperture and higher energy, in general, than the one before.

And just in perspective, Janus had about a 10-centimeter round aperture up through Beamlet, 40-centimeters square, so much larger apertures.

In terms of the materials, Janus was silicate laser glass. Nova was phosphate laser glass.

The materials that we used even for things like the, the multi-layer coatings for mirrors and polarizers, going from, in Nova, from titania silica. Beamlet was hafnium silica. Has advantages for damage resistance.

And then even fundamental things like KDP crystals. These were infrared lasters.

For Nova, the beginning of Nova, the biggest crystals you could buy were about this big. Nova got them up to this size, and then for Beamlet, even larger still.

So, so that's part of what we do in buying optics, both for looking backwards in time and going forwards, is, is, to advance technologies, whether it's the materials themselves or the manufacturing technologies. For example, in NIF, here we'll be manufacturing at a much higher rate than was ever done before, especially for Nova; roughly, you know, anywhere from sort of, you know, five to 20X, the manufacturing rate.

So, and the way we do that is to partner with the optics industry. We've done this for the last 25 years and what, a big part of our mission is to develop and then transfer advanced manufacturing technologies; develop them in place wherever we can, but the idea is find out what we need to do, make sure it's developed, get it in place in industry, and then move on.

So, to accomplish the requirements for NIF there are a number of advances in optics manufacturing technologies that were needed. And I summarize them here briefly by discipline.

And then what the key technology requirement is for NIF in laser glass, it's going from batch melting to continuous melting and forming. In crystals, going from rapid crystal growth, on the order of 10 millimeters per day.

Fused silica: Optimizing the boule geometry with a much higher product yield and a product delivery rate.

Fabrication, both for flats and for lens fabrication, having im-, better grinding, much higher speed polishing, and deterministic figuring. And "figure," it's, it's a term from the industry. It means bring the wave front into specification.

And then optical coatings: Better process design, better control. Reduce defects for improved damage resistance, and then high throughput.

So I'm going to go through all of these things with you today. So those are the technologies.

I want to just illustrate for you how we manage the flow of these optics. And we manage them from the material manufacturing through finishing and coating, and then on-site processing, where they're cleaned and coated for delivery into the LRUs.

And this is just illustrated for crystal. So here's a rapid-growth crystallizer that produces the material.

It goes on. It gets finished.

This is the diamond-turning machine that does the final finishing. And then here for processing, where it goes through an automated cleaning process, and then on to cell gel coating.

So that's, that's a specific illustration. What I've got here is a flow chart more comprehensive of how we do it.

In order to accomplish this, we either have new or augmented facilities that have been built at vendors with proven track records. These are the companies that we've worked with for the last 20 years.

And I trace these for you sort of two ways. There's the material vendors. These are the ones that supply, for example, the laser glass, the BK-7 substrates for the mirrors and polarizers, fuse silica substrates for lenses and windows, and the crystal boules, KDP or a deuterated KDP.

We also track it this way, okay? In this case the, the red is for the laser glass. The laser glass goes on to Zygo for finishing.

Some amount of it will be small-tool figured. I'll talk about that a little bit; and then into the warehouse.

The green sqaures are for the mirrors and polarilzers, so BK-7 finished at either, it will be Zygo or Kodak. Kodak winds up being a flexible facility. It could have four, three different colors here.

On to LLE, that's the Laboratory for Laser Energetics at the University of Rochester, or Spectra Physics for coating; again into the NIF warehouse.

Blue is the fused silica, blanks getting fabricated primarily by Tinsley, also by Bond, into debris shields; into the NIF warehouse.

And then crystal's grown by either Inrad, Cleveland Crystals, or Livermore, finished at Cleveland, and then into the warehouse. And then -- Where they're stored.

And then they're brought out and processed just in time for installation in the NIF. So, what I want --

Yes, sir.

DR. VOGT: When you have two suppliers, for example, like the laser glass, --

DR. ATHERTON: That's right.

DR. VOGT: -- could one supplier do the whole job?

DR. ATHERTON: Yes, either one of these. We have facilitized so that either one can do the entire job.

So what I'm going to do now is in just

a little bit I'll take you through each of those components kind of one by one. But again, just to put this all in perspective before I, I get into that part of the talk, we're going through what I look at as a four-part program that's being followed to meet the NIF optics requirements.

Technology development, this was actually conceived of back during the conceptual design phase. That's done.

Facilitization, that's creating those facilities, and I'll show you where we are there. Technology demonstration, as opposed to development, which is our pilot production, and you can see we're right in the middle of that now, and then transitioning into production.

And that's what we're doing. So, in fact, some of the production is already started.

The fused silica, the BK-7 glass are the two biggest ones. Also deuterated crystals. So now let me talk specifically about laser glass.

Livermore's worked with industry to advance this laser glass technology dramatically in the last 25 years. This is a, another photo that you saw yesterday, but again, Janus, this is 10 centimeters, this is back in '73, up through Nova and

Novette in the mid-'80s, Beamlet in '92, and then continuous melting here.

And again, if you just look at this Beamlet slab, there's more laser glass in this slab than in the entire Janus laser. And in terms of, if you want to talk about volume, in this continuous melting process, it will make more glass for one NIF budget than was in the entire Nova laser.

So again, it's, it's magnitude, it's silicates, the phosphates, and we will need over 3,000 laser glass slabs, and they weigh about 150 tons, for NIF. And in order to accomplish that there are really three main challenges.

It's increasing the production rate about 20X over what we had to do for Nova, and then getting the cost per liter down by about a factor of 5X below Nova. And it's these two together that really drive you from this batch process into a continuous melting process.

The size of the job is just big enough that it, it is, it puts you onto a new technology curve. But then having done that, we have to produce glass with a quality equal to or better than Nova.

Now, in Beamlet, that's using the batch process, we actually did that. So Beamlet glass was made to the NIF requirements.

Okay, so our challenge is, okay, do it continuously, but maintain quality.

DR. VOGT: When will you know?

DR. ATHERTON: Let me just speak to that. I'll, I'm getting to that in the next few minutes, and then I'll, if I haven't answered your question then, I'll, I'll take care of it then.

So, the U.S. and France have facilitized two companies. You asked about that.

The two companies are Schott Glass Technologies in Duryea, Pennsylvania, and Hoya Optics, the U.S., in Fremont. These are the only major suppliers of laser glass in the world today.

