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NASA LONG-RANGE PLANNING MEETING

Lunar Exploration and Settlement

Presentation by Dr. Gilruth

12:30 p.m.,
Wallops Island, Virginia

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P R O C E E D I N G S

GILRUTH: Gentlemen, I was telling George Low at lunch that the last time I was here was on a planning conference in which we planned how we were going to do the Gemini program, and how that might interface with a program called Apollo. This was before Mr. Kennedy's declaration of purpose, of landing man on the moon, and Apollo at that time was a curcumlunar type program.

I was at planning conference here earlier than that, in 1952 as a matter of fact, at which we planned the X-15 and I remember in discussing that, our Chairman of our group who was Dr. Puckett said, "But why fly man? Why not fly an instrument?"

Now that's the first time I ever heard that, and I made the same reply then as I've been making in all the years since.

A great deal has been said in the past about why we go to the moon, and different people have had different explanations of why. At the time Apollo was started, the goal was set very materialistically to pick something that was too hard for the Russians to do and that we could still do, and the mission was very carefully calculated to be just that, and it was well calculated, because if it was much harder to do, we couldn't have done it, I'm sure. It was just about our limit, and of course as history has shown, it was too tough

for the Russians and had pretty well taken the starch out of their program.

In fact, their flight which is now in its eleventh day isn't even in the newspapers.

I don't know how long this will last. Perhaps the Russians now have got a big goal so they can tell their people about catching up with those bad Americans and after they get ahead of us, maybe we can sell a program again to catch up with the Russians. It may be that these things have to go in waves of some kind.

As a matter of fact, the Apollo program has been so spectacular that it is going to be difficult to follow it with another step. This flying to the moon is pretty hard to match with flying in earth orbit, even with a gigantic station. I think a gigantic station would be a logical sequel to it, but certainly a small space station of the pre-Apollo design of six or eight men in a can isn't going to look very big by Apollo standards.

Now as far as Apollo or as far as exploring the moon, or lunar settlement, no matter what we do in the immediate future, the lunar program is going to stop after the next few Apollo flights, and the question is how long will it stop, and what will come next, and when. And we're talking about the next thirty years.

I think it is surely inevitable that there will be

another major lunar program or a continuing lunar program, and I believe the goal will be the establishment of a lunar base, and I mean a permanent lunar base as compared with a temporary base although there will no doubt be-- I mean a base on the surface.

There no doubt will be a temporary base on the surface to get the necessary information about the site and there will no doubt be an orbiting phase of this program to determine just where to put the base, the first base.

Now there is one thing very different about a base on the moon and a space station in earth orbit and that is a base on the moon can be ultimately self-sustaining, as you have the materials there on the moon. We don't know what they all are, but we know enough about them already that we know, for example, that we can extract the oxygen we need from the soil there.

To help me in this -- in other phases of the discussion of the lunar base and settlement I have Dr. Faget and Captain Scherer who are going to go into more details of the transportation system costs, trade-offs, and the science on the moon, and the resources and how they might be extracted and used, and so on.

But I might just go myself a little bit into some of the incentives. The incentives are really quite good for a permanent base on the moon. I think if it weren't for the

fact that it's so hard to get there and get back, the transportation cost, that this really has a lot more appeal than the space station in earth orbit, that and the fact that it could be truly permanent and self-sustaining.

Actually, it is harder to get there and get back, and it is too far from the earth really to do good earth resources from. But one could make a very interesting case, just on basic science grounds, for lunar geology, astronomy both optical and radio, experimental laboratories. Because of the low gravity, high vacuum, low background noise and remoteness and this sort of thing, it would be an ideal place for an experiment in colonization such as we discussed yesterday evening.

It might also be thought of as-- You know, man is a funny animal. Someone once told me man is the virus of the universe and he likes nothing better than to go out somewhere and establish a new base and dig in and then expand. That's really part of our problem on earth. We always want to expand, even when it is not in our own interests to expand beyond a certain point.

Colonization of the moon would I think capture the minds of the people of the world. There would be a great deal of interest in this kind of a project, in my opinion, especially if there was true colonization with men and women and the problems of establishing a new life in that environment.

We might also look on this as really a king -- not king-sized but king-quality atomic bomb shelter where the archives of the earth might be stored, or the knowledge and the science and the seeds for a new race if, as worst might come to worst, we destroy ourselves with the H-bomb. In other words, it might be a hedge against the end of the world, such as Nevil Shute wrote his famous book about.

Somewhat along the same lines -- I haven't heard anything about this lately, but we used to hear about the moon as a military base. I think that in talking with the boys who have been to the moon and looked back at the earth, their reaction was when they looked at the earth and it's about the size of a thumb nail, they say, "Gee, it would be a lot tougher to fire a ballistic missile from here and hit a pin-point than it would be to do it from the earth."

[HE WHO CONTROLS THE MOON, CONTROLS THE EARTH]

But I'm sure the military minds might have some other ideas. I haven't heard what they are, but that's something that might be considered.

The moon has two things that you will never get in a space station. One is raw materials and the other is gravity, and both of these things might be important. It was discussed in Dale Myers' presentation, the possibilities of a recreation area in the space station. I think the possibilities are even greater on a lunar base because one would have some gravity but old codgers could go up there and fly

around and leap around and feel young again, and it's possible that some day, if the transportation costs could be brought down, as Dr. Paine was discussing, that you might even have a Lunar Hilton up there.

I think you've got to think a little bit about the cost of something like this when we discuss even the base that was in Dale Myers' session this morning. I think we're looking, if we're serious about a small village in space or a permanent lunar base, you're looking at costs per year that are about like we are spending on the Vietnam War, and that I think is kind of a sobering influence on some of our thinking, or should be.

Now our plan here is simply to set the stage for a discussion and my two colleagues here, Dr. Faget -- Captain Scherer will carry on now and Dr. Faget will come next.

Max?

SCHERER: I want to talk a little bit about I guess the engineering aspects of this. Primarily it has to do with what we can use at the moon and the cost of transportation, things of that nature.

Dr. Gilruth pointed out we do have the possibility of getting oxygen at the moon, and it is of known existence and it can be freed from the rocks merely by having suitable equipment at the moon -- I'll say a little bit about that -- and energy. Of course the energy could either be solar energy

or nuclear energy as the case might be.

The next most important element at the moon from the standpoint of a self-sustaining base would be hydrogen because this would then give you water and of course water and oxygen are the two most vital necessities to man. However, there is no -- well, let's say unknown existence in any appreciable quantity. As near as I can tell, the largest source of hydrogen at the moon right now is from the solar wind.

This doesn't mean there isn't any water-- It doesn't mean there isn't any hydrogen on the moon. It just has not been discovered yet.

PAINE: How much comes from the solar wind? Is there any quantity there at all?

FAGET: I'm told that 10 cubic yards of lunar material has enough solar wind material to produce 1 pound of hydrogen or something like that. It's pretty poor, ten cubic yards per pound. That's approximately ten tons per pound, I believe, a cubic yard being about equal to that.

PAINE: That sounds like kind of a rich ore.

NAUGLE: You mean you get a pound of hydrogen from 10 yards; that's not bad.

I thought you'd be talking in terms of molecules instead of pounds.

FAGET: I don't want to vouch for that number. It was given to me in a very off-hand manner, just like I'm

giving it to you here, so take that with a grain of salt.

I think the recovery of anything at that ratio from the standpoint of mineralogy processes is pretty poor. It's a very difficult thing.

LOW: How about water?

FAGET: No water has been found in the material we have gotten back, so we have to look for it.

JASTROW: You have to be careful because there may be no water on the moon, but there certainly can't be any in the maria because you now know from 11 to 12, that they have been baked out 1200 degrees, so there would be neither water nor organic materials in any maria like what you have at the surface, but there might be at the highlands.

FAGET: Let me go a little further here before we start surveying all this material.

VON BRAUN: Talk a little louder.

FAGET: Instead of concentrating on the microphone, I'll just talk louder.

The next two things you'd like to have after hydrogen and oxygen or the other things you are going to need primarily are carbon and nitrogen and again, the probability of finding these is pretty small, but they should be explored for.

We have thought about this. A number of years ago we actually made an analysis on the possibility of are

there any areas on the moon which never see the sun? And theoretically there are undoubtedly-- Of course this from a theoretical, statistical standpoint -- craters near the poles where there are areas of continual darkness.

If there is any free water vapor, methane, ammonia, whatever you might have the contains hydrogen or contains carbon, certainly you would have frozen lakes in these areas.

The other possibility of course is subterranian. There might be frozen layers some distance beneath the lunar surface and these must be explored for. I think Captain Scherer will say something about how we might go about doing that. Certainly if there is a well there, that's where we're going to locate the base.

And I think that's the only point that I want to make here. When you consider talking about bases, particularly a self-sustaining base, we would like to locate it near those resources which will support our necessities.

I'd like now to tell you a little bit about the oxygen situation.

May I have the next slide?

(Slide.)

Of all these elements, oxygen is a very big thing and we'll get into that right away.

Here is the surface material from which we might be able to get oxygen from and from the oxygen thereby derive

water.

This is an assay, a rough assay. Obviously these minerals are combined together in various chemical compounds, but primarily this is what we have on the return fines. You see we have a number of metal oxides; by weight and importance from the standpoint of obtaining water, primarily it's the ferric oxide, 16 percent of the weight, and that is very important because it is easy to get oxygen from iron oxide.

From these things we'd like to get water and oxygen and we have been looking into both hydrogen reaction to obtain water and a floating reaction. As a matter of fact we have been in touch with Dr. Schmidt at Lewis. I think he's your expert on fluorine, and he's very interested in doing this.

LUNDIN: He's interested in anything connected with fluorine.

FAGET: Well, we've got him. He's working on this.

I want to talk a little bit about these two processes.

MATHEWS: Incidentally, Max, that 43 up there, as I understand it, is also the total amount of oxygen that is in the fines. In other words, of all the material, there's about 43 percent oxygen.

LUNDIN: You mean the moon is almost half oxygen?

CLARKE: Yes. ?

FAGET: You can recover 40 percent oxygen from a

batch of the lunar material.

GILRUTH: It's the only way it is like the earth, though. It is very unlike the earth in all other respects.

(Slide.)

FAGET: If we would use the hydrogen process, it's a very simple process. By just percolating hydrogen through the fines, the dust that is already present with heat, you can release oxygen and get this reaction where we obtain water vapor and iron.

The other oxides don't react with the hydrogen and none of the reactions are such that they bind the hydrogen so that when you blow the hydrogen through this hot stuff you just get water and hydrogen, unreacted hydrogen, and it continues through there without losing hydrogen.

So that this is a good way to release oxygen in the form of water which in turn can be electrolyzed.

LUNDIN: What temperature does it go at? What temperature is that process?

FAGET: The temperature we think will start around 1,000 degrees Fahrenheit. We are fairly certain of a very high reaction at around 1500 degrees Fahrenheit.

