MATERIALS FOR MAN

I INTRODUCTION

Welcome to the Materials and Structures presentation, Materials for Man. You are located in our Materials Processing Laboratory where much of the large metal forming and melting equipment used in our research programs is located. During your tour of this Center today you will see many technology advances which will have a major bearing on the way we all live. Although the principal objectives of our work in materials and structures are aerospace oriented, the advances being made in providing advanced materials and structural design techniques are applicable in many areas outside the aerospace field as well.

(1) The first slide lists some key aspects of our materials and structures research that directly benefit other industries and thereby all of us in our everyday lives. I will show how our work in the areas of fracture mechanics and fatigue can lead to greater reliability of structures; how we are contributing to the development of lower cost manufacturing processes for high temperature superalloys; how advanced ceramic materials can lead to lower weight, higher temperature turbine machinery components, and cheap automobile exhaust anti-pollution devices; and finally how advanced polymers and composites can lead to safer structures from the standpoint of fire retardation and high pressure containment.

II RELIABILITY OF STRUCTURAL MATERIALS

To increase the reliability of a structure we must be able to so design it so as to guarantee its safe operation for the desired time. This laboratory has pioneered in the two major fields listed

(2) on the next slide that contribute most markedly to increased reliability of structural materials. These are fracture mechanics and metal fatigue. Fracture mechanics is the science that deals with the strength of materials when small cracks or flaws are present. Unfortunately it is practically impossible to build a structure in which there are no flaws whatsoever. These flaws may take the form of inclusions in castings, or not quite perfect welds. Since millions of dollars are frequently involved in building such structures, it becomes a matter of great importance to establish whether the structure can safely be used. Studies of the fracture mode of materials under loads and in adverse environments enable us to do this.

The second key aspect that influences structural material life is fatigue resistance. You are probably all familiar with the term "fatigue". It is the gradual "tiring" process that materials exhibit when subjected to the repetitive application and removal of loads or temperature. To design effectively we must be able to predict in advance of service to what degree such repetitive loading cycles will decrease material life. The short film I will show you illustrates these types of problems in several structural applications and shows examples of how we are conducting research in these fields.

BEGIN FILM

This sequence illustrates typical staging operations for placement of men and equipment into earth orbit. The booster stage separates from the vehicle. Here is another view of the booster case separation as it falls away into the ocean. In previous missions booster stages were not recovered. These cases undergo severe loads on take off, separation, and impacting the water. To reduce costs of future missions, we plan to recover and use these cases.

This next sequence depicts some of the tests that are conducted to establish the sea water impact loads they will experience. Sea water can degrade the load carrying capacity of many metals, particularly in the region of flaws. The next sequence shows how we study this in the laboratory. Here a notched specimen is subjected to tension. The marker indicates the failure load. A duplicate specimen is similarly loaded. To simulate the salt water environment drops of salt water are introduced to the notches. Failure occurs at a much lower load. In this way we learn how much the strength of a metal containing a flaw of a known size is reduced by salt water. It is then possible to accurately set inspection limits which will determine if a tank may be reused. This laboratory has developed a number of fracture toughness test techniques which have been adopted by the American Society for Testing and Materials and are used as standards throughout the world.

Next, we will see typical examples of structural fatigue. Here an aircraft landing gear is subjected to repetitive loadings encountered during landing. This has a damaging effect on the materials and we must know how to accurately design for it. Fatigue is also caused by rapid heating and cooling as in this small rocket being tested here at Lewis. Each firing introduces temperature gradients in the metal which produce high stresses. We are developing techniques for predicting life of structural materials which undergo repeated mechanical and thermal loading.

To do so we work with laboratory test specimens. You can see the hot metal specimen expand and contract. The response of the metal surface as seen through a microscope is shown here. Tiny fissures open and close during cycling. These grow and link up to form a major crack that causes failure. Note specimen failure.

END OF FILM

We use precise measurements together with metallurgical studies of materials subjected to such tests to develop fatigue life prediction techniques.

During the past two years we have developed at this Center an entirely new and what promises to be an extremely accurate method of predicting fatigue life in advance of service. We call it the strain range partitioning method. It takes into account the effect of temperature as well as mechanically applied loads, all types of loading spectra, and it is equally applicable to all metals, ferrous and non-ferrous alike.

(3) The next slide is a representation of some of the results we have obtained to date in predicting fatigue life by this method. Each point on the figure is a laboratory test point. The actual specimen life is plotted against the predicted life. If all the predictions were perfect, all the data points would fall on the 45^{o} line. Although perfect agreement was not attained, the agreement shown is exceptionally good. It falls within a factor of 2 and is substantially better than was possible only a few years ago.

We are continuing to further refine this method in our laboratory. Universities as well as various industrial organizations are also evaluating this method in their laboratories. It is expected that the strain range partitioning method will permit designers of complex structures whether they be automobiles, airplanes, or any other industrial machinery, to achieve far more reliable products.

III SUPERPLASTICITY IN HIGH TEMPERATURE ALLOYS

Manufacturing costs represent a major portion of the cost of most products. This is particularly true of high temperature and high strength nickel and cobalt alloys, the so-called superalloys used in turbojet engines and other hot components of turbomachinery such as disks and blades. Because these alloys must be so strong, it is obviously a difficult and costly procedure to shape or form them. One of our major research efforts is the seemingly contradictory aim of making these alloys stronger for their intended use in engines, yet make them more readily formable. This can be accomplished by superplastic deformation using a new process called the prealloyed powder technique, another area in which this Center has made pioneering advances.