And both of these companies have supplied glass, again going back 20 years, for major ICF facilities throughout the world: Nova, Phebus in France, Gekko in Japan, OMEGA at LLE, and most recently, Beamlet.

Now, working with the CEA, these companies have developed this continuous melting technology. And if you look at these, these systems, these are the most advanced optical glass melters in the world today, both of them.

And having exercised them, we have,

what we've proven out so far in this production rate and the cost polls, we've actually demonstrated them in these pilot production runs. And what I mean by that is you have to be able to make enough glass, these 3,000 slabs, by 2003, in order to hold schedule. Both companies have shown that they can meet the production rate.

Then there's the intrinsic manufacturing costs. What does it cost just to operate one of these melters and put phosphate glass out in slabs?

And what we've shown, too, is that the intrinsic manufacturing cost has been met. So now what it really comes down to, and I'll, and I'll speak about this in a lot of different ways, is yield to specification. Okay?

So, intrinsically we understand the costs of the manufacturing processes. We can get the rate we need, and we can get that rate from either company by itself, speaking to your point again.

Okay, both companies have built roughly 30,000-square-foot facilities. This is a picture of the Schott facility in Pennsylvania from the outside.

This is one of the Hoya, also roughly a 30,000-square-foot facility, from the inside, which you're looking from one end of the building. Up on this floor right here is where the melter sits.

The glass is melted and conditioned, homogenized. Then it goes down into a forming region on the first floor below this point, and it flows through a long oven where it's quartz annealed, okay?

And if you look at the other end of the building where that glass comes out, in either building you see something that looks like this. And so Hoya and Schott have both produced NIF-size laser glass using this continuous melting technology.

This is what the glass looks like coming out at the one end of the Hoya building. This is what it looks like coming out of the Schott building.

So they both made it. And again, if you look back in perspective in '95 or even '97, we were still projecting that these companies would be able to build the melters and be able to operate them; that they'd be able to produce phosphate glass in a continuous strip at this size, and they've both done it.

And so our focus as we go forward is refining the process in order to maximize the yield to assess specifications. You all know that there have been several issues that we are working through in terms of what these specifications are.

The biggest one is the OH content of the glass, what we sometimes shorthand call "water," okay? And there, the issue with the "water" is that it reduces the excited state lifetime of neodymium.

So, we're trying to get the "water" content down by roughly a factor of three to four over what the pilot glass was, okay? And, and the reason that "water" is, is an issue is that it turns out again that there is enough differences in the continuous melting process, the residence time in the glass in the the parts of the melter where the glass is dried is less than in the batch-melting process.

And so it turns out that the raw materials need a tighter, a tighter spec on OH for continuous melting than for batch melting. And the course, in the course of doing this pilot rn last year we discovered that and we've quantified that. So I want to take you through what our plans are for that.

The second issue is the homogeneity. And that is, you know, Ed spoke of that yesterday, that we've got tight wavefront specifications on the homogeneity of the glass. It's nominally about six-wave peak to valley.

And a fair amount of the glass, we've got some glass that, out of the pilot that actually meets the homogeneity specs, but we also got a fair amount of the glass that was, that did not meet that specification. We believe that a lot of that was because of the, the vendors exercising the melters, trying to get the "water" content down.

And as, as a lot of you can relate to, if you've got a process, any kind of a continuous process, if you're jerking things up and down upstream, you'll see that in, in properties downstream, okay?

And so, in, in exercising the, the melters upstream trying to get the "water" content down, there's variations in the homogeneity, which gets reflected in the index of refraction, variations in that that produced errors in the transmittal wavefront that were not acceptable.

Now, we believe that the glass, you know, going forward will be better than that. But again, what we have, we were concerned about what the wavefront would be in this continuous melted glass, and so we made sure that we had a technology, a finishing technology that could correct that.

And I want to speak to both of those things. Those are the two issues that we are most concerned about.

You guys may have heard about others, things like platinum inclusions. That is not a dominant concern going forward.

Okay? It's really OH, and it's homogeneity. I want to speak to both of those.

So, at Livermore we have installed and operated a rotary calciner to demonstrate raw material driving, drying. Calcining is just the act of taking material and heating it up to drive off, you know, some volatile component. That's all calcining means.

In this case what it's doing is taking the starting materials for the laser glass, heating them up to drive off water which is either physically or chemically bound to that raw material, and then cooling it back down again. So it, conceptually it's very simple.

There's a heating region where you drive off the material. There's a drying region, and then there's a collection region.

DR. VOGT: There's no water used in the manufacturing process at all, is there?

DR. ATHERTON: No. In fact, in fact, it's the other way. There, in the manufacturing process there's a, part of the, of the melter is actually, it further dries the glass, okay? Okay?

So, what we have shown here, this is operating, this is taking actual starting material from both Schott and Hoya, and actually running it through this calciner. And we have shown that about 90-percent of the OH can be removed in doing that.

And removing that 90 percent of that OH is what gives us a lot of confidence. By, by the models that we have developed and applied to their pilot production campaigns, the results and the actual detailed melter designs, we believe that this will get us either to or extremely close to what the, the requirement is, okay?

And the other important thing is, in terms of a technology response, these are well-established methods for drying raw materials. This is not, you know, something that had to be invented or, or, or even particularly discovered. People know about this.

So, both Schott and Hoya are installing calciners for their Fiscal-'00 pilot campaigns. They will be in place.

DR. VOGT: You've said this, it's getting us close. You didn't say it's giving us a margin.

DR. ATHERTON: Well, what, what, what we have, actually several different steps that we are planning, that the companies are planning to introduce that if they all worked as well as intended, we would actually get below the specification, okay?

DR. MOSES: There's one other thing you should know, Robby. You know, right now we're, I think we're at 400 parts per million, --

DR. ATHERTON: On that order, right.

DR. MOSES: -- and we're shooting for 100 parts per million. Even if we had the glass as it is now, you could, by adding the capacitors to the power lines, reach the system specification that you had.

So even though I, I have great confidence they will succeed, from the point of view of the operating system, it's a fairly low risk situation. But it is a spec we have for the manufacturers, and we are pressing them on, on meeting that spec.

DR. VOGT: I'm sensitive to it because

I've had OH problems before.

DR. ATHERTON: Yeah. And as Ed talked about, you know, we're talking about, you know, in the hundreds of parts per million. It's relatively low. And, and I understand what you're talking about.