So this is a very simple scheme that one of our fellows at Houston has thought up where you use solar energy in the form of a reflecting mirror. You concentrate the heat in the reaction pot. Hydrogen goes through the pot, comes up

to the top, and of course what you get is water and hydrogen. The water is condensed out and the hydrogen is recirculated and the condensed water will then be electrolyzed to produce oxygen and replenish your hydrogen.

So this doesn't use up hydrogen. What you get out of here in this reaction is like four pounds of oxygen for every hundred pounds that you put in the pot.

Next slide, please.

NAUGLE: What sort of size of solar reflector goes with what sort of poundage, do you know, Max, at all?

FAGET: I don't know. I don't have that.

Now with the fluorine, all of the oxides on the moon will react with fluorine and they all react in this manner. The fluorine merely kicks the oxygen out and you get the fluoride instead of oxide. And it was pointed out if you get all oxygen back-- There is no reason to believe you can't.-- you can get something like ~~forty~~ 40 pounds of oxygen for every hundred pounds you put in the batch.

Now of course you end up with a lot of tieing up of fluorine that you won't get back, and the way to get the fluorine back out is to run potassium vapor which then in turn captures the fluorine back from these metals. Then you electrolyze the potassium fluoride and get the basic fluorine and potassium and you repeat the process.

One of the good things about this process, you not

only get the oxygen out of the rock but you get all of the metal which, if you want to do other kinds of manufacturing, you have a nice source of metals such as aluminum, iron and titanium. I don't know what you do with the silica. We're not going to be making transistors, I guess.

May I have the next slide?

(Slide.)

This of course is a more complicated thing, and it shows here all the equipment you need in a very schematic form.

The fluorine goes through. Out of this thing you would get your oxygen. You would also put your potassium vapor in here and from that of course you would get your potassium fluoride. You electrolyze the potassium fluoride to replenish your fluorine and your potassium-- I've done it wrong.

The oxygen came out here (indicating).

At the reaction temperatures we anticipate that the silica fluoride will also come out as a vapor. IT will have to be condensed here and of course after it's condensed it will be allowed to drip back in the pot and what would come out would be fairly pure oxygen.

We would have a purifier here to make sure there is no fluorine or fluorides in that.

This reaction-- The basic reaction here is

exothermic. In other words, it can take place and no heat has to be added. The reaction rate of course would have to be controlled by the rate at which you push fluorine through there. Energy would have to go into the system at this point (indicating).

The advantage of this over the other, of course, is the larger yield per batch and the fact that you don't have to have the very high temperatures, but on the other hand, it has got this disadvantage of dealing with two very bad things to deal with, potassium and fluorine. I think this is going to take some doing.

All right, next slide, please.

(Slide.)

Okay, this just summarizes the features. With hydrogen we can get four pounds of O_2 and with the fluorine we get forty-two pounds of O_2 per 100# of man. dust, and we also will get the metals out of there.

PAINE: You also get iron out of the first process as I recall it, don't you?

LUNDIN: Yes.

FAGET: Out of the first process you will get iron, but if you want it, you have to refine it out of the other oxides.

PAINE: But you would have a nice vacuum, melting environment for doing that.

FAGET: Yes, indeed.

PAINE: The iron would be substantially heavier so even at a one-six G you'd get a separation --

FAGET: Yes. That could be done if you want iron.

The total energy consumption: we haven't run that yet. I'm not sure that that reaction is better than this one. I kind of think that this one is probably a much more feasible thing to do from an over-all engineering standpoint (indicating).

NAUGLE: What limits you to the four pounds of water per hundred pounds of lunar soil?

FAGET: That's all the oxygen that is bound up in iron. And this of course means that for the same amount of oxygen, you've got to have ten times the amount of stuff going through the process.

VON BRAUN: How much fluorine-- Do you recirculate all the fluorine?

FAGET: Yes, all the fluorine and all the potassium used in this reaction is saved, and all of the hydrogen used in this reaction is saved.

VON BRUAN: When you say the reaction is exothermic you are really saying that by continuously exposing the lunar fines to the fluorine, you always get more energy out?

FAGET: That's right. What costs you though is getting your fluorine back. You have the potassium fluoride

which you've got to electrolytically get back --

VON BRAUN: Without any replenishing of the fluorine you are continuously extracting heat from the lunar rocks? Is that right?

FAGET: That's right.

VON BRAUN: This was my question. If you bring the first batch of fluorine to the moon and you start up with a certain mass of fluorine there, then you can, according to what you say, continuously extract heat from the lunar soil without any new energy added.

FAGET: No, without any energy to get the oxygen out of the soil. But to get the fluorine back, to get it back from the potassium, you have to do the electrolytics.

VON BRAUN: That requires more energy than the flourine --

NAUGLE: You've got the sun for that, or presumably you could recover some of your heat there.

VON BRAUN: How much of the heat that you are producing-- What is the percentage of heat you are producing?

FAGET: Again, I just say this from the standpoint of a small, pioneering engineering basis. I don't think you try to recover the heat from this. I think it would not be worth it. Probably you'd want to get your electricity for the electrolytics by solar or nuclear power plants and not get fouled up with all that business.

JASTROW: What is the energy requirement per pound of yield? The order of magnitude?

FAGET: I don't know. I suspect it is probably pretty close to the same in both cases.

JASTROW: You don't know the order of magnitude?

FAGET: We're still studying the process.

PAINE: It is probably comparable to aluminum smelting on earth.

FAGET: I would think so.

MATHEWS: One advantage of fluorine is that it's a very dense fluid so that you can handle a lotmore of the stuff in a small container. You can come and go on the surface.

VON BRAUN: Can you make an order of magnitude estimate? For example, if you want to continuously produce enough oxygen to keep six guys alive on the moon, how many kilowatts roughly do you have to have continuously in the electrolysis process to keep this going, this fluorine? Roughly is it ten, or a hundred, a thousand? What do you need?

NAUGLE: All you need to do is just roll out however many kilometers of solar cells you need.

VON BRAUN: That's not my question, though.

FAGET: We've been working on this whole thing about a matter of two weeks and these are questions I've

asked, Wernher, and I have not got the energy balance yet.

LUNDIN: It's fairly straightforward.

FAGET: I don't think that the energy is going to be the big thing. I really think if you prepare to go there and set up a small plant that the equipment for the plant and all is the same order of magnitude as the equipment for, say, a small nuclear plant.

VON BRAUN: Speaking of oxygen production, it looks like we have several tradeoffs here available. One thing is, we continuously make new oxygen out of the soil with this. The other is if you build a vegetable garden and use photosynthesis so that we have a combined Sabati-Bosch cycle.

FAGET: We have to find that link of ammonia so you will have fertilizer. We haven't got that far yet.

You are right. Of course just from the standpoint of drinking water -- This is a very interesting thing here. -- you can get four pounds of oxygen from a hundred pounds of material. If you just want water on the moon, with the oxygen being free all you have to do is bring the hydrogen.

So this means that the way you can get the water for maybe about 12 percent of what it costs-- If you carry hydrogen to the moon it will cost you about 12 percent of what it would cost if you brought the --

LUNDIN: Carbohydrate will give you eight or nine pounds of water.

FAGET: That's right. So this is very good from the standpoint of the water needs of the colony; the freight for water has gone down by that factor.

MATHEWS: You may want to carry ammonia to the moon because you will need the nitrogen. It's a good way to package the hydrogen, too.

FAGET: All right. I'm going to say more about what we could use the oxygen for later, from the standpoint of the over-all transportation system.

May I have the next slide, please?

(Slide.)

We always end up with people worrying about rescue. From the standpoint of a large lunar base -- I'm not talking about a lunar landing or anything like that -- I think you would end up with this type of philosophy on rescue, that you would depend on enough substance to the base, enough spare room redundancy and so forth that you would deal with equipment failures in that mode as opposed to being ready to evacuate the whole base from some catastrophe you have in the equipment.

Natural catastrophes which would be a lunar quake or a volcano or a big meteor or something like that --

PAINE: A tidal wave in the mare.

CLARKE: Is that the NASA spelling of catastrophe, incidentally?

(Laughter.)

FAGET: Medical! We would have a doctor there. And it is kind of interesting that statistically you are going to have a medical problem for every 300 man days and that alone indicates that you are going to have medical facilities at any sizable base, and that's what we say we will do.

All right, now I'm going to talk about transportation.

Next slide.

(Slide.)

This is a model of a transportation system: the earth here, and the moon here. And before I get into this very far, let me say that we have studied both nuclear and chemical transportation between here and the moon. We have also studied it for planetary flight, and in the MSC studies, that chemical system is better than the nuclear.

When we are talking about chemical systems we are talking about present-day hydrogen-oxygen systems. When we are talking about nuclear systems we are talking about the kind of nuclear system we might be able to get by the next ten years and is something that will come out of our present NIRVA program.

Be that as it may, this model has been set up on the basis of a chemical system all the way, and it is

interesting from the standpoint of the numbers that are generated. In other words, we are using chemical for the earth orbital shuttle to get up to the staging area from earth orbit. We are using a chemical system to go from earth orbit to lunar orbit to the staging area, and then another chemical system to go to the surface, all with the same specific impulse in the neighborhood of 460 seconds.

Now what does this mean?

We start off here at the lunar base and we want to supply 10,000 pounds a month to the lunar base, and a return cargo shown here like 2.5 thousand pounds coming back. This 2.5 thousand pounds a month is just a practical estimation of what it takes for the men and the seats and the food supply and everything like that has got to come back. We would double that in the return from the staging area and then we'd add another 2.5 thousand pounds for earth orbit back.

Now these return cargoes don't affect the model very much but I just want to show that they are in there.

Starting on the lunar base, in order to get the two 10,500 pounds to the lunar base, and this return did, you need almost 50,000 pounds in lunar orbit. And in order to supply that amount in lunar orbit, you need 323,000 pounds in earth orbit. And in order to provide the stuff in earth orbit, if you are orbiting staging areas at these two locations

I'd consider them extreme -- but the worst case is 270 miles, a 55-degree orbit.

This represents our current thinking on the space station. It takes 23 million pounds a month to get your 10,000 pounds out there. If we worked from a more favorable orbit in earth, 29 degrees, only 100 nautical miles high -- and there is some doubt as to whether that is high enough from the orbital decay standpoint -- it would only take 14 million pounds a month.

The interesting thing I think is the ratio of the earth orbit to lunar base because we have just been talking about an earth orbital colony and the number, the ratio here is about 30 to 1. So from the transportation-logistics standpoint, at least at first glance, it is 30 times as much to supply an lunar-orbital base as an earth-orbital base.

Now later on I am going to show you that we can reduce this factor by four. In other words, the ratio might end up something like 8 to 1 if we use the moon base as the supplier of oxygen in the transportation system.

MATHEWS: How big a base are you talking about?

FAGET: We're talking about a base that takes 10,000 pounds a month.

MATHEWS: Right. Is it 10,000 pounds or 10,000 tons?

