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MAJOR UNCERTAINTIES INFLUENCING ENTRY PROBE HEAT SHIELD DESIGN

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MR. CONGDON: I'm going to start out wearing, appropriately, a gray hat this morning as I present Dave Carlson's paper, but as I move on to the second paper, I think you will notice the hat becoming progressively whiter.

As Phil just mentioned, the first paper discusses major uncertainties influencing the design of an outer planet probe heat shield; these uncertainties were ones which were considered most critical in our recent study effort on the adaptability of existing Pioneer Venus hardware to a Saturn/Uranus probe. The second paper gives some of the accomplishments and interesting results which we at Martin-Marietta have seen so far in our effort to develop a high purity silica reflecting heat shield for outer planet missions.

Most of the material that I planned to present in this first paper on probe heat shield design uncertainties has already been discussed in considerable detail this morning by other speakers. Therefore, to cut down on a lot of redundancy, I will go through these view graphs rather rapidly and just re-emphasize major points.

As you have seen several times this morning, there is quite a large range in the entry heating environments to be expected for an outer planet probe (Figure 6-16). This is due primarily to large uncertainties in composition and scale height of the planet atmospheres. This Figure shows analytically predicted convective and radiative heating rates vs. time, covering the cool, nominal and warm atmosphere extremes for a Saturn entry probe. For the cool dense atmosphere, entry heating consists of very intense convective and radiative fluxes for very short time periods. For the warm atmosphere extreme there are long convective and radiative pulses of relatively low intensity. Also, it is very evident that the importance of the radiation component changes significantly in going from the cool atmosphere to the warm atmosphere, which has a

Range of Predicted Entry Heating for Saturn Entry
Due to Uncertainty in Atmospheric Composition