Okay, so that's the OH. Now, wavefront.

The wavefront yield for the laser glass can be improved by small-tool figuring. And I want to take a minute to explain that, because, again, this is a little bit of jargon.

Most glass, clasically it gets finished on a very large, continuous polishing lathe, and I'll show you a picture of one here in a, in just a few minutes. And so the, the polishing head is actually very much larger than the optic itself.

So, you can do things as long as any variations in the, the, the, the homogeneity are in relatively long length scales, sort of in order, you know, of half to a-third of the size of the optic, you can figure, figure out those errors even on a large lathe. If they get to be on the order of, you know, a few centimeters, you know, sort of this size versus this size, then these large polishing lathes cannot take that homogeneity out.

But, it turns out Kodak has what they call small-tool figuring. This is an actual size of the head.

This is, is actually a Nova turning mirror, but they've also applied it to, to laser glass. And so by, by putting the optic on an, on an interferometer they actually will generate what the actual wavefront is.

They can turn that into what they call a "hit map" and then determine where they want to selectively remove material in order to make the transmittal wavefront meet specification. So they're changing the optical path to compensate for changes in the index of refraction.

And that deterministic figuring can compensate for the glass inhomogeneity by this preferential surface removal.

DR. VOGT: But it costs more.

DR. ATHERTON: Costs a little bit more, okay? It turns out that, that the, the, the, the incremental cost of doing that, that step is on the order of about ten percent of the cost of the glass itself. So it costs a little bit more.

DR. WARNER: Is this just on the ends

of the slabs?

DR. ATHERTON: Pardon?

DR. WARNER: Is it just on the ends of the slabs?

DR. ATHERTON: No, it's on the faces.

DR. WARNER: On the faces.

DR. ATHERTON: Yeah. The, the slabs go through at Brewster's angle, so, so, yeah, they, they, this would be square, think of, or a rectangular slab sitting like this.

And this, this small head would traverse back and forth over that optic, and based on, you know, the amount of time it dwells there, that, that will determine how much material is removed.

DR. MOSES: This is just like --

DR. ATHERTON: Ed?

DR. MOSES: You can sort of think about this as a very local deformable mirror, right? It's just in the surface itself you put little deformations in to make up for the bulk property, the bulk property heteroogeneity.

DR. ATHERTON: And, and we were concerned enough, going back several years, about how well this continuous melting would work that we actually had Kodak do this on several slabs for Beamlet, install the slabs on Beamlet, and show that the process worked.

DR. MILLER: You might comment on what's the amount of material you have to take off.

DR. ATHERTON: Yeah. Well, you know, the, the, the material going into this for this process to work efficiently, it still has to have a transmittal wavefront of a wave or better. So we're talking about taking off, going from one wave, which is order 600 nanometers, this is a wave at Heaney (phonetic), down to, you know, a-sixth of a wave, which is on the order of 100 nanometers.

So we're talking about taking off, you know, a few hundred nanometers of glass. It's not a lot of glass, and we're talking about very tight specifications.

DR. WARLAUMONT: How tight do they have to be?

DR. ATHERTON: I'm sorry?

DR. WARLAUMONT: You're talking about taking these things down to a-tenth of a wave?

DR. ATHERTON: Sixth of a wave at Heaney.

DR. WARLAUMONT: A Heaney wave?

DR. ATHERTON: Yeah. Okay.

DR. MOSES: So everyone is talking about thousands and thousands, you know, thousand-thousandths of atoms, right? Angstroms. Just Angstroms.

DR. ATHERTON: So, so this is what we're doing in transitioning this continuous melting technology from development into production. In '98, okay, this was a big step for us.

In '98 we actually proved in the development campaign that you could melt, continuously melt glass at full size. Okay? That hadn't been done before for this phosphate laser glass, which is a tough glass to melt.

Okay, in the pilot last fiscal year we've proved out the production rate and the cost. Okay?

And to be honest we had hoped that we would also be proving out the yield to specifications. These two areas that we talked about, we were not able to prove that, so we are going to do follow-on campaigns this year, second pilot, with a goal of proving the yield to specification, and then moving on to production.

The other thing I also want to show

you, again to put it in context, because this whole program up through this point right here was cost shared with CEA, because CEA, as you know, is building its own laser. They are planning on building a 240-beam laser comparable to NIF, larger than NIF.

And so, and we've done all of this planning jointly with CEA. And it's been a, a very good collaboration.

And so again, what we are doing now with CEA is, is strategizing with them how our second pilot and our production will transition into their production for the megajoule. So again, they aren't the only ones that are acutely interested in how well these, these laser glass companies are doing, and we're working with them to make sure that not only will we have enough glass, you know, that, that will work well for NIF, but also their laser megajoule project.

A SPECTATOR: What does "CEA" stand for?

DR. ATHERTON: It's --

A MEMBER: It's the --

DR. ATHERTON: It stands --

A MEMBER: -- the French DOE.

DR. ATHERTON: It's the French DOE.

A MEMBER: Tommy guns.

DR. ATHERTON: Oh, okay.

A MEMBER: They're building a NIF in France?

DR. ATHERTON: Oh, okay. Thanks.

A MEMBER: Megajoule.

DR. ATHERTON: Laser megajoule, okay? So --

DR. VOGT: Remember, they need independence.

DR. MOSES: Yeah. Only the French.

DR. ATHERTON: So, okay. So that's the laser glass itself, but once you've continuously melted all this laser glass, you're a long way from having slabs that you can install on NIF.

So Zygo, in Middlefield, Connecticut, expanded its fabrication facilities for finishing the NIF amplifier slabs, and it also turned out to be cost-effective to have Zygo also finish the mirrors and polarizers. So they have also kind of a 30,000-square-foot facility for doing the NIF amplifier slabs, mirrors, and polarizers.

The heart of their system are these ring polishes. They've built and installed all of their finishing equipment.

And this, this is a 168-inch, what they call a ring polisher. The rest of the industry calls it "continuous polisher," but, and they use that for the final figuring.

The 168 inches, if you're you're quickly working it out, that's 14 feet in diameter. Okay? That's an enormous thing.

What you're seeing here is just the part of it that's above ground. Actually most of it sits down in a pit below ground level, okay?

These were enormous, enormous machines. They can fit six amplifier slabs on the machine at the same time.