FAGET: Ten thousand pounds. It doesn't make any

1 difference; the ratio would be the same.

2 GILRUTH: Aren't those just ratios?

3 FAGET: Yes. We had a great deal of trouble de-
4 ciding how big the base should be, and we decided in our
5 own strategy for the meeting that we wouldn't try to describe
6 the base. We would just try to get you people to tell us
7 what you thought the base might be, and give you some idea
8 of the problems we see right now.

9 I guess what we're really saying is we are not
10 that sophisticated in our thinking right now about what you
11 might want in a lunar base in 1990 or something like that.

12 VON BRAUN: Would you repeat what you said about
13 the reserve course, please?

14 FAGET: In setting up this model here, we said
15 from a practical standpoint you just can't send things out
16 to the moon all the time. Passengers are going to want to
17 come back. Undoubtedly there are going to be some products
18 from space, even if it is just pictures.

19 So that the transportation back home is two and a
20 half thousand pounds a month from the lunar base. We
21 doubled that. We can add another two and a half thousand
22 pounds from the lunar staging area--

23 VON BRAUN: Where do they come from? You lost me
24 there.

25 FAGET: Probably primarily people and --

VON BRAUN: You mean there are people in the staging area in lunar orbit --

FAGET: Not two and a half thousand pounds of people --

VON BRAUN: -- who would like to go home?

FAGET: Every person costs about a thousand pounds. This is like 25 people returning every month. That's one way of looking at it.

NICKS: I'm a little puzzled because there is a steady state aspect to this.

FAGET: It's a steady state model.

NICKS: You've got to end up with some accumulation on the moon and some use in the form of propellants. That's farther out in your numbers there?

FAGET: This is the accumulation on the moon, and if the people on the moon get to feeling like we're making a garbage area out of it, I guess maybe they'll declare war on us. I was telling Chuck that they've got all the advantage.

WYATT: Max, that ten and a half thousand that you put on the moon, a lot of that will be some propellants to bring the rest of this back, so it's not all going to be --

MATHEWS: No, that's payload.

FAGET: This is all payload. The propellants to the moon are absorbed in this model. Part of this forty-eight

thousand pounds of stuff in the lunar orbit is propellants to make the round trip. That is not in that number.

WYATT: Okay.

CLARKE: At what level of business would it be worthwhile going to an equatorial base for launching from the earth?

FAGET: This model does not include whether the base is equatorial or polar or anything else. There are two unique factors, two unique locations on the moon. One is equatorial and one is polar.

CLARKE: I mean launching from the earth.

FAGET: Launching from the earth.

Now from the standpoint of energy --

MATHEWS: Max, you've missed the point.

CLARKE: My point is this: When you get to a certain rate of transportation to the moon it may be worthwhile rescheduling your launch base to the earth's equator. Look at the big saving you already have in those figures, from 55 to 29.

FAGET: This is indicative, the 55 degrees and the 29 degrees. Going from 55 to 29 was a small savings. The big saving was a reduction in the altitude of orbit. So there would be some reduction. I would imagine it would be not more than about 2 or 3 percent to go to equatorial on earth.

MATHEWS: The other thing is actually the saving in going from 29 to equatorial is less than going from 55 to 29.

FAGET: It would be 2 or 3 percent at best.

Now when you get to the moon, if you have a base located on the equator, on an equatorial orbit of the moon, there undoubtedly would be a saving. This is the ideal model that says you have access to the base from lunar orbit all the time. In the real case it is going to cost you weight, the kind of weight to get to the base. So you would like a base on the equator or you would like a base on the pole, the one on the equator being better than the one on the pole.

The one on the equator is accessible to earth orbit all the time, or accessible from this trans-earth business all the time, as well as access to the base from equatorial orbit. The polar orbit-- The base is always accessible from polar orbit. The transportation from earth to polar orbit is only optimum twice a month.

But anyway, this was not considered in this model.

LUNDIN: What happens to your 30-to-1 ratio if you use nuclear instead of chemical?

FAGET: If you use nuclear instead of chemical I am sure it is going to cost you more money, at least for our present kind of spaceship. It's about half.

WYATT: I think you will find it is much better than

that.

FAGET: No, it isn't.

WYATT: We have done some calculations that says that ratio has come down from about 30 there down to about -- let me think -- down to about 7 or 8.

LUNDIN: I think once you re-use the thing a lot, the impulse would really pay off. The trouble with the nuclear outfit is it is so darn heavy, but once you get into orbit it doesn't matter.

FAGET: Let me say two things about the nuclear rocket here, and I'm going to say a lot more before I'm over. I want to impress you with two things:

The nuclear rocket with 300,000 pounds of propellant has got almost the same energy as a chemical rocket with 540,000 pounds of propellant. The ratio is 2 to 1. The propellant delivered to the nuclear rocket is delivered at a ~~capacity~~ density of 4 pounds per cubic foot. The propellant delivered to the chemical rocket is like 20 to 25 pounds per cubic foot.

Now our shuttle studies show that right now the volume in the shuttle is costing us as much as the weight carried, so if you can cut the density of the cargo in the shuttle -- and we have not taken this into consideration in our cost study -- but that just about wipes out all the gains of a nuclear rocket right there, just on the first step.

MATHEWS: The important point, of course, is that if you are manufacturing oxygen on the moon, then that greatly impacts the picture. If you're manufacturing oxygen on the moon, then this changes the picture.

PAINE: If you had a good power plant in orbit, maybe this is the first of the manufacturing operations we were looking for.

VON BRAUN: Chuck just said, very importantly, I think Max said it is certain we can make oxygen on the moon. It is not so certain we can make hydrogen on the moon. We have a chemical system and we can utilize it effectively to utilize oxygen on moon to further enhance the advantage of the chemical system.

FAGET: In any case, though, we have not considered using oxygen manufactured on the moon for return flight, but we do use it in this case, going from orbit to the surface and then back up.

MATHEWS: Ultimately you can consider it, if you have a big enough plant, use it for supplying the return trip.

GILRUTH: That 30-to-1 ratio does not depend on getting oxygen from the moon?

FAGET: The 30-to-1 ratio is the simple model where we just are taking everything from the earth, but when you can get oxygen on the moon -- I might as well tell you about

this now if we're going to argue about it. If you have oxygen on the moon then the shuttle that works between the lunar orbit and the surface goes down with just enough oxygen for the down trip, and hydrogen to get back up, but the hydrogen is one-sixth the total amount of up fuel.

It unloads its cargo on the surface of the moon. The model used went down with 1800 pounds of oxygen, 10,000 pounds of cargo down, 6,000 pounds of hydrogen. Three thousand pounds are used on the way down. Okay.

Now when you get there, you still have the 3,000 pounds of hydrogen. You've put on board something like about 20,000 pounds of oxygen for up-- No, it's 18,000 pounds for up and 20,000 pounds more so you can come back down next time.

PAINE: What does that do to your ratio then, the 30-to-1?

FAGET: That cuts it to 8-to-1. It cuts it a fourth. That's the ideal case.

Now if you're doing it on a batch it only cuts it a matter of three. In other words, if you have an equilibrium case where this is a constantly maintained staging area and all the hardware is continually being used, then your gain factor is four to one.

On the other hand, if you are making sorties to the moon, then it would be like three to one, and this just has to do with the hardware used. From a practical standpoint

somewhere between three and four in this case is very, very good.

PAINE: But what that would work out then to is, in order to maintain this thing going on a daily basis, you are talking about five shuttle trips a day from earth surface to earth orbit, at 50,000 pounds payload.

FAGET: No, no. This is the weight at earth, 23 million pounds at earth. This (indicating) is how much you need in earth orbit, 323,000 pounds a month in earth orbit.

PAINE: Delivered to earth orbit a month?

FAGET: A month.

PAINE: Which is about 10,000 pounds a day.

FAGET: No, it's only six flights a month.

PAINE: Six flights a month. That's right. So that's not bad. A couple of shuttles could handle it.

NICKS: Wouldn't this business of using the oxygen from the moon also tend to help you if you use it on that launching to earth, or are you including that? In other words, are you using lunar oxygen to inject you on the trans-earth trajectory?

FAGET: No, just using lunar oxygen for this area here, up and down.

NICKS: Why couldn't you also make that pay --

FAGET: You could, you could.

NICKS: --- and help the ratio?

FAGET: We just haven't got that in yet. But it would pay for the return. Yes, it would.

NICKS: It looks like several things would favor it.

FAGET: Yes. It would have a big impact.

NICKS: It seems conceptually it might even be better to supply the earth orbital node with oxygen from the moon than to bring it up from earth. I'm not sure on the numbers but possibly because of the low escape velocity and all, a direct return to earth orbit with oxygen from the moon might be cheaper to supply this whole operation.

GILRUTH: You're right.

FAGET: You are right, because somebody else has done this. That's what I've heard, that the optimum use of oxygen from the moon is to supply oxygen to earth orbit from the moon.

Now this ends up to be quite a big transportation system you've got going when you do that.

3 MATHEWS: It tends to be a growth version. I think you start out probably in steps, like Max is talking about, where you use the oxygen for your lunar orbit operations and then maybe you use it for the return voyage and ultimately, as you build up the system, you may carry it to earth orbit.

NICKS: That already begins to make that symbiotic

picture of having the station in orbit,using the moon as a place to help it, be viable and a reason for going to the moon. Things like this begin to work on each other so that you get more logic out of why you are going there and so on.

FAGET: You know, from the standpoint of just what it costs in propulsion, hardware, and all that, it is pretty clear theoretically you could do better if you get the oxygen in earth orbit from the moon. But we don't have Cape Kennedy on the moon; I want you to remember that if you're trying to supply 300,000 pounds a month of oxygen to earth.

NICKS: It only needs 7,000 feet per second to get off the moon and that's a big difference because the Cape Kennedy requirement is different.

ARMSTRONG: But it also needs 10,000 pounds to slow it into earth orbit. When you add those two together --

MATHEWS: You use aerodynamic braking.

ARMSTRONG: As long as you're going to use that, you might as well pick up the oxygen in the atmosphere.

PAINE: While you're doing it?

ARMSTRONG: Yes.

CLARKE: I pointed out this paper, 1949, on the electromagnetic launching. You could supply anywhere around the solar system from the moon, not only earth orbit, because you're so near the gravitational -- the top of the gravity world, but you've got to get almost to the Cape

Kennedy stage.

FAGET: We're probably going to end up flying all our missions from that teeny little planet around Mars if we keep this up.

(Laughter.)

CLARKE: That's what it was built for.

(Laughter.)

PAINE: Why do you think the Lord put it there?

(Laughter.)

FAGET: All right, let's go to the next slide.

(Slide.)

I want to tell you a little bit of the details that I've got on here. The space task group report did use a nuclear stage for orbit to orbit transport. Marshall has got contracts that are trying to describe this stage and they are looking for five or ten re-uses, and it has these characteristics:

Burnout rate, 87,000 pounds; propellant weight, 300,000 pounds; liquid hydrogen. The best estimate we have made on unit cost of that thing is like $65 million a copy.