(4) The next figure illustrates schematically the steps involved in the production of precision high temperature parts and shows that the prealloyed powder process involves fewer steps and less material than conventional forging procedures. The prealloyed powder process is shown on the left. It eliminates making a billet as well as multiple forging operations. A multi-component molten metal is atomized by a gas stream. The droplets solidify in powders which are compacted to any desired shape. This also reduces the amount of scrap loss and results in overall cost reduction as well as simplification. On the right is the standard forging operation. This involves casting a billet, and a number of sequential forging steps to achieve the final product.

(5) The next figure compares the microstructure at 750X of the powder product and the conventional cast version of the NASA-TRW VI-A alloy. It is apparent that the powder product has a much more homogeneous structure than the casting in which the molten metal cooled more slowly. As a result, the various microstructural constituents are distributed more uniformly and make this product more formable at high temperature than the conventional coarse structured material.

(6) The next slide compares the tensile properties of the NASA-TRW VI-A

prealloyed powder product and its cast counterpart over a temperature range from room temperature to 2000°F. The former shows a marked strength advantage up to 1400°F. Above 1500°F there is a rapid drop in its strength properties and the cast version is stronger. Accompanying the drop in strength, however, there is a dramatic increase in ductility for the powder product. At 2000°F its elongation is over 300 percent, or an order of magnitude more than that of the cast alloy at the low stress of 1500 psi. The very high ductility is referred to as superplasticity and it is this property that enables us to eliminate many of the steps in a conventional "forging" or forming operation. In other words, the material can be formed to any desired shape by applying low loads at a high temperature range up to 1400°F where the prealloyed powder product shows such a marked strength advantage. This is precisely the temperature range where many turbine engine components such as the turbine disks operate.

Live Demonstration of Superplasticity

I will now show you superplastic behavior in a prealloyed powder product and thereby indicate its potential for ease of fabricability using one of the strongest, most deformation resistant high temperature nickel-base alloys available, the NASA-TRW VI-A alloy. Two test specimens -- one made by the prealloyed powder process, one cast-- were heated to the same temperature, 2000°F, in these furnaces, and were simultaneously loaded earlier in my talk because several minutes are required to stabilize the specimen temperature and for the elongation process to occur. (Turns on gage lights) The prealloyed powder product is being deformed by a load of only 80 pounds, whereas the cast material is being subjected to a load of 240 pounds. Elongation (ductility) is indicated on this gage. (The powder product is seen to have elongated dramatically, more than 2 inches, while the cast material has elongated only .05 inch.) I will now open the test furnaces and you can view the two specimens.

The inability to significantly deform the cast specimen under a much higher load demonstrates that a great deal of energy would be required in conventional forming processes such as forging in order to change the shape of such a high strength material. The severe deformation under a much lower load of the prealloyed powder version of the same alloy shows that substantially lower energy is required. An example of a prealloyed powder processed part is the disk shown in the display. This particular disk is a Pratt & Whitney F-100 engine 11th stage compressor disk. This illustration shows that the prealloyed powder concept is already beginning to find applicability in the aircraft industry. Far wider use throughout the entire industrial community can confidently be expected.

IV CERAMICS FOR REDUCED WEIGHT AND HIGHER TEMPERATURES

Reduced weight and the ability to withstand ever higher temperatures are major goals of materials research for jet engines. A totally different class of materials called ceramics affords great promise for substantial improvements in these properties. You are all familiar with the hard white material that acts as an insulator in your automobile spark plugs. That material is aluminum oxide. Although alumina is adequate for spark plugs, our intended applications require greater high temperature strength and higher resistance to cracking upon sudden high temperature changes. Our research has identified other ceramics, namely SiC and Si_3N_4, to be most promising for turbomachinery applications.

(7) The high temperature strength of SiC and Si_3N_4 in comparison to the strongest cast Ni-base superalloy is shown in the next slide. Here, their relative strengths are plotted against temperature. The nickel base superalloy drops off in strength rapidly as temperature approaches 2000^{o}F. Above 2000^{o}F, however, the SiC and Si_3N_4 ceramics are much stronger and also exhibit very good strength retention up to temperatures nearing 3000^{o}F.

The ability of Si_3N_4 ceramic to withstand higher temperatures than the strongest nickel alloys will be dramatically illustrated in this live demonstration. Two specimens (holds up sample) are being heated up to approximately 2400^{o}F, the anticipated use temperatures in advanced turbine engines. Material temperature is being indicated by these temperature dials. The specimen on the left is a currently used nickel base superalloy. On the right is a sample of silicon-nitride. Both specimens are subjected to the same load through this cantilever beam system. At about 2400^{o}F the metal sample begins to soften and the weights will cause it to bend. I will now turn off the torches and the temperature will drop.

Even though the silicon nitride specimen has experienced a rapid heating cycle there has been no change in shape and no surface damage or cracking. Although substantial advances have already been made, further work is still required, particularly in the area of fracture toughness, with ceramic materials. Si_3N_4 parts such as this stator vane displayed here (picks up sample) are already becoming prime candidates for use in stationary electric power turbomachinery. This component is currently under evaluation by Pratt & Whitney for such an application. They estimate that use of these ceramic components would result in a 5 percent increase in power output per unit.