Again, Zygo, in its development program, has done a lot of work to develop a very efficient technology for bringing this glass into final figure requirement, but the issue is that the homogeneity has to be able to meet spec in order for Zygo to be able to meet spec. This having Kodak's small-tool technology is what gives us the ability to accept, to effectively get glass much less expensively than we would otherwise.

So that's their finishing technology.

DR. WARLAUMONT: Who comes first, Kodak

and then Zygo in the process?

DR. ATHERTON: No. What would happen is that, if we had glass that we said, "Okay, it, it, it doesn't quite meet the homogeneity requirement," what we would do is actually send that to Zygo, have them apply the edge cladding, do the grinding and finishing down to about a wave, okay, and then they're done.

So they, they can't make the sixth wave requirement with their technology, so they would take it to a wave, send it on to Kodak, where Kodak would do the final small-tool figuring, and then it would be delivered to NIF. So, it would go, it would go the glass companies, Zygo, Kodak. Yeah.

DR. VOGT: The process was used in the keck (phonetic) also.

DR. ATHERTON: Yeah. Exactly right.

Okay. So Veeco, which actually purchased Wyco several years ago, but it's now Veeco, and Zygo have built and installed 24-inch phase-modulating interferometers for in-process inspection and QA of the NIF optics.

There are ten of these 24-inch interferometers that have been built for NIF. This is one of them, actually at Zygo.

So now I want to talk just, just briefly about the mirror and polarizer coatings. These coatings will be made at, I mentioned earlier, a combination of Spectra-Physics and LLE using very highly deterministic deposition technology.

This is a picture of LLE coating chamber opened up. The, the substrates are mounted up here in this planetary where they're rotated along this axis and then also around here.

About 1,600 mirror and polarizer coatings will be deposited on roughly 400 square meters of BK-7 glass.

DR. VOGT: Where else is being done by Spectra-Physics?

DR. ATHERTON: Down in Mountain View.

Okay, and again as part of their technology development program they've developed wide-band optical monitoring and, and realtime error detection in the coatings on the optics themselves so that they can also do realtime error correction, and even reoptimize the coating design based on any errors that may have been introduced on previous steps.

So both LLE and Spectra-Physics believe that they will get yeilds in excess of 90 to 95 percent for all of these mirror and polarizer coatings.

A MEMBER: These are all hard coatings, now?

DR. ATHERTON: They're all electron beam coatings, EB.

So now on to the fused silica optics. Livermore and the semiconductor microlithography industry both are driving fused silica and lens manufacturing technologies. This explosion several years ago in the demand for fused silica for microlithography drove Corning to do a lot of internal R&D that supplemented some R&D that we had there in order to significantly improve their fused silica manufacturing process, and to the point where we actually last year negotiated a fixed-price contract with Corning for all of the NIF fused silica at our cost goal, okay?

So that has been an extremely successful program that Corning executed. Tinsley, and it was bought by the Silicon Valley Group, so it's now SVG-Tinsley, will be fabricating the, the fused silica blanks into leses and, and windows.

Here's a picture of one of the first fused silica transport spatial filter lenses. And I know it doesn't look like a lens, but remember, these have very long focal lengths, so.

And we need about 2,500 of these with more than 12,000 liters of fused silica. And like the glass companies and Zygo, the SVG-Tinsley has completed construction of about a 30,000-square-foot facility up in Richmond for making the lenses and windows.

There's a nice picture of it. And they're actually operating their equipment.

They've got their stuff all installed and they're operating it for the lens window, lens and window pilot production. This is a picture of their computer-controlled optical surfacing machine, what they call CCOS, for surface figuring.

Tinsley has technology very similar to Kodak's. They use subaperture tools for doing final figuring of their optics.

Again, it's deterministic, efficient, and it's very cost-effective. So that's fused silica.

I'd like to move on now to crystals. Single crystal boules of KDP and deuterated KDP, which is, we call DKDP, will be grown for NIF using rapid-growth technology.

Ed showed a picture of this yesterday. The technology several years ago as it came over from Russia, you could make crystals this big. You could hold them in your hands.

Okay, it took us several years, but we have successfully demonstrated that you could grow crystals of this size, 5- to 600 pounds, that meet the NIF requirements, using this technology. Okay?

DR. VOGT: You will grow them in-house?

DR. ATHERTON: That's not our plan. And in fact, again, going back to our mission is to develop the technology and get it out into industry.

DR. VOGT: Do you have to send the lady along to get that?

DR. ATHERTON: No, we don't. No, we don't.

In fact, if she had to be everywhere all the time we'd have real trouble. And I'll speak to that in just a second.

So we've had, I think, two remarkable successes in this program. The first one is the title, that the rapid-growth pilot production has produced 25 percent of the full NIF system needs.

Here's a picture of, of two of our crystallizers installed at Livermore. But I think even more successfully than that is that we've successfully transferred the rapid-growth process to Cleveland Crystal and Inrad, who are already world leaders in commercial crystal growth.

So both companies are today able to grow these rapid-growth crystals using this technology. And in fact, Inrad made a little splash a couple of months ago.

Here's a cover of *Laser Focus World* with a picture of 600-pound crystal, okay? This was grown by Inrad at Inrad with their crystalizer that, that was installed at Inrad in the background, with another crystal growing in it.

So that's the crystal growth. Once those boules are grown, though, you're not done.

You have to actually finish them. This is showing the doubler configuration.

There's three different configurations within a NIF boule: The pockel cell, it's a Z cut, the axis running this way; the, the doubler is tipped 41 degrees and clocked 45 degrees within the boule. This is a doubler. Tripler is just tipped 59 degrees.

Okay, so, so what we, so we start with a boule that's on the order of 55 centimeters cubed, about 500 pounds, and we need to get, as Ed English spoke about, roughly 41-by-41-by-roughly one-centimeter thick plates. And depending on how these crystals lay out in the boule, depending on the orientation, you get somewhere on the order of between five to 15 plates out from each boule.

And of course these plates have very tight requirements for orientation, for flatness, and for smoothness. So the two machines toward the end of the process are particularly important.

We've built a prototype, KDP flatness machine, and it has met the NIF performance goals. This is a picture of that, that prototype with a block up on, on top.

It's got a vertical spindle diamond tool on a, on a flight cutter. And this prototype, this actual prototype will be converted to the first production machine by an industrial partner.

So Livermore has, has expertise in precision engineering. We apply that expertise to come up with a process and the machine tool that would meet the requirements.