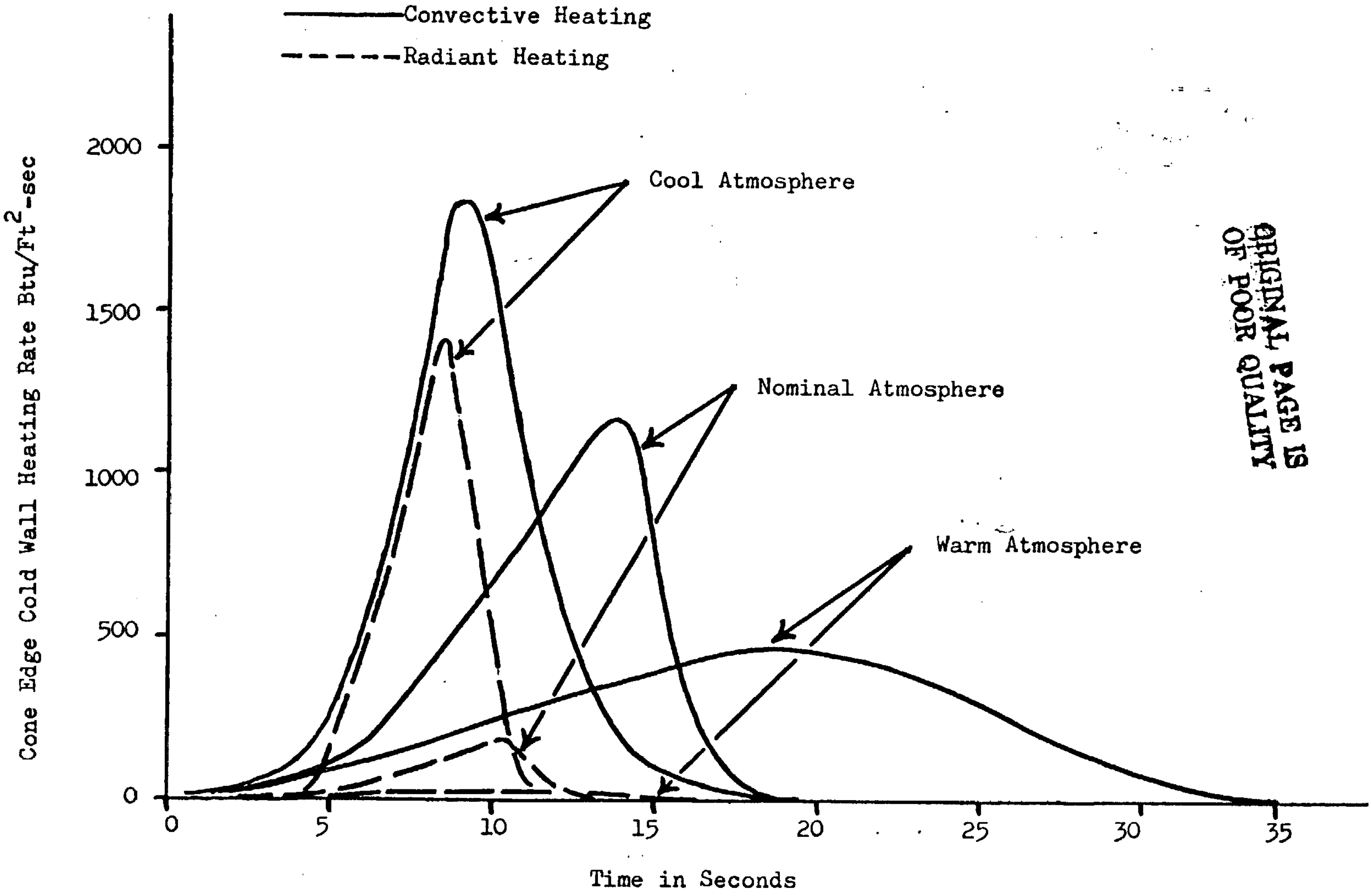

Figure 6-16

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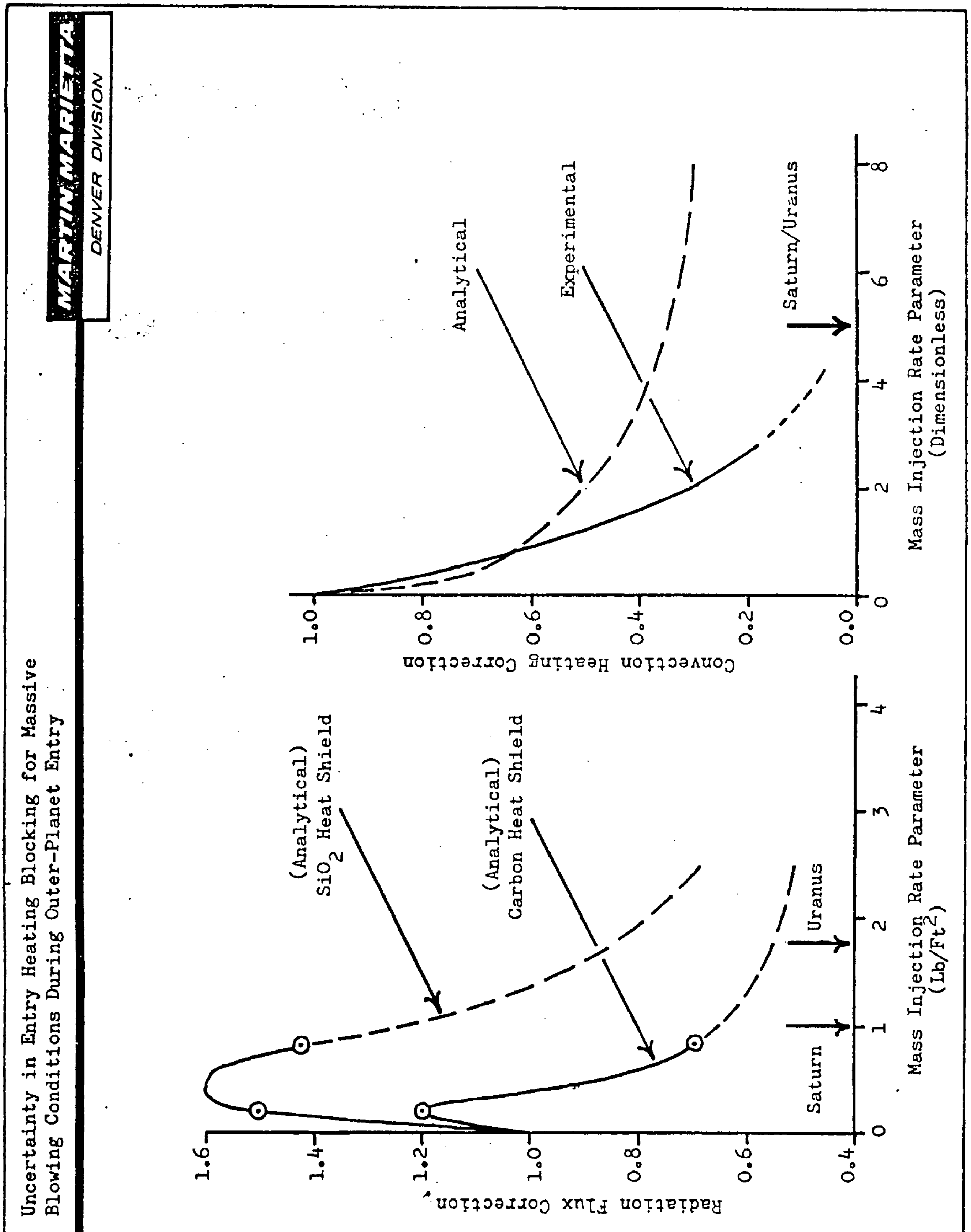
bearing on reflecting heat shield use; the cool to nominal range is the range where a silica heat shield could be used most effectively.