Because they are cheap, lightweight, and can withstand very high temperatures, ceramics are also finding very practical and important application in anti-pollution devices for automobile engines. In the conventional internal combustion engine exhaust gases contain objectionable quantities of carbon monoxide and unburned hydrocarbons. To complete the burning of these, thermal reactors employing ceramics have been developed. LeRC has been conducting a thermal reactor material test program for the Environmental Protection Agency and a ceramic thermal reactor such as the one

(8) on display has been built and evaluated. The next slide shows a cutaway view of the entire thermal reactor. The shell is a cast iron housing and the ceramic core is centered within the housing by light metal corrugations. Hot gases from the engine cylinders with

injected air added to them enter the reactor via the ports as shown and flow to the ends of the inner SiC core. During passage through the core and the annulus between the inner SiC core and outer SiC core the gases (CO and HC) are more completely burned to CO_2 and H_2O. The burned gases exit at the central port. Silicon carbide operating at temperatures up to 2000^{o}F has performed excellently in thermal reactors tested in a station wagon operated by the LeRC for more than 21,000 miles. Here then is yet another alternative for the automobile industry in its efforts to reduce harmful exhaust gas emissions.

V - 1 FIRE RETARDANT POLYMERS

Safety is a prime aspect in aerospace as well as industrial applications. Plastics are a major component in both. We are developing fire retardant plastics to reduce the danger of fires wherever these materials are used. Plastics are polymers. Polymers are long chains of interconnected atoms, principally composed of carbon, hydrogen, and oxygen. Other elements may also be present. The model I am holding represents a small portion of a typical plastic, polyethylene. The black spheres represent carbon atoms and the white represent hydrogen atoms. Upon the application of heat virtually all polymers burn in air and give off smoke and toxic fumes.

A common way to improve fire retardant properties is to alter the chemical composition of the polymer during synthesis. This can be done, for example, by substituting halogens such as chlorine atoms for some of the hydrogen atoms in polyethylene (demonstrates by means of the model). This is a molecular model of polyethylene in which some of the hydrogen atoms have been replaced by chlorine. The green spheres represent the chlorine atoms. This chlorine containing polymer is known as polyvinylchloride. The combustion products from plastics which contain halogens, however, are quite toxic. To minimize the toxicity problem, our approach throughout NASA has been to develop nonhalogen-containing fire retardant polymers. This is a model of an aromatic polyamide that has outstanding fire retardant characteristics. The blue spheres represent N atoms and the red represent oxygen.

The Monsanto Corporation has developed a fire retardant polymer known as Durette. Under sponsorship from the Johnson Space Center in Houston, Texas, Monsanto developed a modified Durette which was used to weave the fabric for the astronaut coveralls and sleep restraint equipment (shown on the display) used in the Skylab mission. You will see next by this demonstration how fire retardant this material is compared to conventionally used plastics. Suspended in this open-ended chimney-like glass cylinder connected to our toxic fume hood system is a piece of a very commonly used plastic such as we wear or use commonly in our homes. (Speaker places torch against plastic). As you can see, this plastic is easily ignited by the flame and continues to burn after removal of the flame. The Durette fabric on the other hand is remarkably fire retardant. (Speaker is unable to sustain burning with the plastic in the other cylinder.) Durette obviously has other potential applications, in addition to its aerospace uses, such as for fire fighting equipment, draperies, etc.

It is obvious that significant advances have already been made in the area of fire retardant polymers research. We are also attempting through other molecular changes to achieve polymers with increased toughness, strength, and use temperature capability up to 600^{o}F. Such properties are needed to make polymers useful as a binder or matrix material for fiber reinforced plastics which we call composites. Because they are lighter, stronger, and stiffer than metals such as aluminum and titanium we are developing a whole new composite technology so that these materials can be substituted for such metals in turbine engine fans and compressors and in aerospace structures.

V - 2 COMPOSITE TANKS FOR GREATER SAFETY

Commonly available composites are already used in many other applications such as car bodies, boats, etc. I am going to describe just one of many aspects of our work with composites, the development of composite pressure vessels for space power systems. You will see that in addition to increased strength and reduced weight, composites afford the opportunity for making such vessels a great deal safer.

For a number of years, NASA has been pursuing the development of
(9) composite pressure vessels such as that shown in the next slide. In such an application, the composite generally consists of continuous fibers which are wound longitudinally and circumferentially in an uncured resin matrix, into the desired pressure vessel shape. Since composites are porous under high pressure, it is usually necessary

to provide a thin metal liner for this type of pressure vessel. The major technology emphasis has thus been on development of a composite tank-liner system that would allow the tremendous strength advantages of composite materials to be realized.

(10) The next figure shows the potential of various materials for strength and stiffness. The materials shown are ordered in accordance with their relative ability to carry load or resist bending. Corrections have been made for differences in density. Load carrying capability 10 times as great as with aluminum can be obtained with a fiber reinforced resin (PRD49-III/epoxy). Four times the stiffness of aluminum can be achieved with the same material. Various degrees of improvement in strength and stiffness are apparent with different composites compared to either aluminum or titanium.

When these composites are used for a pressure vessel application,
(11) as shown in the next figure, significant weight benefits can be achieved. A weight savings of 50-pounds can be obtained with a PRD49-III/epoxy composite vessel compared to an all aluminum vessel. Weight savings of this magnitude are not only extremely important to space vehicles but they can have significant impact on earth based systems.

As shown by the stationary exhibit, an application of NASA developed composite technology resulted in reduction of the weight of emergency breathing apparatus by as much as 10 pounds. Since this equipment must be used in the most strenuous of circumstances, this is no insignificant number.