We'll now have it outfitted into an industrial machine by, by a partner, and also it will build, that partner will build a second machine as well. So that's, that's the, what we sometimes call the semifinishing machine, or the flatness machine.

Moore Tool Company is building the final finishing machine. It's actually here at Livermore undergoing acceptance testing.

We've just done preliminary acceptance testing, but it indicates that that machine will meet the NIF crystal surface roughness requirements. And what you're actually looking at here, again this is a spindle.

This is a horizontal spindle. There's a flywheel you can't see, fly cutter going this way. The part is mounted on a vacuum truck and it traverses back into the board that way.

This is a copper test part, full-sized copper part that, that was machined to 3.2 nanometer surface roughness, okay? And this is just data that's from last week, so we're kind of excited about that.

Okay, so I've taken you now through laser glass and amplifier slabs, mirror and polarizer coatings, lenses and windows, and through the crystals. I want to just take the last few minutes here and talk to you about the on-site processing.

The NIF optics will be cleaned in the

Optic Processing Development Laboratory. We call it OPDL.

This is over in Building 391 West. We have a 10,000-square-foot facility for doing the glass optics.

These are automated aqueous cleaners for the glass optics built by JST. This is in the old Shiva bay, okay, for those of you who know Livermore.

It's about 10,000 square foot of Class 100 cleanroom space for doing the glass optics. Across the hall we have about 3,000 square foot that will be used for the crystal optics.

Forward Technologies has built an automated nonaqueous system for precision cleaning of the the crystals. So after the, after the, the optics are cleaned, then the fused silica and crystal optics then beyond that get a sol-gel antireflection coating.

And that will be done for the fused silica coatings in a dip coater built by Chemat. The crystal coatings will be done on a spin coater built by Karl Suss.

This is actually an adaptation of, of a photoresist spin coater that Suss built for the semiconductor industry.

So just to conclude it, we've got production facilities that are complete and operational. And we've really tried to draw on the best, not just of the U.S., but of the world.

We're getting optical components, including some of the, the BK7 substrates from Ohara and Pilkington up in North Whales. Our technology and facilitization program is still on track, and we expect full pilot validation this fiscal year.

That's still what we expect to, to achieve. So, with that I'd be happy to answer any questions.

THE CHAIR: Questions?

DR. VOGT: I had a question maybe which isn't fair to ask you, but maybe I should ask Ed. What kind --

THE CHAIR: We don't have to be fair.

DR. VOGT: You have to be to the individuals.

THE CHAIR: It doesn't say that in the Charge.

DR. VOGT: Aah, okay.

But my question is: What kind of major R&D activities are going on which relate to the project, and to what extent are they under your jurisdiction, and to what extent are they outside your jurisdiction?

DR. MOSES: Under the new organization, as Bruce Tarter talked about it yesterday, all, all of it is under my jurisdiction.

DR. VOGT: It will all be under yours?

DR. MILLER: Let me just comment that that, yeah, that has not, has not continuously been the case under the project, --

DR. VOGT: Yeah.

DR. MILLER: -- but that is the case now.

DR. VOGT: For the future. Yeah, but what are the major R&D efforts underway right now?

DR. MOSES: Well, as we keep hearing, you know, 3 Omega damage is the major R&D.

DR. VOGT: Yeah. That's the major.

DR. MILLER: And the problem with answering the question, just to be careful, is what do people mean by R&D, you know?

DR. VOGT: Yeah.

DR. MILLER: I mean, as, as Ed said, he doesn't think he has any R&D issues going. In other industries people would judge some of the things he's doing as, as R&D-ish.

I think the basic problems we have are material issues at 3 Omega that, from the point of view of the project, I'm not talking about the point of view of the ignition --

DR. VOGT: Yeah.

DR. MILLER: -- or target design --

DR. VOGT: Yeah.

DR. MILLER: -- or fabrication.

DR. VOGT: Yeah.

DR. MILLER: I think there's a huge amount of system engineering issues that have to be taken on. I understand the cleanliness, you know, the phenomenalogy of cleanliness.

We're doing that carefully. But, you know, when you, when you come to the, to the nub, the damage, the 3 Omega damage is what we're interested in understanding better.

THE CHAIR: What's your philosophy with respect to spares?

DR. ATHERTON: We're planning to have about two-percent construction spares to allow for any, any issues in bringing up the laser. Then we plan to have, take these same companies that are doing the production for the construction project, and as for Nova, those same companies would supply optics, any replacement optics needed to support operations.

And they would be follow-on contracts funded by the Operating Program in order to enable operations.

THE CHAIR: So, so they will keep themselves facilitized?

DR. ATHERTON: That's, our plan is that those facilities will stay useful through, really through NIF operation, 20, 30 years.

THE CHAIR: Uh-huh. Uh-huh.

DR. MOSES: I think it's important to realize and, you know, hopefully we'll get to talk about this some other time in the, in the deployment logic. You know, NIF does not exist at one second. It exists, it becomes into existence over years.

And the issue of when you're operating and when you're building it are, are sort of, you know, not easily separated, so therefore, the issue of spares in, in, in turning it on are really issues of operating, operating the laser, and just running the laser.

It's going from one bundle to two to six to 12 to 24 bundles, and it will be operating and being maintained while it's going through that whole time period.

THE CHAIR: Humm. My concern was that, you know, you have a fair number of things that are unique, and the, the suppliers out there are not all the most stable companies in the world. You know, it's not like General Motors.

You can't predict that they're going to be here 30 years from now with any certainty. That's what was my, what was driving my question.

DR. ATHERTON: Uh-huh. Yeah. Well, in, in -- Two things.

One is I think that it's very hard to speculate about, you know, companies, you know, going out of existence. That is highly speculative.

THE CHAIR: Humm.

DR. ATHERTON: The thing that I would say is that these companies may also participate in doing production for the megajoule laser. CEA is interested in utilizing whatever excess capacity that there may be at these companies for building its project, which goes into 2008 or thereabouts.

THE CHAIR: Uh-huh.

DR. ATHERTON: Also this, this equipment, the vast majority of this equipment was

GFE. You know, it takes money to take, I'm sorry, government-furnished equipment.

DOE owns it. So in other words, let's say that a company decided that it was going out of business or getting out of this business or whatever.

You know, for, for a finite amount of money we can actually take that out and set up other companies in order to do that production, so yeah.