Our in-house studies on the chemical propulsion stage that is comparable to that one -- We got onto this from looking at our earth orbital shuttle and using the same propulsion technology as proposed for the nuclear engine, and it contained 190,000 pounds in the earth orbit, which is a

very nice feature about this chemical propulsion stage.

What I'm trying to say is it not only makes a jim-dandy stage to go between the moon and the earth but if you mount this stage on a booster stage on the earth orbital shuttle, it then can carry 190,000 pounds of payload up into earth orbit. For those things that you can't cut down to smaller than 190,000-pound chunks, it will be very handy.

And by building it so it can be refueld it is re-used, there's a burn weight of 60,000 pounds and it carries 540,000 pounds of propellant, and it costs $36 million apiece, based on the same costing technology as this one up there.

Now these are just unit costs. They don't have anything to do with the development costs.

May I have the next slide?

(Slide.)

All we've dealt with, we figured all the non-recurring cost was going to come from somewhere else.

This is a comparison of the two stages. The chemical stage, although it carries twice as much propellant almost, as you can see is physically a lot smaller, but this is just a size comparison.

Okay, let's go ahead.

(Slide.)

This is why I take issue with Wyatt here.

This shows the relative performance of these two stages. This is the payload in thousands of pounds, and the velocity to be gained by the stages.

I think you can see with the kind of payloads we are talking about -- this line here -- the chemical and nuclear stages provide a right comparable performance. Nuclear is just a little bit better, but the over-all performance is fairly comparable.

WYATT: I'd like to get together with you. I guess you are using about the same mass fractions -- it looks like it.

FAGET: One of the things that we have done was to get a little bit more hard-headed on the specific impulse.

WYATT: What did you use?

FAGET: Well, the basic NIRVA system has got 825 seconds of specific impulse. We feel that probably can be achieved, although it will take quite a bit of development to do that. The effective specific impulse, though, is around 780 per second, using it as best we can. And we made a number of projections on this.

What happens to that nuclear reactor is as it produces the heat to produce the propulsion it is also producing isotopes and the total reaction run time is proportional to the total amount of residual isotopes. Now these isotopes start decaying or they are decaying of course immediately

after shutdown, and they produce enough heat after shutdown so that up to 48 hours after shutdown you are still burning hydrogen for that system. Otherwise you'll melt your reactor down.

Propulsively, we can't use that hydrogen very well. To begin with, the specific impulse of that hydrogen is considerably lower than 825 seconds. Furthermore, its effective performance is 'way down. As a matter of fact, there are a number of these burns that are doing harm instead of good. They occur at times when you don't want burns.

LOW: Have you had a chance to talk to Mal Kline about this?

FAGET: What's that?

LOW: Have you had time to talk to Mal Kline?

FAGET: Yes, I have.

LOW: Does he agree?

FAGET: I guess I wouldn't want to say what he thinks about it.

(Laughter.)

He doesn't agree completely.

LUNDIN: I don't understand this one too well. I'm sure it is probably my fault.

What have we got here? The change in velocity --

FAGET: This is the velocity --

LUNDIN: -- that can be imparted to --

1 FAGET: -- the ideal velocity, imparted to this
2 much payload. You've got 400,000 pounds of payload. The
3 nuclear will probably get 13,000 feet a second and the
4 chemical will probably get around 12,000.
5 LUNDIN: With stages that have that almost two to
6 one propellant loading difference?
7 FAGET: Yes. This much propellant for the nuclear
8 and this much for the chemical.
9 LUNDIN: You have kind of adjusted the propellant
10 loading to give you the same delta V for a given payload.
11 FAGET: We've compared these two stages.
12 LUNDIN: Yes.
13 FAGET: We've compared the two stages.
14 LUNDIN: You really kind of did that. That's why
15 they come out so much alike. If you'd taken the same gross
16 weight -- which I'm not saying is the right way to do it --
17 then you'd have a much different delta V.
18 PAINE: It is really 300 versus 540.
19 LUNDIN: If you make one twice as big as the other
20 it will give you about the same delta V to a given payload.
21 GILRUTH: That's exactly the right conclusion.
22 LUNDIN: And you're driven to that by the volume
23 considerations of the hydrogen.
24 GILRUTH: Right.
25 FAGET: The chemical thing is smaller.

WYETH: Smaller volume, yes.

CLARKE: Has anybody done these these studies using ammonia, liquid ammonia, for nuclear rockets?

FAGET: Oh, yes.

CLARKE: Does it work?

LUNDIN: The very early ones were but the impulse gained was not enough to pay off the extra mass fraction and everything else. And the molecular weight is --

FAGET: I would think that your ammonia thing would not be as good as the hydrogen-oxygen. I think you get 150 percent higher with hydrogen-oxygen than you can with an ammonia reaction. You are temperature limited in ammonia to much lower temperatures than your combustion temperature of hydrogen-oxygen.

MYERS: But you'd get your fertilizer.

(Laughter.)

MATHEWS: The other thing you have to keep remembering is if you are producing oxygen on the moon, those numbers change.

FAGET: The numbers change, and they change fairly well in the chemical. The nuclear doesn't know what to do with the oxygen.

LUNDIN: There is something very attractive about having a thing there in space that is almost half oxygen that only takes 7,000 feet per second to get away from.

CLARKE: One of our greatest assets.

VON BRAUN: You'd have five times as much oxygen by weight as hydrogen.

FAGET: Incidentally, I'd just like to say here I'm not here to talk about transportation systems That's Chuck's job -- but our costs on planetary flights come out the same. The chemical system is better by a factor of about two to one for interplanetary flight. And this again is all an impact of the fact that we are planning to have a shuttle.

Now we can get this kind of weight going up at a very low cost, and the chemical stage is able to get itself into orbit and carry a payload while it's doing it. The nuclear stage might be carried into orbit either by a 921, which has been our basis for costing, or broken down into pieces and carried up on the shuttle. But even when it's carried up on the shuttle it is not as cost effective.

VON BRAUN: What about the current cost, disregarding oxygen supplied from the moon. Suppose I have a nuclear shuttle up there that just came back from the moon and it is emptied into earth orbit, and I have a chemical which is also empty, ready to go back.

How many refueling flights by shuttle do we have to make?

FAGET: We haven't made any attempt to decide how

1 this factors in. We have used ten flights for both. We have
2 said that the nuclear is good for ten flights and the chemical
3 is good for ten flights, which obviously is wrong. The burn
4 time on a nuclear is about five or six times as long as the
5 chemical rocket per flight because it has much lower thrust.
6 So if you can get ten flights out of the nuclear,
7 you can probably get fifteen out of the chemical.
8 JASTROW: What's the cost per pound of orbited
9 weight using the shuttle for the hydrogen versus chemical?
10 Is it the same?
11 FAGET: We were estimating that the cost for the
12 chemical was a little less than $100 a pound. The nuclear
13 was more. And this had to do --
14 JASTROW: A little more?
15 FAGET: The nuclear was-- We were limited to 40,000
16 pounds of cargo in a nuclear, so about $6 million a pound,
17 and in the case of the chemical, it would carry 70,000 pounds
18 up on a flight because we could use a lower orbit, and the
19 same shuttle would carry the 75,000 pounds because of a
20 higher density.
21 JASTROW: The cost per pound is half?
22 FAGET: To get it up into orbit, yes. That's
23 probably about right. And this is not trying to optimize it.
24 If we optimized the shuttle for chemical carriage we would
25 do better, but we didn't.

JASTROW: So that factor cancels the factor of two?

FAGET: That's what I said.

JASTROW: On a cost basis then they're about equal, or very roughly?

FAGET: Roughly.

VON BRAUN: A nominal shuttle of say 50K payload would carry 40K liquid hydrogen because of volume restrictions whereas it would carry up to 75 K into low orbit?

FAGET: If we optimized the shuttle as a tanker for chemicals, we would end up with a smaller cargo bay. The consequence of that is the shuttle would carry more weight. The cargo compartment-- On a three and a half million pound lift-off shuttle, the cargo compartment is costing us about four pounds per every cubic foot. We trade off four pounds of payload for every cubic foot we're putting in the cargo bay. That's a rough figure.

MATHEWS: Another way of saying that is that the effect of volume on the payload is equal to the effective payload itself?

FAGET: That's about right, as a first strike at it. Some shuttle configurations are not that sensitive; others are more sensitive. It tends to be that the more efficient shuttle configurations are more sensitive to the volume.

NAUGLE: What would electrical propulsion do here

that doesn't take any propellant at all?

MATHEWS: I think when you talk about nuclear you had better be careful that you are talking about the NERVA system now.

FAGET: This is right. What we are really saying is that the NERVA system really isn't good enough to beat the chemical system. We are not saying that nuclear propulsion is not the thing to do. We are saying that the NERVA technology is going to lose in a flight on any mission.

NICKS: Along those lines I've been looking for broadly based numbers. Let me tell you what kind of things we ought to work on, and I think this may be of interest.

The mass energy conversion factor for LOX-hydrogen is 10^{-10}. For nuclear fission plus hydrogen, the NERVA system, it is only 5×10^{-10}. So basically the mass energy conversion possibilities are five times better, and we're talking about getting twice as much as some other ways.

But for nuclear fusion, the picture is a lot different. You're talking like 4×10^{-3} which is like two orders of magnitude better, if you could do that. That's why some of those kinds of things might be more interesting to work with.

GILRUTH: We really ought to be working on some kind of a fusion reaction rather than the reactor, but we're limited by the materials.

FAGET: We ought to work for a fusion reactor and we ought to set our goals at 1200 seconds or something better than that.

MATHEWS: Much higher.

PAINE: Probably an order of magnitude.

NICKS: At least 2,000 seconds.

PAINE: At least 2,000; maybe 4,000.

NICKS: There's lots of ways to get that if you think about it, but it takes a lot of work.

GILRUTH: We ought to look at some innovative process, I think.

NICKS: It ought to be as good as a turbojet engine that gets 2,000.

WYATT: I think one observation here: You said something to the effect that you could get the fuel into orbit relatively cheap. If you measure this again against the payload delivered to the moon or a round-trip, a fraction of it, this runs the cost of either of these systems that look about the same, the delivered cost, into very high numbers.

FAGET: I'm going to have a matrix on cost that will be more revealing.

Let's go ahead.

(Slide.)

I'm bringing something up which I guess should have been brought up a little earlier, but this is the mode we use

for the chemical system that I have talked about. We use a two-stage system. We put two of these chemical propulsion stages up. The first stage accelerates out of earth orbit and achieves almost enough velocity to make the trans-lunar flight. It tapers, comes around, and decelerates back to the same staging orbit.

MYERS: Propulsively?

FAGET: Yes.

The second stage goes around decelerating in a lunar orbit, staying there for a while, discharging cargo, accelerating out of lunar orbit and then decelerating back into earth orbit.