Now when you size a heat shield, you have to cover the extremes in the entry environment. For the engineer, it is very difficult to design the most efficient heat shield for such a wide variation in the anticipated entry environment as shown in this typical case; on the one hand, the heat shield is designed for high surface recession and, perhaps, spallation, while on the other hand, the heat shield is designed for thermal soakback. Unless such large uncertainties can be narrowed, the heat shield system cannot be fully optimized.

A second item in this first category of heat shield uncertainties (Figure 6-17) - a category which we could label as "Entry Heating Uncertainty" - is the uncertainty of the effects of ablation species on entry heating. This slide shows radiative flux correction vs. mass injection rate and convective flux correction vs. mass injection rate. One would expect, normally, that the radiative flux would be attuned or blocked by ablation species. Analytical predictions recently performed here at Ames and at Aerotherm have shown that for Saturn/Uranus entries, using carbon and silica based heat shields, there is an augmentation of the radiation flux at lower values of the mass injection rate parameter. This is shown in this first graph at values on the abscissa less than one. The ablation species themselves are radiating. More computer analyses are needed to further definitize the shapes and values of these curves - as you can see in this graph, both curves are based, essentially, on only three points.

In the second graph are shown a curve of analytically predicted convective blocking plotted out to high mass injection rates expected for Saturn/Uranus entry, and a curve of


Uncertainty in Entry Heating Blocking for Massive Blowing Conditions During Outer-Planet Entry
MARTIN MARIETTA
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Radiation Flux Correction,
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0
1
2
3
4
(Analytical) SiO_2 Heat Shield
(Analytical) Carbon Heat Shield
Saturn
Uranus
Mass Injection Rate Parameter (Lb/Ft^2)
Convection Heating Correction
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
Analytical
Experimental
Saturn/Uranus
Mass Injection Rate Parameter (Dimensionless)

Figure 6-17

convective blocking based on a correlation of some earth re-entry and ground test data for relatively low injection rates. At higher values of the mass injection rate parameter there is disagreement between the two curves. As addressed by several speakers earlier this morning, this is not necessarily an analytical shortcoming, but rather, a consequence of radiation/convection interaction at such high entry velocities. The point of this graph is that there is considerable uncertainty in the magnitude of convective blocking for Saturn/Uranus and other outer planet entries and the heat shield sizing strongly depends on degree of blocking. More computer work should be performed to further definitize convective blocking as well as radiative blocking and, wherever feasible or possible, tests should be conducted to confirm the analytical predictions.

A second category of major uncertainties influencing entry probe heat shield design is uncertainty in material performance (Figure 6-18). For the carbon based ablators, probably the biggest uncertainty is the uncertainty of spallation under intense heating. This was discussed earlier by John Lundell and other speakers. Spallation is difficult to model analytically and, in addition, adding extra thickness to the heat shield to prevent spallation failure modes can lead to an excessively heavy heat shield. Tests and flight experience with carbon phenolic have shown that this material is susceptible to char cracking and spallation. At Martin Marietta, research has been performed to come up with an improved carbon phenolic, one less prone to spallation, and some progress has been made to date in this area. Shown in this slide are two different formulations of carbon phenolic tested under the same conditions, radiation exposures at 1500 Btu/ft^2-sec for 3 seconds. The formulation on the left was found to spall consistently, while the one on the right was very resistant to spallation under these test conditions. More development is needed on carbon ablators to further reduce spallation problems.