DR. VOGT: It's been done by, by people like me before that we have operated a company which was bankrupt until our product was out of the door and into production.

DR. MOSES: I think there's another issue here. I think that Jeff is understating.

You know, he talks about the semiconductor industry and the optics industry. You know, these industries are not shrinking industries.

It's really booming. And I think there's a lot of future in this.

DR. PAPAY: But to what extent are you the sole contract, or what fraction of their capability are you for what period of time over time? In other words, if you're 80 percent of, of their production during the next X years and then you drop off and there's nobody coming in behind, maybe CEA --

DR. ATHERTON: Yeah, I can speak to that. We, you know, we, we are, the smallest company that we work with is Cleveland Crystals, sort of a 50-, 60-man operation. And even at that, NIF will be no more than a-quarter of its business, okay?

And that's, that, that pegs the high end. And it can be, it can be somewhat less than that.

You know, these other companies --

DR. PAPAY: Wait. When you say 25 percent of their business, in that facility or in their business as a whole?

DR. ATHERTON: No, in that facility.

DR. PAPAY: Okay.

DR. ATHERTON: Yeah. So, so even for the smaller companies, NIF doesn't come anywhere near, you know, 50 to 80 percent of that company's business.

And wherever we can, we have set up backup capabilities so that if we have production problems at one particular company, that we've got enough capacity at other companies able to do that same kind of work to take care of, of, you know, schedule, any schedule issues.

We've also planned for only five-day

operations. You know, we have, we can go to, you know, full, you know, seven-day, three-shift operation at any of these companies to take care of, of, of potential, you know, short-term interrupts.

And you guys are absolutely right. And, and, you know, if you take a five- to 20-year horizon companies, they get bought, they get sold, they take on, you know, different initiatives, but it's been stable.

You know, we've been working with the same basic set of companies for 20 years. You know, there will be some amount of turnover, but I think we've got the kind of capacity and flexibility in trying to make sure we've got backup companies in order to take care of it.

THE CHAIR: Any other questions?

(Whereupon, no response was had.)

DR. ATHERTON: Thanks a lot.

(11:13 a.m. PT)

THE CHAIR: We're now ready for public comment period. I would ask each speaker to identify his or her affiliation, and please keep your remarks to five minutes per speaker.

First speaker is Stephen Kelley.

PUBLIC COMMENT PERIOD:

MR. KELLEY: Where do I -- Go up there?

THE CHAIR: Right there.

MR. KELLEY: So there's five minutes?

THE CHAIR: Yes.

MR. KELLEY: First of all I want to thank you for this opportunity to have a public hearing. My name is Stephen Kelley, and I'm a tax-paying, tax-paying citizen.

I live in Oakland. I'm a high school teacher and a co-founder of the Oakland Hanover Echo Village and a member of Tri-Valley CARES and a human being, hopefully exploring.

And I'm interested in life. And I wrote this poem to give another perspective to what's happening here.

NIF: Let's redesign reality and say no. This moment is. We choose to live, expand, or contract, contract and die moment by moment, not really knowing we can choose to explore.

Life is technology and economics. Technology and economics need honor and applause.

Thank you. And ecology, arts, a spirit of wonder, these are all dancing, expanding community of mystery.

NIF is attempted, deceptive, fear

control. The old white patriarchal pharocey priesthood of control in new scientific. The emperor has no clothes.

NIF, nifty alovescent attempted control. The world's most powerful laser with 50 times more energy than our enemies. One hundred ninety-two laser beams penetrating, ejaculating into reality's nuclear woumb.

Guilla defiled, screaming into the very heart of the stars.

Is life control controlled ecstasy or the ego beyond control, male personality's wet dream come true. To what end?

Exhaustion, anger, anxt beneath a happy face. Wild nosis is always beyond control.

NIF is a death wish against, against whoever is not White, rich, nice, normal insanity, fantastic technocratic, mini-brained thrusting to go beyond human helplessness, hopelessness.

There is no hope. Nothing works. Experiment. Feel the helplessness, the hopelessness.

Experience what is this moment, not knowing, disarmed. There, there is where life lives. Who am I? Who am I really this moment?

Is it possible I am at my deepest

nuclear core? Is it possible I am who am already?

Ready to step into the maturity of mystery or NIF. Nagasaki, Livermore, nuclear deserts, exploding, imploding, human hearts."

And I want to end with just 20 seconds.

(Playing a flute.)

Thank you.

THE CHAIR: Thank you.

Next is Jacquelin Cobasso (phonetic).

MS. CABASSO: Thank you. My name is Jackie Cabasso. I'm the Executive Director of the Western States Legal Foundation in Oakland.

First I have a couple of questions for the Department of Energy, then a comment for the Panel.

In the most recent Green_Book the Department of Energy Defense Program's Fiscal Year 2000 Stockpile Stewardship Plan, a Memorandum of Understanding between the Department of Energy and the Defense Threat Reduction Agency is described as follows:

Quote, to ensure the implementation of design features required for weapons effects testing on the National Ignition Facility. Some types of experiments discussed include ones that would use a lithium hydride atmosphere.

So my questions are: How would operating the NIF at lower energies, as has been speculated here, affect plans for conducting weapons effects experiments, including those using exotic materials? Would it make early use for weapons effects experiments more or less likely?

Along the same lines, would operating the NIF at lower energies make experiments of any kind employing plutonium or uranium more or less likely?

The language used here yesterday by laboratory representatives to describe the Stockpile Stewardship Program represented a notable departure from past Lab rhetoric, and some of it was refreshingly honest. For example, Gilbert Weigand stated, "This is how we maintain our nuclear weapons superpower status."

This perception, I might add, is shared by most countries around the world.

However, some of what was said was frankly startling. It seems that justification for the NIF is constantly expanding.

George Miller at one point even suggested that NIF experiments would be critical to certify specific weapon types such as the W80 at some point in the future. I wonder if this new assertion was meant to send a message that the Lab would be prepared to recommend the reassumption of underground testing if this panel in any way were to put the brakes on NIF. And I hope that's not the case.

Unless many top nuclear weapons designers and policymakers have been misleading us for some time, existing nuclear weapons can be maintained in a safe and reliable state for some time in the future using equipment and technology which already exists.