Now in the case of the nuclear system, we are penalized. We just use the one-stage system. Now the effect of this will be shown in the matrix. I'm just talking about what we did.

PAINE: Is there any advantage to using a sort of a negative slingshot on the way back?

FAGET: There might be, except that the energy in lunar orbit is so much smaller than the earth departure.

PAINE: You've gotten rid of the payload.

FAGET: That's where the payoff is; that's right.

We could have used a two-stage nuclear system but we were very concerned about recoupling the two stages together for the next trip. We've got a hot nuclear engine and

we didn't think it was very feasible to work around that engine whereas in the case of chemical it is feasible to bring the two together. (USE TELEOPERATORS)

What happens when you do this using two chemicals at once, it puts about twice the payload as one nuclear, so it comes out pretty good, except that you make fewer trips. You have got to bunch your cargo up a little more.

Could we have the next slide?

(Slide.)

These are the assumptions that we made here. I think I've talked about them all, so let's go ahead.

(Slide.)

All right. Now, using the nuclear propulsion NERVA engine we looked at a number of cases here where we used one stage and two stages, and where we re-used these stages or threw them away, and it turned out that we have always been a little bit concerned as to just how important is it, you know, re-using all this hardware.

Taking the first case, you can deliver 136,000 pounds to lunar orbit with one of these NERVA stages. If you would launch your 921 the first time it would cost you $1,500 a pound, if you only made one mission. On subsequent missions, by re-using it, it would be $357 a pound.

Now if you were able to launch this nuclear stage using the earth orbital shuttle by some modular means -- one

of them of course is just breaking it down into sizes that will fit in the cargo bay and break it up that way, and another one is one I will show you -- the cost of the first flight is much less because you are saying the cost of the 921 and of course the cost of subsequent flights would be the same.

Now if we decided just to throw it away, use it one time and throw it away, it delivers a lot more payload into orbit and because of that, its cost gets within the same range as the steady state system. It's not competitive with the 921 launch because this costs you like a hundred million dollars itself, but if you can launch it with a shuttle, it is down to $436 a pound compared to $367 a pound.

This has the advantage, though, that you make a mission any time you want. You don't have to sustain that system. You don't set up this great big operation overhead. Certainly if, instead of going in one load, we went in two stages, we would end up delivering a lot more payload to the moon and if we just launched it with a 921, it would be $887 and subsequent missions we could get for $224 a pound.

And if we were to launch it with a shuttle, the same subsequent cost but the initial cost would be $540 a pound.

Now I think the number I want you to remember is this $224 a pound. You can achieve that using a two-stage nucear system. That you can do.

GILRUTH: That means coupling the hot engine, though. I thought you said you were worried about that.

FAGET: I'm trying to say this is the best you can do; if you can overcome all these technical problems, you can get it down to $224 a pound. If you can't, you're up to $367 a pound.

PAINE: How many re-uses do you calculate here?

FAGET: This is for however many re-uses you can get. If it would be 50 times, it would be that.

WYATT: Basically that is just propellant cost, isn't it?

FAGET: That's just propellant.

PAINE: That's not amortizing the system; that's just propellant?

FAGET: You amortize the system on the first flight, and then after that it is just the cost of subsequent flights.

PAINE: Just propellant?

FAGET: Yes.

MATHEWS: Max, what kind of trends do you get with a low answer in the stages you use with the two-stage system?

FAGET: I guess I don't have that number, but I would imagine it would be better. In the two-stage throw-away, this number here would probably be about 700,000, and it would be down to about $300 a pound, or something like that.

CLARKE: I hate to be a spoil-sport, but how long is the public going to stand for a sky full of hot nuclear engines barrelling earthward at 25,000 miles an hour? I think it may be a constraint on the whole operation, and another reason for going for fusion and probably forgetting all about fission.

FAGET: Now let's look at the chemical.

(Slide.)

We ran a number of cases on the chemical and I guess the first one is the most interesting case, at least to me, and that is where we just use one of these chemical stages. We do not re-use it because it only goes one way and delivers 280,000 pounds and it only costs $318,000 per pound. And that's in the same ballpark with all the numbers you saw except that one very agonizing case where you try to recouple the nuclear stages.

So this number here is interesting because you are not committed to any particular rate. You just launch one of these any time you want, and you don't have to maintain all these balls in the air at one time.

WILLIAMS: Let me ask a question that applies both here and to the previous one.

When you say that you're low in the second column, you're talking about payload to the moon, so you wind up with a higher payload capability and you bring nothing back

from lunar orbit to earth orbit?

FAGET: No, sir. The stage is left in lunar orbit, when it gets to lunar orbit.

WYATT: Incidentally, that payload to lunar orbit includes the fuel to come back, doesn't it?

FAGET: In this case there is no fuel to come back.

WYATT: Okay. So that's the difference.

FAGET: That's the whole thing right there.

Now if you try to re-use this stage, the payload drops from $280,000 to $120,000 a pound. The first mission costs where you have to amortize the $36 million for the stage is $666 a pound, and the subsequent missions $417, so this is not competitive. It is cheaper to throw the thing away when you go one stage than to try to keep it going, to say nothing of the operational overhead.

Of course this whole thing changes the minute you start using oxygen from the moon. This case applies to the early bases, before you've been able to set up a colony there.

Then if you re-use both the stages and you have two, then you can get the chemical down to $250 a pound, which is competitive with the best number we saw for the nuclear, which was $228. Or if you re-use the first stage only, you have a little bit better number, and you've got to figure the single chunk of payload delivered, if that means anything to you.

Okay, next slide.

MYERS: Those costs do not amortize development costs? It is based on operational costs?

FAGET: Replacement costs. It does not amortize development costs; that's right, neither the shuttle nor the chemical.

(Slide.)

This is the system that we would end up with then. We would end up with this earth orbital shuttle and a tanker, the same booster here, the chemical propulsion stage, and the payload. And the payload would include the advanced L-M, so it would end up doing the shuttling from the lunar orbit to the surface of the moon -- the propellants that go there, the people, and everything else.

The point is that you don't have to launch the payload separately. They go up with the chemical propulsion stage, and then subsequently get refueled by the tanker to make the mission to the moon.

Next.

(Slide.)

To give you a better idea of what the chemical propulsion stage looks like, we've used the engines that were developed on the shuttle.

Next.

(Slide.)

A couple of our guys I think have invented something that looks pretty good here for making the nuclear shuttle better. This is a scheme to launch the nuclear shuttle on the booster for the earth orbital shuttle, using the first stage there. It would be arranged on a booster stage, the same way you saw the chemical propulsion stage, only it would not use the nuclear propulsion for injection into orbit. It would use this tank filled with hydrogen.

We would add another oxygen tank to it, and a high pressure, hydrogen-oxygen engine.

This package turns out to be short enough and small enough in diameter to fit in the shuttle bay, so all this job of this oxygen tank is to get the nuclear stage into orbit. Once you get it up there you send another shuttle up for capture and re-use.

LOW: Who invented that?

FAGET: That was invented by Jack Funk and Hugh Davis.

This is not enough hydrogen for your nuclear stage but you don't have any payload up there either. So the next flight, if you take another tank identical in size to this, and another one or the same one probably, oxygen tank and engine and you replace the NERVA engine with the payload, and that would be the second flight.

Next slide.

You would couple these two tanks and payload together and you would be ready for your mission. So this would be what gets up on your first flight. You will not have this shroud there any longer because you would have a nose cap on it.

The second flight would be this oxygen tank and the payload.

So using this system we can indeed talk about earth orbital shuttle launch NERVA stages. However, I want to point out again that even when you do this, at best the nuclear system looks like an even trade with the chemical system;when you consider the development costs and other reasons, I don't think you want to do it.

I think that's all I had, so if anybody has any further discussion, okay. Otherwise, we'll listen to Captain Scherer.

SCHERER: Captain Gilruth asked me if I would discuss some of the experiments that pertain to this subject.

First let me say that lunar based studies have been going on for some years, and we have a lot of background on it. Probably the most complete one is known as the Rieser Study. It's about five years old, and at that time a group of scientists were brought together and divided into panels, and they brainstormed and came up with a large number of prospective experiments, and I will show you this at a

glance, a listing of them, for possible discussion purposes.

Last winter, that is, eighteen months ago, STAK devoted a period of their winter study, one of their winter studies, to a lunar base, and that is one of the more recent items.

My office put out a lunar base updating here in March of last year.

Of course some of the data returns from Apollo 11 and 12 has modified some of the thinking on it.

Critical to the base and the colony I think is the knowledge of the environment as well as the possibility of resources. New data in terms of the environment I think the Surveyor partially brought back. We are proceeding with analysis very slowly and carefully, but as a general simplification I think the Surveyor was in quite good shape. The electronics, the internal electronics of the camera were in excellent shape, far better I think than most people anticipated.

There were no meteorlyte hits that were unambiguous. There are a few that most people think came from the landing itself, and I guess the same is true of the dust on the mirror, the change in the waffling of the footpad --

PAINE: The dust on the mirror is believed to be associated with the landing?

SCHERER: Yes, sir.

MATHEWS: Which landing?

SCHERER: Apollo 12. Surveyor had part of that mirror dust covered after its initial landing which was a bouncing one. But after the Apollo landing the front of the mirror was pretty well covered. It was too good a pinpoint landing.

GILRUTH: That's a good kind of problem they have there.

SCHERER: We also can now say from the Apollo missions that the moon is seismically quite quiet, which is important from a lunar base point of view.

GILRUTH: Once you disturb it though it sure does take a long time to quiet down.

SCHERER: Yes, sir.

LUNDIN: Did you say it is quiet?

SCHERER: Yes, some hundred times more quiet than the earth.

LUNDIN: What did you mean when you said no meteorite hits were unambiguous?

SCHERER: I mean there are a few but they were thought to be particles blown by the landing. That's what I meant.

MYERS: They were only on the side toward the landing?

SCHERER: Yes, sir.

SHAPLEY: All the apparent ones were ambiguous and probably not meteorites.

SCHERER: That's the way I meant it.

LOW: Doesn't this mean they were all developed in the low velocity --

SCHERER: I don't have any data on the size of these things but they could be fairly-- You noticed how that dust sprayed from the movies. It's pretty good velocity compared to the --

LOW: But it is relatively low compared to meteorite velocities.

SCHERER: But not for the secondary type particles.

PICKERING: They haven't found any of those little melted craters like they do on the rocks?

MYERS: Does the distribution frequency then seem to be lower than we thought it was? We have a pattern of meteorite frequency that you might expect.

SCHERER: We have got a pretty small area there. I don't think there was enough sampling that you could really make a statement about it.

MATHEWS: Going back to this seismic behavior on the moon, have we got everybody working on that who possibly can be working on it? To me it seems to be one of the most scientifically things that we have gotten. Maybe I'm just not up on it, but I don't really see any well developed

1 theories as to why the moon behaves the way it does.