Uncertainty of Carbon Phenolic Spallation
Under Intense Heating

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Models Viewed After Exposure to Xenon-Arc Lamp Radiation at 1500 Btu/Ft^2-sec

3 Sec. Exposure	3 Sec. Exposure
Char Cracking	Char Cracking
Spallation	No Spallation

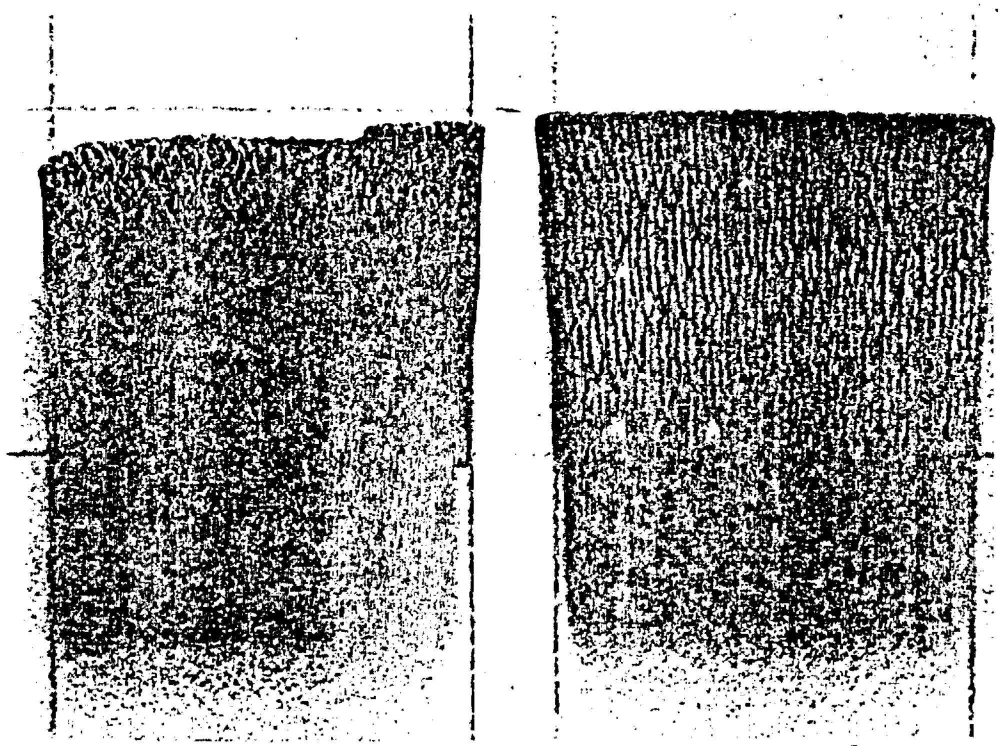

Figure 6-18

Moving on to the white reflective materials, fuxed silica in particular; when a silica heat shield reaches temperatures in excess of approximately 1700°C, the particles begin to coalesce, voids are destroyed and the heat shield begins to become transparent. This bulk vitrification event is a severe failure mode because the radiation can be transmitted directly to the substructure. The presence of impurities in the silica matrix, especially alkali metals, enhances vitrification, primarily because the alkali metals cause stronger absorption of short-wavelength visible and ultraviolet radiation and the heat shield heats up more rapidly. We at Martin Marietta have made progress in developing a silica heat shield which is resistant to bulk vitrification under high intensity radiation. This was accomplished primarily by going to higher purity fused silica powders. Figure 6-19 shows a material which we fabricated and tested last year under our IRAD program. The material could withstand high intensity xenon-arc lamp radiation of about 1000 Btu/ft^2-sec for times in excess of 25 seconds. This model was one that was exposed for 25 seconds. Except for a thin layer of powdery silica on the surface, the model was not degraded in any obvious way by the exposure. The model shown here on the right was exposed for 30 seconds and it did vitrify. These models, by the way were about 0.2 inch thick. For comparison, some commercial materials that we tested, for instance some Glasrock products, vitrified in about 3 seconds under the same radiant flux. So we have made noteworthy progress in developing an improved silica reflector, we have delayed the occurrence of bulk vitrification out to relatively long time periods. The fused silica configurations that we are presently working on are even better performers than this IR&D-developed configuration; this is the subject of the next paper. An uncertainty with a fused silica reflecting heat shield is this: we must be certain that we have a material that can withstand the combined radiative and convective pulses without becoming transparent at a critical moment causing failure; we must be certain of the conditions at which bulk vitrification occurs.