However, along with the weight advantages of composite pressure vessels there is another and far more important advantage -- greater safety. The energy stored in a pressure vessel is proportional to pressure, volume, and compressibility. To contain high pressures requires that conventional metal tanks have very thick, heavy walls. When these tanks fail they do so in a manner not unlike a hand grenade. The violence of the failure breaks the tank apart and hurls
(12) fragments at high velocities to further the damage. The <u>next figure</u> shows that a composite pressure vessel, however, fails in a completely different fashion. Although the liner will rupture, the composite will continue to carry the pressure load while the fluid only leaks through very small cracks and openings in the composite structure. In this failed composite pressure vessel, there is no outward evidence of failure. When the tank is sectioned, as shown on the right, the shattering of the liner can be readily observed. What is important is that the failure has been contained.

My <u>next demonstration</u> will highlight this safety advantage. Although this demonstration is being conducted with small tanks, the composite tank principle can be applied just as effectively with very large pressure vessels. In the large box to your right are two cylinders. The one on the left is a composite vessel, the one on the right is made from a ferrous alloy. You are viewing this through a mirror for safety. I will first increase the pressure in the composite vessel. You can only tell that the tank has failed by the drop in pressure on the dial above the tank. Notice the quiescence of this failure. . . . . .

I will now pressurize the metal tank. (B O O O O O M). There was an obvious contrast between this failure and that of the composite tank.

I have attempted to indicate several ways in which materials and structures research under investigation at this Center have significant potential for making products lighter, cheaper and safer. After all, any area of endeavor can only be as ambitious as the materials available will permit it to be.

STOP 7 JOHN FRECHE 3105

CS 67717 1) MATERIALS AND STRUCTURES ADVANCED PROVIDE

CS 67718 2) MATERIALS RELIABILITY IMPROVED BY

CS 67719 3) LIFE PREDICTABILITY BY STRAIN RANGE PARTITIONING

CS 67720 4) POWDER PROCESS SAVES FORGING STEPS

CS 67721 5) MICROSTRUCTURE OF NASA-TRW VI-A ALLOY

CS 67722 6) TENSILE PROPERTIES OF NASA-TRW VI-A ALLOY

CS 67723 7) CERAMICS ARE STRONGER THAN METALS ABOVE 2000° F

CS 67724 8) CERAMIC LINED AUTOMOBILE THERMAL REACTOR

CS 67725 9) GLASS FIBER FILAMENT WOUND PRESSURE VESSEL

CS 67726 10) COMPOSITES ARE STRONGER AND STIFFER THAN METALS

CS 67727 11) COMPOSITE TANKS ARE LIGHTER

12) COMPOSITE PRESSURE VESSEL FAILURE (CS-67517)

STOP #7.