2 SCHERER: I think it's mysterious. We have some

3 other scientists here in the room. Maybe we can address that.

4 Bob, for example.

5 JASTROW: I suggested one thing to Ewing once.

6 Not being an expert, I mentioned it to him, which he found

7 reasonable, namely, if the moon's internal temperature regime

8 is decidedly lower, there should be less lost in the seismic

9 sense, even in the outer layers. Maybe that's the signifi-

10 cance of the ringing.

11 I don't know whether that stands up under close

12 examination.

13 SCHERER: To answer your question, Chuck, we don't

14 have all the experts but we have a number of people who are

15 very interested in this. First, the team itself are experts.

16 Nathan is not the top man, but Ewing and Pressock and others

17 are closely tied in with the deliberations, and just the

18 phenomenon has attracted a lot of people, and there's an

19 awful lot of people looking at it.

20 GILRUTH: Let me tell you one thing. This is a

21 very tiny amplitude oscillation that keeps ringing compared

22 to what you might think and of course it is going for three

23 and a half hours in the case of the impact of the S-4-V

24 compared with one hour for the impact of the L-M.

25 Now I think it is significant that the velocity of

transmission of both the pressure wave and the sheer wave through the lunar soil was according to what would be expected, based on the velocity of sound measured in the lunar rocks back to the lunar receiving lab. It was very interesting.

And there is one other thing that's significant and that is when the S-4-V impacted, the sound wave would have to travel a chord of the moon rather than around the surface and that would take it 40 kilometers below the surface at the deepest point. It was indicated that the velocity of sound through that much depth was still the same as the stuff that we picked up on the lunar surface.

So all of these things only add to the mystery of why this very tiny amplitude just keeps on going. So it might be less lossy but I don't know why you would expect it to be less lossy if it were a little hotter.

JASTROW: No, colder. Less atom displacement, less friction.

GILRUTH: If you took some earth and made it a little colder --

JASTROW: At 40 kilometers, it's fairly high, and there's a fair amount of yield. If the moon is really considerably lower temperature, it's a very simple-minded thought.

PAINE: I think Chuck's question was a good one, though, namely, we do have quite a mystery here and we ought

to be sure that we are identifying who we'd like to work on it and make sure he's getting support.

SCHERER: I hope we are doing that.

The key point I'm trying to make here is that the moon is seismically quite quiet which, from a lunar base point of view is good.

The question of resources: We certainly don't have any evidence of water on the two mare landings. Getting to fresh volcanic regions such as mares' hills probably is, or to rilles which in recent publications, one last week, theory has it may have been water, and to the highlands themselves near the surface, is important in determining whether or not we have these.

May I have the first slide, please?

(Slide.)

We were talking about experiments last night, and I don't know what it might look to you to you to be, but these are blisters rather than craters. And one of the theories has it--

May I have the next slide, please?

(Slide.)

-- that these may be caused by an entrapped pool such as this up here, forming this type of blister.

Now we have two experiments that may tell us whether or not this is true, an electrical properties

experiment which is planned for the last several Apollos, and a radar sounder, a lunar sounder. And I have here a photograph that I just received.

Walt Brown out at JCL has a prototype of this sounder and he's just made an aircraft photo with it and the detail is I think extremely good for this type of thing. This is a scale of maybe 25 to 30 miles in length.

(Handing to Dr. Paine.)

It was reported to me yesterday that he had discovered water -- not discovered, but he had verified a water table, a known water table at a depth of 800 feet.

SHAPLEY: How many feet?

SCHERER: Eight hundred.

PAINE: What are we looking at here?

VON BRAUN: What is this?

SCHERER: This is a radar tracing. Dr. Pickering knows more about this side-looking radar taken from an aircraft of a glacier field, a glacier mountain. Some of the dark areas are just shadows.

VON BRAUN: What is the message now?

SCHERER: The reason I was showing you this is that the detail of this prototype experiment which is planned for Apollo 19 is very good.

CLARKE: How far does it penetrate into the ground?

SCHERER: As I say, last night I was told by phone

that he had verified a water table at 800 feet.

CLARKE: Eight hundred feet into the ground? Really the rays go 800 feet into the ground?

SCHERER: This was a telephone message I got yesterday.

JASTROW: What wavelength?

SCHERER: I'm not sure what wavelength he was using. The experiment we planned has 10 degree frequencies ranging from a hundred millihertz to -- I think it's 100 kilohertz to 1200 millihertz.

So these are the two experiments that are in the current Apollo program.

Next slide, please.

(Slide.)

To shift into something a little broader as to how we can get to a lunar colony, here is one scheme at least --

NICKS: Could I ask something about the domes you were just talking about, and the point that people had hoped that what they saw emitting from Aristarcus and Alphonsus might be methane, for example. And we haven't been any place yet to see if there is some emission of that kind. I don't think we've been there enough times to give up on the thought that there are other products that we don't know about yet.

SCHERER: That's correct. That's why we have a mass spectrometer in orbit and on the surface for the J

missions.

CLARKE: May I point out that this can penetrate 800 feet into the ground? The Polaris submarines have had it.

PICKERING: No, you have to have dielectric ground.

SCHERER: That may not be a good number. It has not been verified. Dr. Pickering and I wonder whether this is true.

We have, in an evolutionary manner, I think, arrived at a permanent base. This type of program would add to the probability of finding resources, an automated vehicle that might move toward the poles to extrapolate this. The data point data would be very valuable. Perhaps it's not in the cards and the circumstances of today.

The integrated plan type of thing in here, manned orbital missions envisaged various places on the ground for checks, site surveys, a semi-permanent type of base, and here you maintain a rescue orbit type of capability and check experiment feasibility for a permanent base type production.

Next one.

(Slide.)

In our study we have a list of goals for lunar bases and let me just pick out a couple of these.

Whatever lunar work we do, the plan at the year 2000 or so for a base would determine the focus of the

precursor type of work we do. I'll talk a little bit more about experiments and resources.

A launch platform for planetary missions I guess we had not mentioned before in our previous talks so far today. This is this experimental colonization that was mentioned.

And finally, a quarantine facility for returning back from planetary missions is a possibility.

Next slide.

(Slide.)

I won't go into these but I want to very quickly-- I have some handouts for those of you who may not be able to read this.

NAUGLE: I think one of the things you might say there-- I think it was sort of implied by one of the things on there, but one of the things that came out of the discussion that we had of global applications is that the moon is also a nice place to back off and study the earth. It is better, for instance, in some aspects than--

Are you going to discuss that?

SCHERER: Yes.

PAINE: Also, many things we said about colonization in earth orbit, quite a few of those things might also apply to this.

SCHERER: Yes, sir. I think there's a lot of common

knowledge. The same things you say about a base in earth orbit applies to the moon. At some place on the moon they have an advantage, and I'm sure some places in earth orbit have an advantage.

MYERS: What Bob was talking about, you have probably more natural resources to support the thing on the lunar surface than you have in earth orbit, but you also have the more difficult transport problem.

SCHERER: Those are the two major problems.

Dale, one of the things we have sort of crudely-- By the time you go through the transportation system going from the earth to the moon, you probably have gotten many of the things out that you would sort of get out of being in earth orbit. You go around the earth and look at it, and that sort of thing. For tourism and that sort of thing, people would probably only go up to the space station for about a week or so.

If you went to the moon for a week or so, you'd sort of get all the benefit out of being in earth orbit, I would think. I don't know.

MYERS: You'd get both.

NAUGLE: Yes.

MYERS: You are also saying that you would get the benefit of the earth -- looking at the scientific application out of the system, too.

NAUGLE: The major thing is that you want to look at as much of the earth as you can with the same apparatus at the same time, and you can look at almost half of the earth, where you are quite limited even with a stationary orbit in terms of what you can see.

MATHEWS: I think in terms of the practicalities of the situation, in addition to the transportation business, I think this base that you put on the lunar surface or in lunar orbit, from a safety standpoint because that is much more remote, really gets developed in earth orbit.

In other words, as I see, say, the systems for the base about the moon would be developed and verified in earth orbit applications where you do have pretty good access and so forth, rather than --

GILRUTH: You're talking about a lunar orbit base now.

MATHEWS: I'm talking about systems, at least initial systems for a surface base.

PICKERING: You wouldn't develop a lunar orbit base of any size. That's just a way station to the lunar base.

An earth orbit base you may develop into some large sized base but there doesn't seem to be any point in a large sized lunar orbit base.

MATHEWS: That's right.

CLARKE: I can think of reasons why you might want

facilities in a large lunar orbit base: communications, rescue, doing the kind of thing to the moon that we're going to do to earth.

MATHEWS: It will be an operating base. Whether it has to be-- How large it has to be, I'm not sure. I think it will be done as an operating base, a safe, stable, fairly mobile -- from the standpoint of access to the surface -- point, but I look at at least that lunar orbiting base as being a step on the way to the surface base.

GILRUTH: You have to do a survey to find out where to put the surface base. I think the real exciting thrust is to get something permanent on the surface of the moon. I think this is what really would make it worthwhile to go all that distance, and it would put it naturally above the space station.

I'm not saying I favor it above the space station but that is what it's got that the space station doesn't have.

PAINE: The other thing that was pointed out in previous discussion, Bob, was it also has one-sixth of honest, gravitized G, not artificial but real G. That is certainly a unique property.

GILRUTH: Yes.

SHAPLEY: Wouldn't another possibility be to have the major base in lunar orbit, and then you take various excursions to many small outposts at different points on the

moon, like touring the Greek Islands by boat?

MATHEWS: That's the interim step in locating the surface base, but I agree with Bob, the only reason we're going to the moon is to get access to the surface.

SHAPLEY: When you go to the moon, though, on this basis you wouldn't go to one place but you'd go to several different spots on the moon.

GILRUTH: I don't think so. I think you want to get dug in on the moon. We want something permanent there, so you can have your colony, and then you go from that base to different places on the moon. I believe you are going to want a permanent colony and you're going to want to use the minerals on there. This is what I think appeals to the human spirit, to dig in and get something permanent on a far-off place. That's what I think anyway.

SCHERER: When we do get onto the surface there are a large number of experiments that the scientists can leave up that would be fruitful.

Next slide, please.

(Slide.)

These were divided in category by this major study we did, and I just flash these to show you.

We had optical and radioastronomy, other types of astronomy here: physics, biology.

Next slide.

(Slide.)

And some of the earth-oriented types of investigations, including oceanography.

There are areas the scale of which, from the moon, is better than or more useful than from earth orbit, and in general you want both. They are supplementary or complementary types of data.

Next one, please.

(Slide.)

I'd like to talk to this chart a little bit. The only message from those three, I want to show you that in a study some 96 separate types of experiments were generated by this group of scientists.

But speaking from this one, in terms of exploring and understanding the moon itself, you've got your own type stuff. This is the type of digging in that one probably or possibly would want to do. You would want to have traverses, though, out to several hundreds of kilometers to get active seismic, for example, to give you the deep outer properties, and certainly the geologic -- the broad geology types of investigations we do on earth, a traverse across a major mascon, for example, or a gravitational traverse and profiling would be very interesting and of great interest.