Further, the manufacture of serviceable thermonuclear weapons presents no real technical problems for the United States and has been well-understood for decades. For example, in 1978, long before the NIF and current levels of computing power were even imaginable, three weapons experts, Norris Bradbury (phonetic), Carson Mark (phonetic) and Richard Garwin (phonetic), wrote to President Jimmy Carter, quote, we believe that the Department of Energy, through its contractors and laboratories, can, through the measures described, provide continuing assurance for as long as may be desired of the operability of the nuclear weapons stockpile in the absence of the underground testing.

Bradbury, Mark, and Garwin apparently were convinced in 1978 that weapons safety and reliability could be assured employing then existing testing capabilities.

Finally, although it is beyond the official scope of this panel's purview, I would ask you to consider, especially in light of Mr. Weigand's remarks about how we can remain a nuclear weapons superpower, the potential role of the NIF, if it continues to go forward in further destabilizing the nuclear nonproliferation treaties and the nonproliferation regime in general.

Perhaps the questions that have been raised about cost overruns, construction delays, and design flaws, provide us with a, an opportunity to fundamentally reconsider this ill-advised project, and to stop it while we still can.

Thank you for your consideration. I have a written copy of this comment to leave, and also a copy of our analysis of Why Stockpile Stewardship is Fundamentally Incompatible with the Process of Nuclear Disarmament I'd like to leave with you.

THE CHAIR: Thank you very much.

Next is Marylia Kelley.

MS. KELLEY: Hi, I'm Marylia Kelley, and I'm still Executive Director of Tri-Valley CARES, and still live on East Avenue. There are a couple of things that I wanted to do today.

One, I wanted to talk a little bit about sort of the charge of the panel, which I didn't get an opportunity to yesterday. And I recognize that your charge is somewhat limited, but one of the problems, in my opinion, with some of the external advisory boards that have gone on before, in addition to them being a little ins-, too insular and too cozy and in some cases having conflict of interest, is just the problem that incredibly smart people were brought together to answer the wrong questions, and they limited themselves to just answering those questions narrowly.

So, I'm hoping that this panel considers part of its charge the ability to go to the Secretary and say, "We're not quite configured to give you final answers on what some of the underlying technical problems are, but, Mr. Secretary, we feel that the NIF's problems do go beyond management issues and system integration issues," although, you certainly won't get any argument from me that there are some serious problems there, but that they also have underlying technical problems that are not yet resolved, and that may continue to be intractable, and that you would recommend to the Secretary to look into them very specifically.

To just take the amplifier glass as one, the demonstration showed you that they determined in 1998, last year, that they could pour enough. Now, remember, this is a facility that began construction funding in '95-'96, and now they know they can pour it, but they can't get it to spec yet.

And again, these are some issues that should have been more fully explored in R&D, and really still in some cases need to be. And I know I don't have time to go through my list of ten again and tell you where they're at, but I can provide further information on any of those if you would like to ask.

The other thing is I do think that this group can recommend to the Secretary that a serious look be taken at the, quote/unquote need for the National Ignition Facility. Its centrality to stockpile stewardship is more a function of its size and cost than of any real mission for maintaining safety and reliability in the existing nuclear arsenal.

And with, with respect to that, and going back to the fact that yesterday I promised you some data from the DOE Surveillance and Evaluation Program which is headquartered out of Sandia, here is the actual data from 30 years of the stock-, of weapons in the stockpile. And you'll notice it doesn't look like the bathtub that George Miller presented in the viewgraphs that you got yesterday.

Most of the, the, these are the number of defect types. Most of the defects are in the first three years.

They're mostly production defects, and then you get one or two to five to seven things that you need to fix each year. The post-DAHRT-II arsenal is right here in the 15- to 17-year timeframe where you have to do one to five fixes a year.

You'll notice that that stays constant. At year 27 there are five fixes. Between Year 27 and 30 there's one fix, none of which had anything to do with aging.

and the summary that Sandia provided says basically nuclear weapons age but they do not wear out. You, you need to maintain them, but DOE has the program, has the personnel, has the facilities that it needs to do that job.

So I will give this to Betsy to make copies. And I've one final question which Ed might want to answer in realtime.

When they were talking about the construction spares, you said that's an operating issue. Does that mean that it's not in the project budget; it's in the operating budget?

DR. MOSES: I don't know the rules, so I don't choose to answer.

THE CHAIR: No, it's up to you.

DR. MOSES: That's, that's a question, and what's in project budget and what's in the operating budget is a serious question that I hope you folks ask about each and every thing, because I've been told by employees that a lot of the cost overrun has been covered up to date by cycling things out of the project budget into the operating budget.

But the operating budget that was presented to Congress was $115 million a year, and if you look at the Nova figures, they were running at about $80 million a year. So I have some questions that if even everything were perfect, is the operating budget for NIF big enough?

And with these serious problems, the

$300 million cost overrun may be, in fact, just the beginning of what's in fact really there. So I'm, I'm hoping that you'll ask some questions about where some of these things are in the budget and take a look at what the final cost overrun may be.

I have --

THE CHAIR: Thank you.

MS. KELLEY: Okay, thank you. I have one final thing to leave with you, which is a NIF book that our group did, and a joke.

There are two typos in here. Nuclear weapons used to be the bane of my existence, and since we started publishing things, typos now are.

THE CHAIR: Okay, thank you.

Is there anyone else who wishes to make a comment?

(Whereupon, no response was had.)

THE CHAIR: Before we conclude this meeting I want to thank some of the people who helped, helped make this easy for us, and comfortable, and a us-, very productive process.

In the Protocol Office certainly Kathleen Moody and Shirah Jones; Lasers and National Security, Charlene Morris, Corinne Ybarra, kathy Cruz Glasgow, dustin Riggs and Jennifer Peterson, and

Steve Simpson and Terry Strahl. And we certainly appreciate all that was done for us, and we look forward to the opportunity of our next visit.

Thank you all very much, and we are adjourned.

(Whereupon, at 11:29 a.m. PT the above meeting was adjourned.)

I certify the foregoing to be a true transcript from my notes.

CSR, CP, RPR

CERTIFICATION

I, Dorothy I. Bunn, a Registered Professional Reporter, Certified Conference Reporter, and Notary Public, do hereby certify that the foregoing testimony was duly taken and reduced to writing before me at the place and time therein mentioned. I further certify that I am neither related to any of the parties by blood or marriage, nor do I have any interest in the outcome of the above matter.