MATERIALS AND STRUCTURES ADVANCES PROVIDE

- INCREASED RELIABILITY
- LOWER COST
- REDUCED WEIGHT
- HIGHER TEMPERATURE CAPABILITY
- GREATER SAFETY

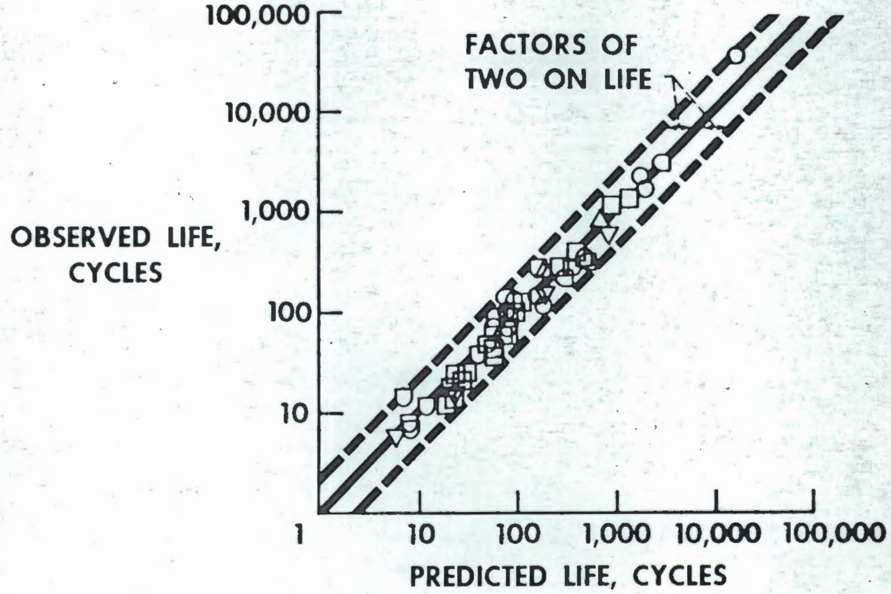
SLIDE 1 CS-67717

MATERIALS RELIABILITY IMPROVED BY

- FRACTURE MECHANICS STUDIES
- FATIGUE STUDIES

SLIDE 2 CS-67718

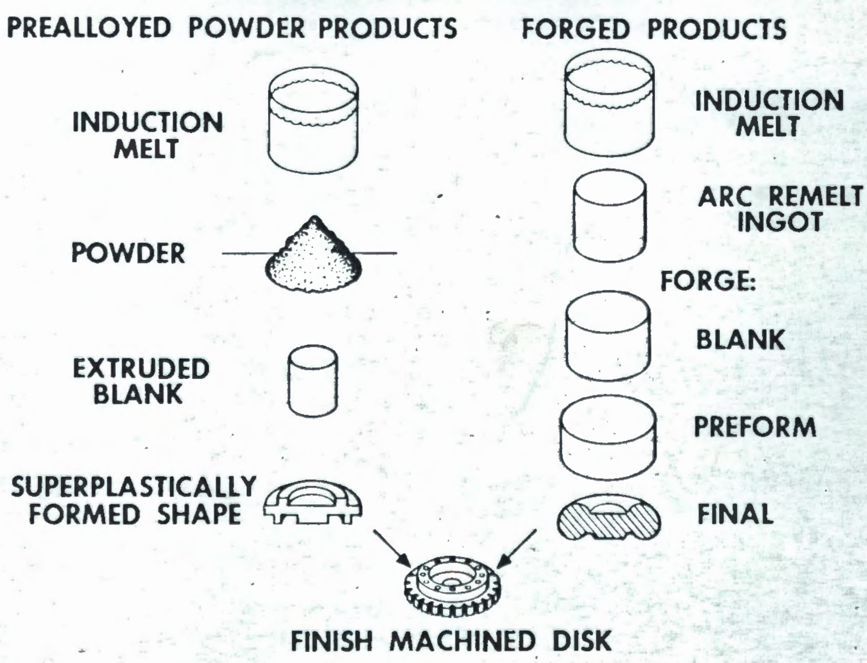
LIFE PREDICTABILITY BY STRAIN RANGE PARTITIONING