I think a lunar base would soon set up a laboratory for sample analysis, perhaps considerably less simple than

the lunar receiving laboratory, a laboratory in which the gross analysis could be done, separating out such things as the hot rock we found on Apollo 12, this Rock 13, some 20 times as radioactive as the average.

There are various engineering and technology types of things that one could think of on the moon, the same types of things you all consider and have talked about in earth orbit. The one-sixth G for medical and the colony itself for behavioral types of experiments, the various biotypes including the ones shown there, and I guess in the biochemistry would come the plant investigation, the botanical investigatoins. We can grow an awfully good liverwort farm on the moon if we found a use for them.

One of the key areas is astronomy. The moon offers considerable advantages in some aspects of astronomy. It has low surface temperature at night, stability, and no wind, no atmosphere, of course. The use of the back side for shielding is extremely important in the video astronomy work.

By using the laser reflectors we know very precisely our distance to the moon and the position and the radio astronomers talk of using the earth-moon line as an interparameter base that is extremely, highly precisely known.

We talked a little bit last night, Clarke did, about gravity astronomy. Incidentally, I checked with Joe Weber today and he anticipates the moon is one thousand times

better than the earth for his experiment.

PAINE: Three orders of magnitude.

SCHERER: Yes, sir. This is the number he's using.

Specifically the plan on this experiment is that it is in our program for the Apollo 18 or 19. When he first proposed his experimental data, most people didn't believe it, and from where I sit, there has been a gradual shifting and I think now the majority do believe it; there are still a number who do not.

We've had several meetings with outside investigators asking advice, and one side says, "The man's an idiot," and the other side says, "He's going to get a Nobel prize."

PAINE: Maybe both.

(Laughter.)

SCHERER: But in theory this is comparable to Einstein, I guess, this theoretical work, so it's an excellent experiment to fly in my opinion.

NAUGLE: Excuse me. Could I mention again here--I'm giving away something I was going to say, but I want to talk about global applications.

But one of the things people now looking downstream think they would like to do would be to reverse the location of the laser pointer reflector and the telescope, put the telescope on the moon and then carry around corner reflectors and set them up and use them to measure this kind

of centimeter-like motion of the earth's surface over a whole shelf, a whole geological area.

JASTROW: What size telescope?

NAUGLE: Presumably something of the order of a 60-inch telescope. You just reverse the situation.

JASTROW: That would be an earthquake detector?

NAUGLE: Yes. This would be something you would set up and use over a long period of time.

JASTROW: You know, this San Andreas fault, if you were to divide the strain rate into the displacement of the 1906 earthquake, it looks like another earthquake around the year 2010, and it would be awfully nice to have some warning. Fifteen feet I think was the displacement.

CLARKE: Remember, that was only a little one. The big earthquake was a hundred years ago. The real big one was in the last century, a much bigger one. There's was nobody around or very few people around.

NAUGLE: There was a very large one apparently down in the central part of the United States, around Missouri, some hundred years ago.

CLARKE: Oh, yes.

JASTROW: This is worth stressing.

NAUGLE: The point of it is, this could have a major economic impact because-- Well, if you could predict it and prevent it or, you know, if you could sort of know

definitely that there was an earthquake coming over the next ten years, or that there would not be one for the next hundred years, in one case you'd obviously build your buildings and make your design on the basis of the earthquake coming, and in the other case you'd say, "Well, hell, it doesn't make any difference because the building will have fallen down, and we can start 90 years from now to worry about it."

PAINE: The old mission records have records of these earthquakes.

SCHERER: The 100-inch telescope is reflecting the moon now on a 16-inch laser that Neil put there. We are looking at a 300 cube which is three times as big as a possibility for a later Apollo mission, and a 30-inch telescope. So if you are building a reflector on the earth, you make it quite large.

GILRUTH: How many observatories are using the laser reflector now?

SCHERER: Over at Leningrad we called a special meeting of countries interested and it was very well attended. The Russians are using it but they aren't ranging. They are getting reflections and the pulses are quite long, but they are not really ranging. They are just demonstrating that they can do it.

The Japanese, the French, the Australians are working on it.

GILRUTH: Without ranging, you don't get anything do you, except a thrill?

(Laughter.)

SCHERER: You get a reflection. They don't have the ground station technique good enough yet.

NAUGLE: Some people get peculiar thrills, Bob.

(Laughter.)

SCHERER: Another type of astronomy is the X-ray, gamma ray type of thing in which the moon, without an atmosphere, can be used as an occulting disk and sweep the sky.

On earth observations, which is a point that John has made several times, the heat balance of the earth as a whole is one example. The heat balance of oceans apparently is of significance to the oceanographers, and that's this gross scale that we're talking about.

Oceanographers are also interested in the precise sea levels and apparently from the moon you can measure this much better than they can now. I think they call it sea surface height, is the words they use.

Of course there's some fundamental physics that one can do in this vacuum if you can keep the vacuum down to low levels with low G and low magnetic fields.

In manufacturing areas the coating of large optical surfaces or large solar cell surfaces in this very large vacuum is one thing that people consider. You can thoroughly

outgas metals so that they form at their max densities. Refining can be done by heat alone so that there are no reducing agents required.

There's another thought I had that is not on this chart, but I don't know how many people have heard this said.

At a STAK meeting Dr. Towns and several of his colleagues got off in a corner after dinner and did some calculating on what it would take to put an atmosphere around the moon, a usable, livable atmosphere, and came up with a number -- This was a back-of-the-envelope type of thing -- and came up with a number of three gross national products. And this atmosphere would last-- Of course it would be temporary, but its temporariness is calculated up in terms of hundreds of thousands of years.

JASTROW: You smoked me out. I'm going to talk about that.

SCHERER: I'm sorry. I just finished, Bob. That's as far as I'm going to go.

GILRUTH: I hear they were talking about an ozone atmosphere because it's heavier and it wouldn't get lost.

PICKERING: We have enough of that in Los Angeles.

GILRUTH: It is very easy to convert with just a little electrical device.

You're going to be using that in Los Angeles soon.

NEWELL: The solar energy coming in and intercepted

by the moon would almost keep up with the escape rate. The only problem is if you put up an atmosphere like that on the moon with its slow rotation rate, hurricanes and tornadoes would make the atmosphere useless.

NICKS: I've got just the rocket to rotate the darn thing.

(Laughter.)

JASTROW: Did you mention radio astronomy on the base?

SCHERER: I did, but I'm going to talk about it again because I'm sure some people want to expand on it.

(Slide.)

Here's some major experiments. I'm going to flash a couple of pictures:

A 2-meter, 100-inch optical telescope is like 30,000 pounds. This is one of the most interesting-- I'm sorry. The X-ray telescope. This is your radio astronomy that scientists are quite excited about, I think.

And then the geo-chemical laboratory.

Next one, please.

(Slide.)

Let me just flash a couple of these to give you a general idea of what they might look like.

The interest in a drill now, without water on the surface, may become higher. This is a 300-meter type of

drill. This is an artist's type of concept, weighing some 20,000 pounds.

Next one, please.

(Slide.)

If we do find a pool of water, this may be a way of getting it.

The optical telescope. This is the 100-inch optical telescope concept. I forget the weight of this thing. This is a .01 arc second type of resolution.

Next, please.

VON BRAUN: Could you explain some of the details?

SCHERER: Beg your pardon?

VON BRAUN: Could you point out some of the things on the previous chart?

SCHERER: Wernher, I'm not an astronomer. I'm not familiar with this. The astronomy panel of this big study group I spoke of came up with this artist's concept.

VON BRAUN: It looks to me like there are two big mirrors, a 260-inch primary mirror and then another 200-inch flat mirror, so the main mirror is in the left upper corner there.

SCHERER: Yes.

VON BRAUN: What's the flat mirror? Oh, the light comes into that tube there.

WYATT: That's a focusing mirror.

PICKERING: Instead of turning the whole telescope around you just turn the flat around.

VON BRAUN: And the flat mirror down the tunnel --

PAINE: Back again to the instrument.

CLARKE: I don't know why you have to put this in all this building. Why can't you have it out in the open?

SCHERER: For thermal reasons.

Next slide, please.

(Slide.)

This is an x-ray telescope which is a considerably smaller type of thing.

Next one, please.

(Slide.)

The radio astronomy layout can be extremely effective on the moon, particularly if it were placed on the back side, and this is a very long wave, this is 18 kilometers.

GILRUTH: What is that structure? What are those loops that go on there?

SCHERER: I'm not sure what they are supposed to be.

NAUGLE: Those are dipoles.

GILRUTH: What would it be physically?

JASTROW: Dipoles.

GILRUTH: Little tiny wires, or big heavy wires?

NAUGLE: Little tiny wires.

JASTROW: Narrow gauge.

PAINE: They are 50 meters long each.

ARMSTRONG: Is this something that focuses?

NAUGLE: No, it's an interferometer.

CLARKE: It would be pretty directional that size.

SCHERER: The interest in radio astronomy has grown by leaps and bounds, apparently, with quasars and all these other kinds of things, and gravely waves, and I don't know what-all, and this is a 1-degree resolution type of thing.

JASTROW: What is the length of this?

SCHERER: Eighteen kilometers.

JASTROW: And the wavelength?

SCHERER: One megahertz.

GILRUTH: What would this weigh, to carry it up?

SCHERER: I had it on a previous chart. 28,000 pounds.

GILRUTH: It would take three trips.

VON BRAUN: Plus the vehicles that are necessary to put all the dipoles in the ground, of course. It's a hell of an installation job. It would require several weeks of work to build that thing.

NAUGLE: Is it clear that it has to be off the lunar surface if there is no water?

SCHERER: It depends on the dielectric constant,

apparently. When this was designed, we assumed that there was more water than there is.

VON BRAUN: How sensitive is this to blackness? Can you go over mountain ranges with that thing, or do you have to go into mare where things are perfectly flat?

JASTROW: You can lay it down in the Kunowski Crater, I imagine.

NAUGLE: It has to be fairly flat. Orders of a centimeter. You can compensate with this but you can't go over a mountain.

SCHERER: As I understand it, a normal type mare with this layout is what is sought.

VON BRAUN: The first Mills-Cross in Australia-- This thing is named after Professor Mills in Sidney. I think that thing is perfectly flat, on perfectly flat ground.

PICKERING: You'd want to have it essentially flat, maybe a few feet you could tolerate, but not very much. I think also you could put it a lot closer to the surface than that 30 meters that is suggested.

VON BRAUN: Since the dipoles are above ground, you can of course compensate for the height of the sticks that you use, but does this require very accurate surveying and all this?

PICKERING: We have to know where they are.

VON BRAUN: Do we have to know with precision where

they are?

PICKERING: Reasonable precision.