In witness whereof, I have hereunto set my hand and affixed my official seal, at Livermore, California, USA, this 16th day of November, 1999.

Notary Public

My Commission expires November 17, 1999.

# APPENDIX

e-mail Message from Per Peterson, Professor, Department of Nuclear Engineering, UC Berkeley dated 15 November 1999:

Per F. Peterson, 11-15/99 1:22 PM -0800, Public Comment Input for SEAB NIF Task Force

Mime-Version: 1.0
X-Sender: peterson@nuc.berkeley.edu (Unverified)
Date:  Mon, 15 Nov 1999 13:22:29 -0800
To:  moody2@11nl.gov
From:  "Per F. Peterson" ^peterson@nuc.berkeley.edu^
Subject: Public Comment Input for SEAB NIF Task Force Meeting
Cc: Bill Hogan ^hogan5@llnl.gov^

Dear Members of the SEAB NIF Task Force:

First please accept my apologies for not personally presenting these comments, as I had to leave the meeting in the early afternoon to return to U.C. Berkeley.  I am Per Peterson, a Professor of Nuclear Engineering at UC Berkeley, and Chair of the Energy and Resources graduate group. My comments relate to the coupling between NIF and graduate education at the major research universities.

Perhaps the most important goal of the current Stockpile Stewardship program is the recruitment of outstanding young scientists and engineers who will maintain, in the long term, the scientific expertise required for national security. These are the people, who thirty years from now, will sit around tables much as you are today finding solutions to problems of major national importance. Our future will rest on their shoulders.

Our Nuclear Engineering department is relatively small. Over the last three years, our three brightest domestic PhD recipients have gone to work at the laboratories, two to Livermore and one to Los Alamos. These three young researchers each have outstanding ability, and I am extraordinarily pleased that they decided to take their careers to the laboratories, rather than accept the more financially lucrative opportunities that were available to them in industry. Put bluntly, they came to the labs for the opportunity to work on the grand challenge of inertial fusion.

NIF plays a central role in the recruitment and training of new scientists and engineers for the labs. From this perspective, by far the most important goal for NIF is ignition. Ignition is the grand challenge, the primary vision, that attracts students. My request to the Taks Force is to communicate the key importance of the ignition goal. Here there are two primary issues. The first is to support the efforts to achieve symmetric light in NIF at the earliest date possible, because symmetric light allows earlier exploration of capsule symmetry issues. The second is to emphasize the importance of keeping sufficient total laser energy to provide a substantial marign for ignition.

It is difficult to overemphasize the importance of your task to recommend the optimal path to bring NIF on line successfully. Please accept my best wishes for success in your upcoming work.

Best regards,

Per Peterson

Printed for Kathleen Moody ^moody2@llnl.gov^

Per F. Peterson, 11/14/99 1:22 PM -0800, Public Comment Input for SEAB NIF Task Force

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Tri-Valley CARES Handout: Report Extract and Viewgraphs entitled "A Summary of the SNL Stockpile Life Study," dated December, 1993

Tri-Valley CARES Handout: Report by Paul Carroll entitled "The National Ignition Facility: Flawed Rathionale, High Cost, and Security Risks," dated September, 1998

Western States Legal Foundation Handout: Report by Andrew Lichterman and Jacqueline Cabasso (WSLF) entitled "A Faustian Bargain: Why Sotckpile Stewardship is Fundamentally Incompatible with the Process of Nuclear Disarmament," dated April, 1998.

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Comments to the Secretary of Energy Advisory Board
National Ignition Facility Task Force
Lawrence Livermore National Laboratory, Nov. 16, 1999
Jacqueline Cabasso, Executive Director

First I have a couple of questions for DOE, then a comment for the panel. In the most recent "Green Book," the DOE Defense Program's FY 2000 Stockpile Stewardship Plan, a Memorandum of Understanding between the DOE and the Defense Threat Reduction Agency is described: "to ensure the implementation of design features required for [weapons] effect testing" on the National Ignition Facility (P. 7-27). Some types of experiments discussed include ones that would use a lithium hydride atmosphere. How would operating the NIF at lower energies affect plans for conducting weapons effects experiments, including those using exotic materials? Would it make early use for weapons effects expriments more or less likely? Along the same lines, would operating the NIF at lower energies make experiments of any kind employing plutonium or uranium more or less likely?

The language used here yesterday by Laboratory representatives to describe the Stockpile Stewardship Program represented a notable departure from past Lab rhetoric, and some of it was refreshingly honest. For example, Gilbert Weigand stated: "This is how we maintain our nuclear weapons superpower status." (A perception, I might add, shared by most countries around the world.) However, some of what was said was frankly startling. It seems that the justification for the NIF is constantly expanding. George Miller at one point even suggested that NIF experiments will be critical to certify specific weapon types, such as the W-80, at some point in the future. I wonder if this new assertion was meant to send a message that the Lab would be prepared to reocmmend the resumption of underground testing if this panel in any way were to put the brakes on NIF. I hope not.

Unless many top nuclear weapons designers and policy makers have been misleading us for some time, existing nuclear weapons can be maintained in a safe and reliable state for the foreseeable future using technology and equipment which already exists. Further, the manufacture of serviceable thermonuclear weapons presents no real technical problems to the United States, and has been well understood for decades. For example, in 1978, long before the NIF and current levels of computing power were even imaginable, three weapons experts, Norris Bradbury, Carson Mark and Richard Garwin wrote to President Jimmy Carter: "[W]e believe that the Department of Energy, through its contractors and laboratories, can through the measures described provide continuing assurance for as long as may be desired of the operability of the nuclear weapons stockpile in the absense of underground testing." Bradbury, Mark and Garwin apparently were convinced in_1978 that weapons safety and reliability could be assured employing then-existing testing capabilities.

Finally, although it is beyond the official scope of this panel's purview, I would ask you to consider -- especially in light of Mr. Weigand's remarks about how we remain a nuclear weapons superpower -- the potential role of the NIF -- if it continues to go forward -- in further destablizing the Nuclear Non-Proliferation Treaty and the nonproliferation regime in general. Perhaps the questions that have been raised about cost overruns, construction delays and design flaws provide us with an opportunity to fundamentally reconsider this ill-advised project and to stop it while we still can.

Thank you for your consideration.

Welcome and Overview: Remarks by Dr. C. Bruce Tarter, Director, Lawrence Livermore National Laboratory, November 15-16, 1999.