SLIDE 3

CS-677 19

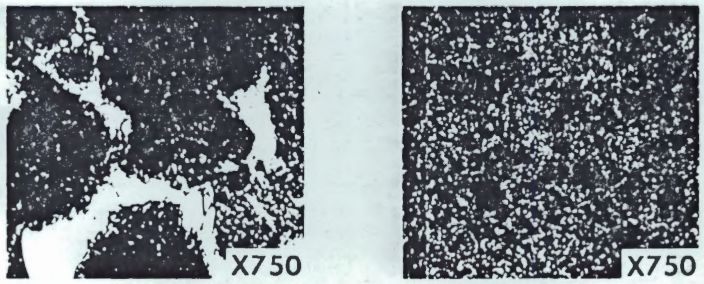
POWDER METALLURGY SAVES MATERIALS AND PROCESSING STEPS



SLIDE 4

CS-677 20

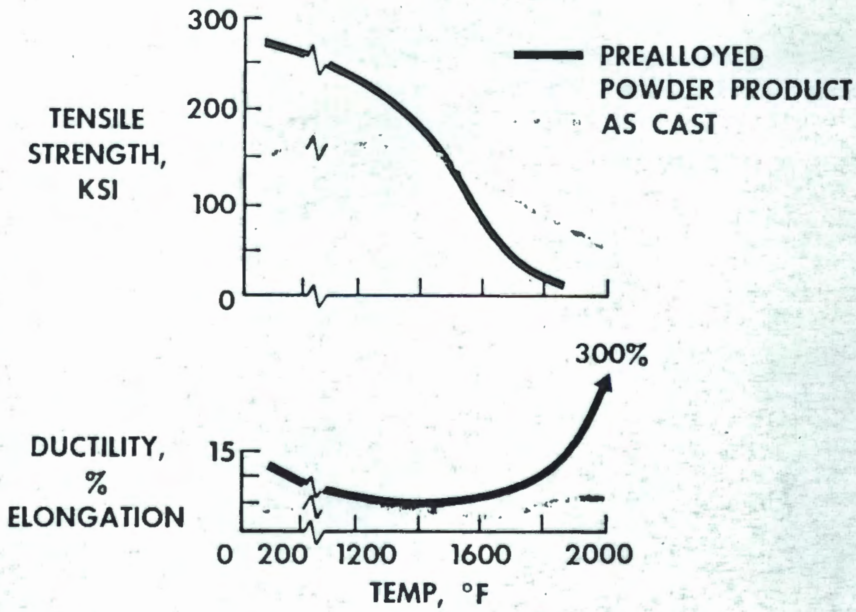
MICROSTRUCTURE OF NASA-TRW VI-A ALLOY



AS CAST VI-A   VI-A POWDER PRODUCT

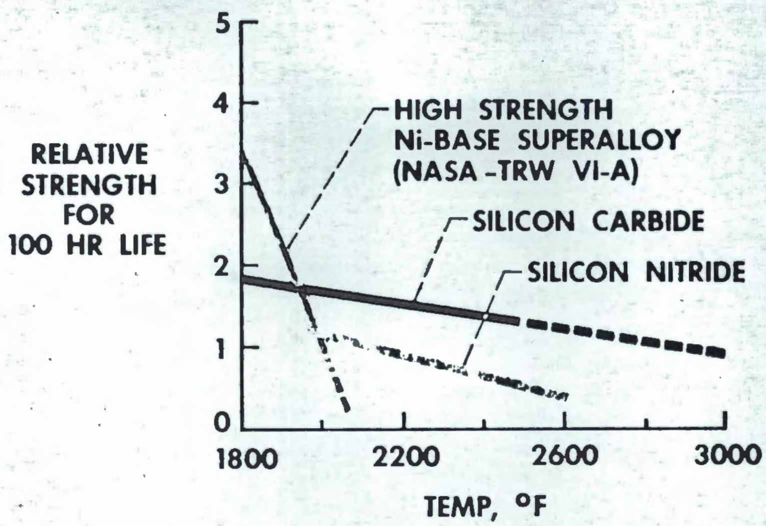
SLIDE 5   CS-67721

TENSILE PROPERTIES OF NASA-TRW VI-A ALLOY