Uncertainty in Silica Vitrification
Under Intense Heating

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Models Viewed After Exposure to Xenon-Arc Lamp Radiation at 1000 Btu/Ft^2-sec

25 Sec. Exposure	30 Sec. Exposure
No Vitrification	Vitrification

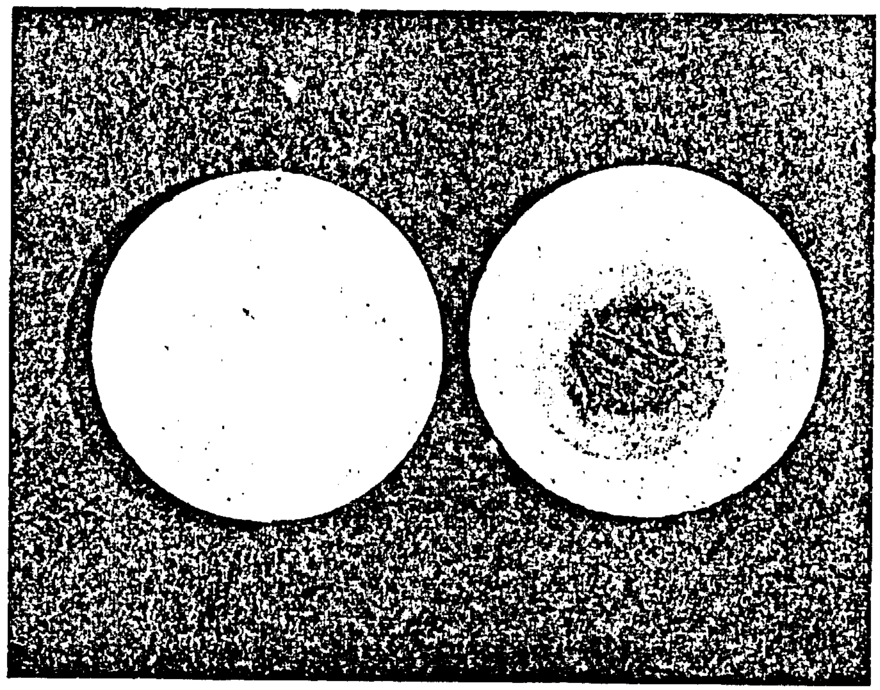

Figure 6-19

Summarizing, briefly, some of the major uncertainties which I have discussed in this paper; the outer planet entry environments are not well defined because of uncertainties in composition and scale height of the planet atmospheres; the augmentation/ attenuation of entry heating by ablation products requires more computer study and testing where possible; carbon heat shields, especially carbon phenolic, possessing improved resistance to spallation need developing, and white silica reflecting heat shields with improved resistance to bulk vitrification need further developing.

That wraps up, essentially, the points that I wanted to cover in this first paper.

DR. NACHTSHEIM: Before you move to the second paper, I think it is appropriate to note that for the technology that is in hand, aside from Jupiter, the biggest uncertainty in sizing the heat shield, from this study, is apparently what is the atmosphere; whether it is the cold or warm atmosphere. And that, coupled with the severe problems for Jupiter - that problem also persists here - I think it is appropriate to draw that conclusion to conclude this talk. And if there are any other questions at this time, before Bill goes on, I would like to entertain them now.

DR. JOHN LEWIS: Just a brief comment: there is reason to anticipate that the blips on these model atmospheres will be brought down closer to the nominal models, most especially the helium rich Uranus model atmospheres and I think it would be very hard to find anywhere models which look like those engineering models of the atmosphere generated as extreme cases with engineering problems in mind and the penalties that were being paid to meet them are obviously out of proportion to the probability that they are real.

UNIDENTIFIED SPEAKER: What was done to the silica materials that you developed to retard bulk vitrification, the models shown in the last slide?

MR. CONGDON: The primary emphasis of this work was just going to higher purity materials and using non-contaminating processing techniques.

UNIDENTIFIED SPEAKER: The models shown in the last slide, are those two the same materials that you have there?

MR. CONGDON: Yes

UNIDENTIFIED SPEAKER: And it takes about thirty seconds to vitrify them?

MR. CONGDON: Let us say something in excess of 25 seconds. When we originally started developing and testing fused silica reflectors, some of the moderate purity materials would vitrify in, say, ten seconds for this exposure. So by going to higher purity materials - materials containing lowered levels of alkali and alkaline earth metals, especially - we were able to delay that bulk vitrification event out to longer time periods.