NAUGLE: You can also help to space them by the electrical connection, the phasing.

TRUSZYNSKI: There has to be a precise relationship, dimension-wise, between each segment and there's a tolerance of something like a 16th of a wavelength to be reasonably practical. That must be quite accurately laid out to get the right kind of pattern.

VON BRAUN: It would appear that basically the modules of which this thing consists are quite simple, and maybe the installation could also be made relatively simple but there's a need for a geodetic job or an electronic job at the end to survey the thing before the crew could leave, to really know what you've got there.

NICKS: The way to do that is to hang it across a crater and start with catenary and now what you've got when you take it up there. They you don't have to survey it.

CLARKE: Send a laser beam. This can't be flat across because the curvature of the moon is terrific over 18 kilometers.

NICKS: So hang it across the crater and start with a catenary, and you've got your dipoles hanging, and you can program it.

JASTROW: John, do you know why this wavelength was

chosen?

PICKERING: It has got to be a long wavelength that you can get from earth.

JASTROW: How far out do you see, so to speak?

NAUGLE: This is one experiment, Bob, that has a sort of a natural size to it. Most other things you'd like to go on building bigger and bigger, but as you say, somewhere down around a hundred kilocycles, I think, the distortion that you get coming into the heliosphere, if you will, you lose-- It does not benefit you any to go to a larger, longer array.

JASTROW: Are radio sources bright at this wavelength or close to it, at 2 or 3 megacycles?

PICKERING: The stuff on the radio-astronomy satellite is the only data in this area.

CLARKE: Wernher has made the point that for real long-wave radio-astronomy you've got to go out to Jupiter, which I guess is outside the scope of this conference because of the heliosphere.

PICKERING: The back of the moon, though, has plenty of opportunity.

SCHERER: I have some data here if you're really interested.

May I have the last slide, please?

(Slide.)

This is just a simple illustration of the geochemical laboratory for differential sample analysis type of work.

GILRUTH: Is that something you bury under the soil?

SCHERER: Yes, sir, for thermal control, and other types of protection.

I asked my people to take the STAK lunar study and the results of the sample analysis today and see what modifications they might make in some of the recommendations, and very quickly we hit a number of them here.

We do know that there is little if any perterbation of solar wind, so the use of the moon as a base for some of the non-lunar sciences is indicated.

We don't see any types of lunar materials that one would want to return to earth. Even the large concentrations of titanium or rare earths are not significant enough.

The excavation and mining appears to be -- that it could be done more easily than we thought prior to the mission. Most of the soil is around the 60 micron area which is an ideal size for processing, just the handling of it.

These people made the calculation that was reported by Max, that 10 cubic yards of soil looks as though it should yield about a pound of hydrogen, and this is based

on the solar wind hydrogen which has pretty well saturated the surface.

The STAK study talked about the many uses for sulfur if it were found in the material. For example, the initial shelter would would possibly be a lava tube which is mortared by melted volcanic sulfur.

Fertilizers for hydroponic gardens is another thing they came up with as a potential for using sulfur; and a nuclear moderator, for example.

There is sulfur in the soil --

GILRUTH: Have they found sulfur in the soil?

SCHERER: Yes, sir, 2 percent in the basalts and the FES.

So that may be a potential.

The final point is there is a metallurgy using basalt, a metallurgy technology that has developed in Czechoslovakia and Poland and several other places, and it looks as though the lunar soil fits the criteria that they have. At temperatures like 1100 degrees these things could be cast directly into bricks and pipes and even spun for insulation and filters. So this may be of significance when we really get into lunar base building.

This concludes the miscellaneous types of things I wanted to bring up to generate discussion.

NICKS: Can you make explosives?

SCHERER: Yes, sir.

Jack Green has done a lot of lunar sulfur technology and reporting and he claims you can make sulfuric -- generate sulfuric acid.

CLARKE: One lunar use which the people at CERN are interested in -- I've had some correspondence with the new philosophy at CERN -- was this is obviously the ideal place to put nuclear accelerators because a cyclotron wrapped around the moon with a 2,000-mile diameter in a free vacuum is a place to put it, or a betatron, or whatever.

PAINE: Along that line, the moon might be a good place to do any kind of nuclear operations if we decide to do large -- the things that don't escape fall to the surface. You know where they are; they aren't in the atmosphere. And it's away from the earth.

And if you look at the earth and the moon from Mars you think of the earth and the moon as a double planet, and it is part of our neighborhood already, not somewhere else. It is really something that you begin to think of using in conjunction with the earth as a resource, it seems to me; for whatever purposes that place offers you nearby that is different from the earth may be an advantage.

VON BRAUN: I was about to ask a question in connection with orbiting facilities, the particle accelerators. Of course potentially one of the most interesting customers

for outer space, because you have the free vacuum and you can utilize dangerous things like superconductive magnets that may explode in outer space, tieing these things to the power supply area. Is it more attractive to build, say, a super two-mile particle accelerator in orbit, or better on the moon?

CLARKE: You will always need a lot of hardware and material for your magnets and your power sources so I think you will have to wait until you have manufacturing facilities.

GILRUTH: It is still too early to say right off. It's a trade-off between the difficulty of getting there and the ability to manufacture from the materials already there.

VON BRAUN: For example, in orbit you could make the point; with a very slight spin you could make that thing perfectly round. You can build it very flimsy --

PICKERING: No.

CLARKE: You have a problem with magnetic fields.

PICKERING: Yes, even with superconducting magnets.

NEWELL: Your focusing problem is your big problem. That doesn't depend much on gravity.

PICKERING: It's cheaper to do it on earth. After all, the cost of a vacuum tube that long on earth is not -- is trivial compared to the cost of getting all that weight into orbit.

MATHEWS: Isn't it the situation here that you

really aren't looking for your particle accelerators; you're looking to use the high energy particles in space. The numbers I've heard is something like -- in terms of, say, getting an order of magnitude increase in Bev as compared to present accelerators which cost something like three billion dollars to build it here on earth.

But in space you could capture particles of several orders of magnitude.

GILRUTH: That's true.

MATHEWS: And you can do it in stay times of the order of magnitude even of several months. So I thought the idea was more to use those particles if they're available.

PICKERING: The free supply of cosmic rays, though, isn't under your control. You just take them as they arrive.

CLARKE: And very dilute.

VON BRAUN: Bill, are you sure that this matter need not be analyzed any further, to build and operate a particle accelerator in space?

PICKERING: The present nuclear machines take more steel than a cruiser.

VON BRAUN: Because they don't use superconductive magnets.

PICKERING: If you start going into those techniques you cut it down wquite a bit but you also have problems of power supply, focusing problems; accuracy of line must be

maintained over the whole system. And if you look at the whole problem of building it and you ask yourself, what did you get by building it at zero G and the high vacuum that plagues you here on earth, I don't think it would come out even very much of a saving.

In other words, the cost of the vacuum itself is obviously trivial. The question of whether zero G would allow you to make the thing more accurately aligned, or something of that sort, that's a little different than the problem of the telescope where you have the single problem of a mirror and a relatively small mounting.

If you had this thing in orbit, for example, what would happen to the thermal shock as the moon went into the shadow of the earth?

VON BRAUN: I think to maintain anything of liquid helium temperatures in the earth's atmosphere is a little bit comparable to the gravitational well that Arthur Clarke was referring to a little earlier. We're always surrounded by the warm stuff and here you build a 4 degree absolute heat well--

PICKERING: But you now use some of space for outer superinsulation.

VON BRAUN: But in space, though, with our cryogenics we have very little difficulty I think in this respect of a benign environment.

I'm not trying to sell these things. I'm just wondering if there is really a foregone conclusion, or is it worth looking into?

CLARKE: I think the moon is the best bet because you want a stable platform. The seasoning properties are pretty important for these big accelerators. You've got your low gravity. You've got your low temperature. You can run it at night halfway down to superconductors. And you are going to have eventually all the raw materials you need, all the iron. Half the moon is made of iron. It's all there. It is going to be another fifty years before you can do it but that's where it's going to be. That's where the action is going to be.

And the other thing is this, too: What a wonderful place for mass spectroscopes and isotope separation. Just fan out your beams miles away and hundreds of feet apart and you're in business.

VON BRAUN: Isotope separation, yes.

PICKERING: I guess one should remember that when the moon has been inhabited to this extent that beautiful vacuum is starting to disappear all the time.

CLARKE: Yes. Like I was saying yesterday about ten Apollo landings. You've doubled the atmosphere.

GILRUTH: Well, I think it's obvious that a lunar base, a permanent lunar base could be built. I think it is

1 obvious that one will be built. The question is when.

2 I think it is more difficult than a space base

3 and I think the space base should be built first. I think

4 it is obvious that the lunar colony or the lunar base has

5 got more of -- at least it is obvious to me that the lunar

6 base has some features that will be exciting and appealing to

7 the human spirit because of the fact that it could ultimately

8 be a self-sustaining society there.

9 I can visualize, as others have before me, a city

10 or a large colony under a dome with this gorgeous view of

11 the heavens, and roof gardens and an atmosphere there, and a

12 delightful state of one-sixth gravity which would allow one

13 to bound around like no man has ever done before, at least

14 for a while until you lost all your muscle tone.

15 You could even visualize having your own set of

16 wings, as your friend Wernher and yours, Arthur, propose.

17 He could really be the Icarus, you know, just put out your

18 arms and fly, or like Sam Small, the flying Yorkshireman.

19 It also has, I think, an even more serious appeal

20 as a place that the human civilization might want to establish

21 as a hedge against the future or against a cataclysm on

22 earth where negotiations might get out of hand and you destroy

23 what you have. I think it has been very interesting to me

24 to study this and to talk with Lee Scherer and Max and others.

25 I had not appreciated I think that the moon had so much oxygen

in it.

It might even be a place to put a permanent station some day.

I think we've got to be responsible, though, and look at it in terms of what else you might do with the kind of effort it would take. For example, we have never drilled a hole in earth below about 28,000 feet. I think there would be tremendous scientific interest in drilling a hole in the earth. As you know, this was started at one time and due to a bad feeling between the head of the Appropriations Committee and the contractor that was doing it, it was killed, and it was a matter of $25 million to do this job.

Of course, it might have cost more than that before it was through.

I think we have to look at things like this, also, in the progress of human knowledge.

So personally, I don't know what kind of priorities the country should give this kind of thing, but it is one of the things that we should all consider very seriously.

I turn it back to you, Wernher.

VON BRAUN: Bob, we still have about 25 minutes now. I am scheduled to keep this discussion going. Maybe somebody else would like to speak.

Neil Armstrong volunteered to tell us something about his trip to Russia, so unless you would like to continue

this discussion on the lunar base, this may be an ideal spot to give Neil half an hour. He has to leave tomorrow evening.

(Whereupon, Mr. Armstrong made a report.)

VON BRAUN: Okay, Thank you very much, Neil. We will take a break at this time.

(Whereupon, at 3:50 p.m., the discussion was concluded.)