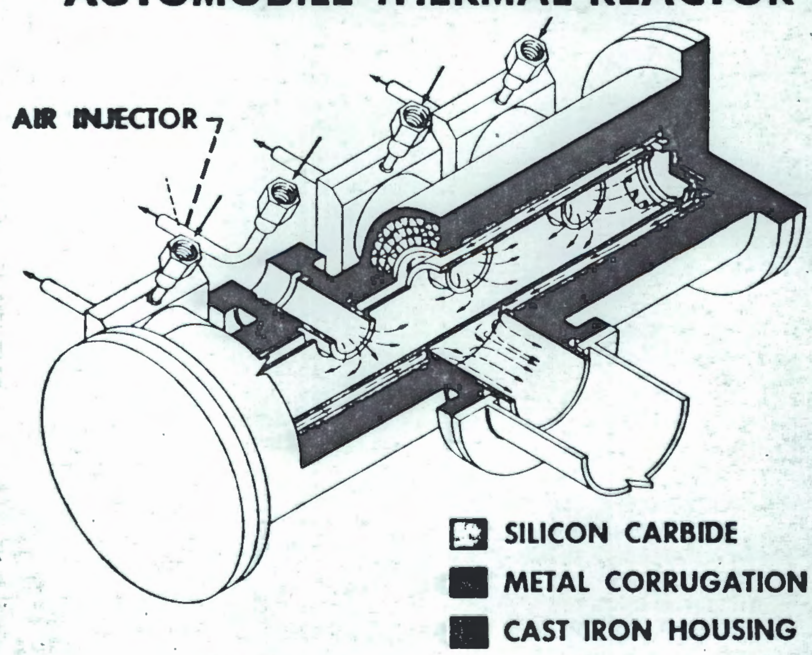
SLIDE 6   CS-67722

CERAMICS ARE STRONGER THAN METALS ABOVE 2000 °F



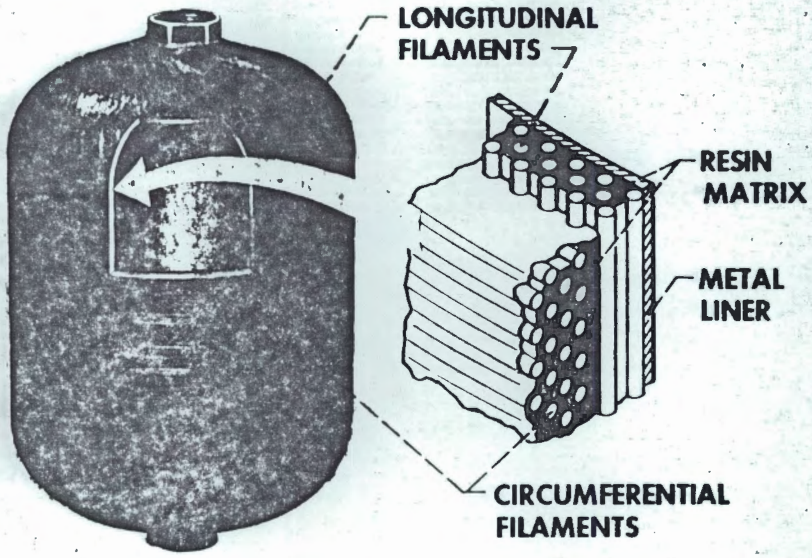
SLIDE 7 ~~CS-677~~ CS-67723

CERAMIC LINED AUTOMOBILE THERMAL REACTOR



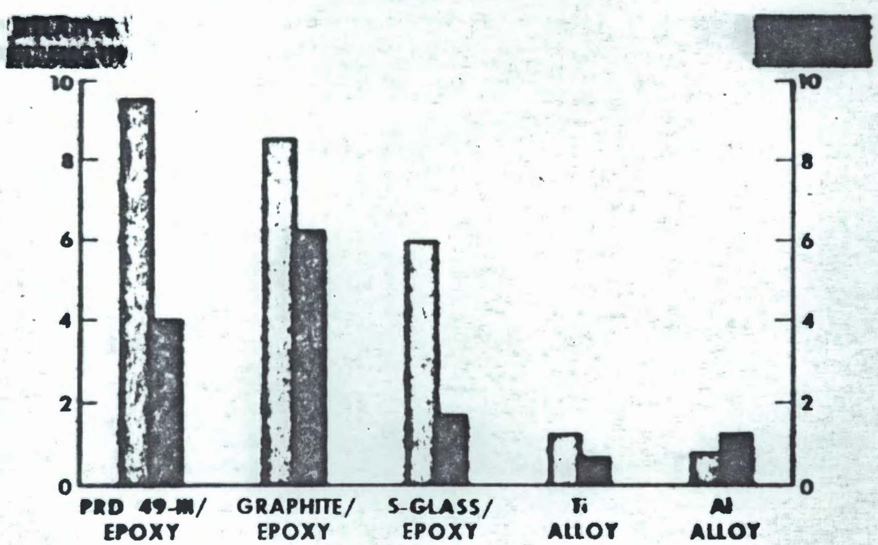
SLIDE 8 CS-67724

GLASS FIBER FILAMENT WOUND PRESSURE VESSEL



SLIDE 9 CS-67725

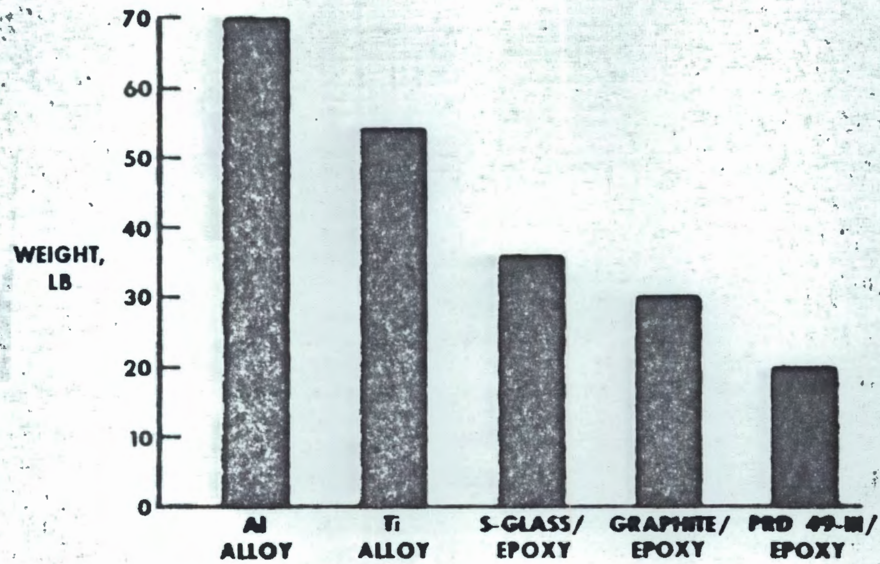
COMPOSITES ARE STRONGER AND STIFFER THAN METALS



SLIDE 10 CS-67726

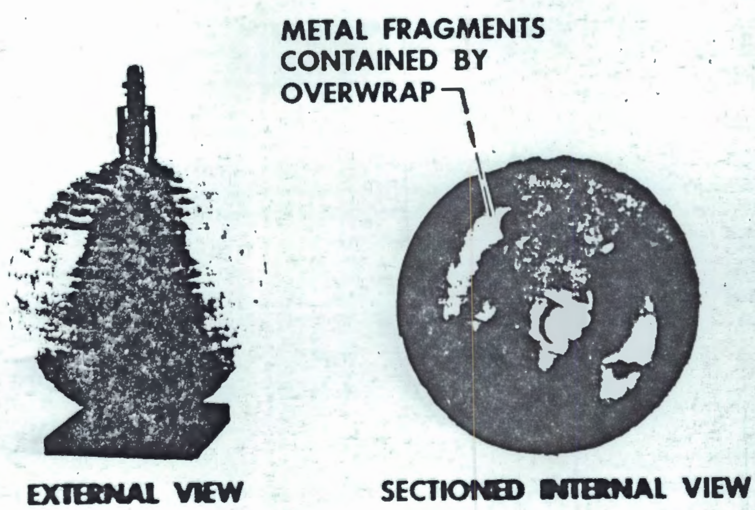
COMPOSITE TANKS ARE LIGHTER

24" DIAMETER SPHERES - 5000 PSI BURST

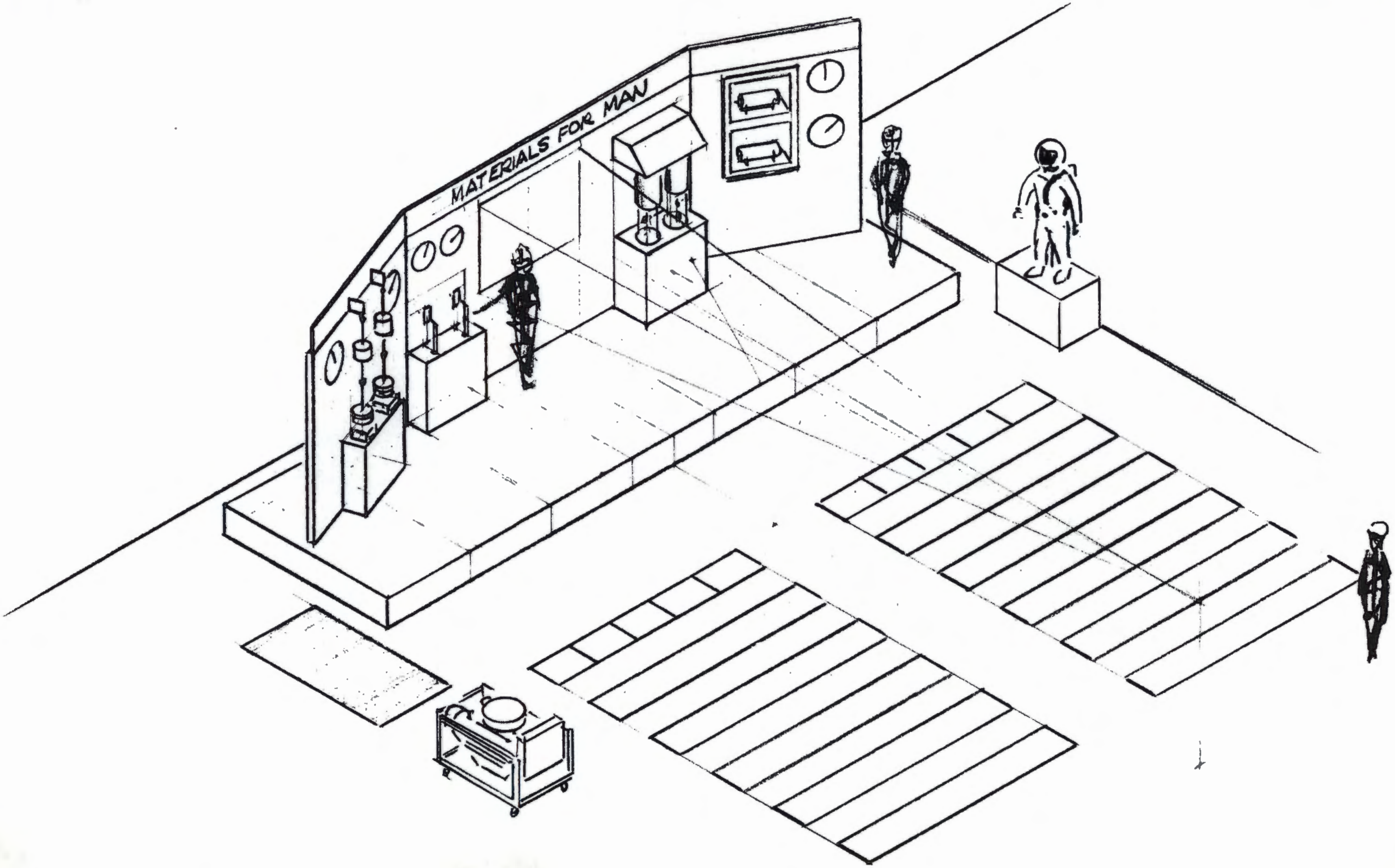


SLIDE 11 CS-67727

COMPOSITE PRESSURE VESSEL FAILURE

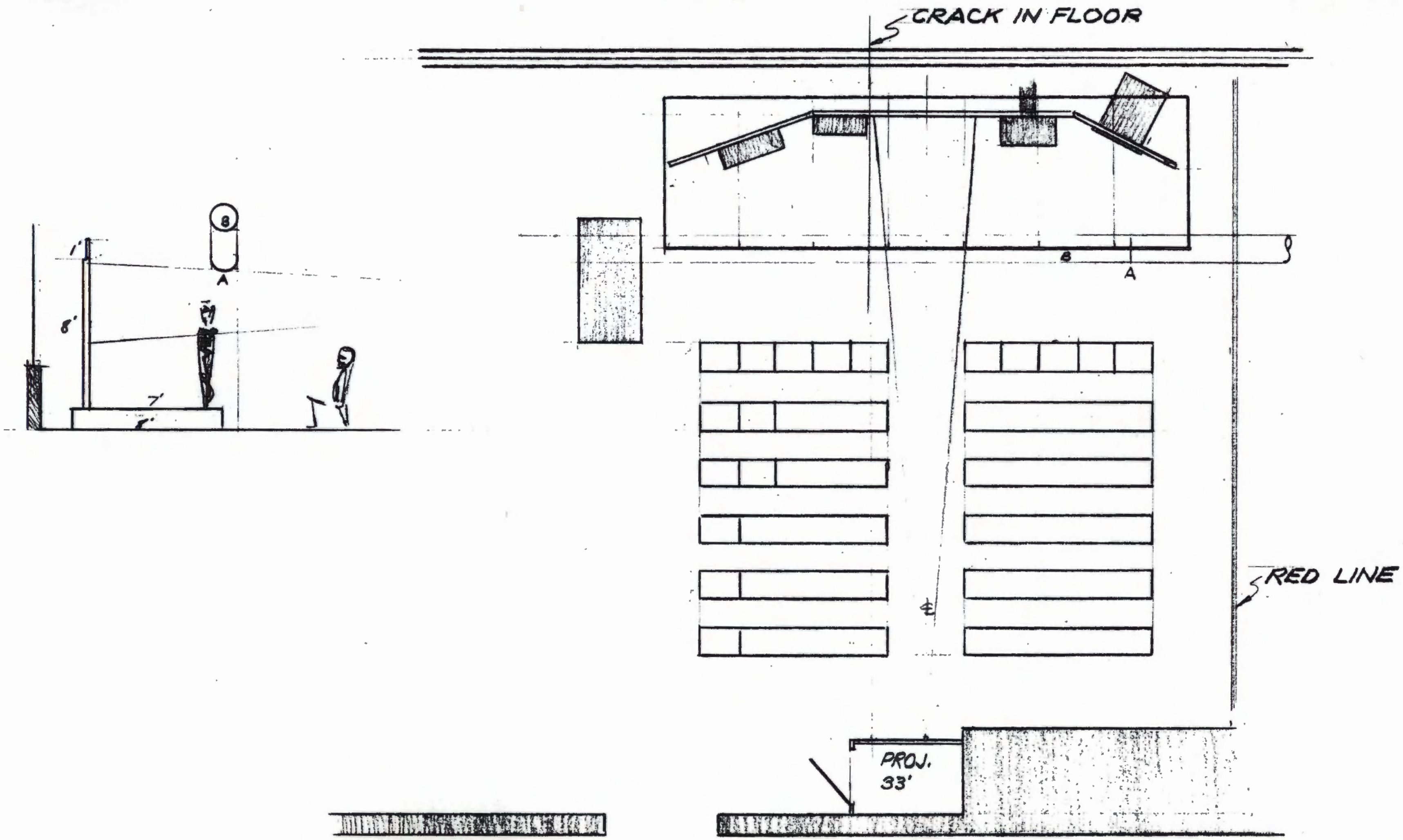


SLIDE 12 CS-67517



STOP # 7 MATERIALS FOR MAN MPL

$\frac{1}{8}'' = 1'$ R.S. 5-17-73

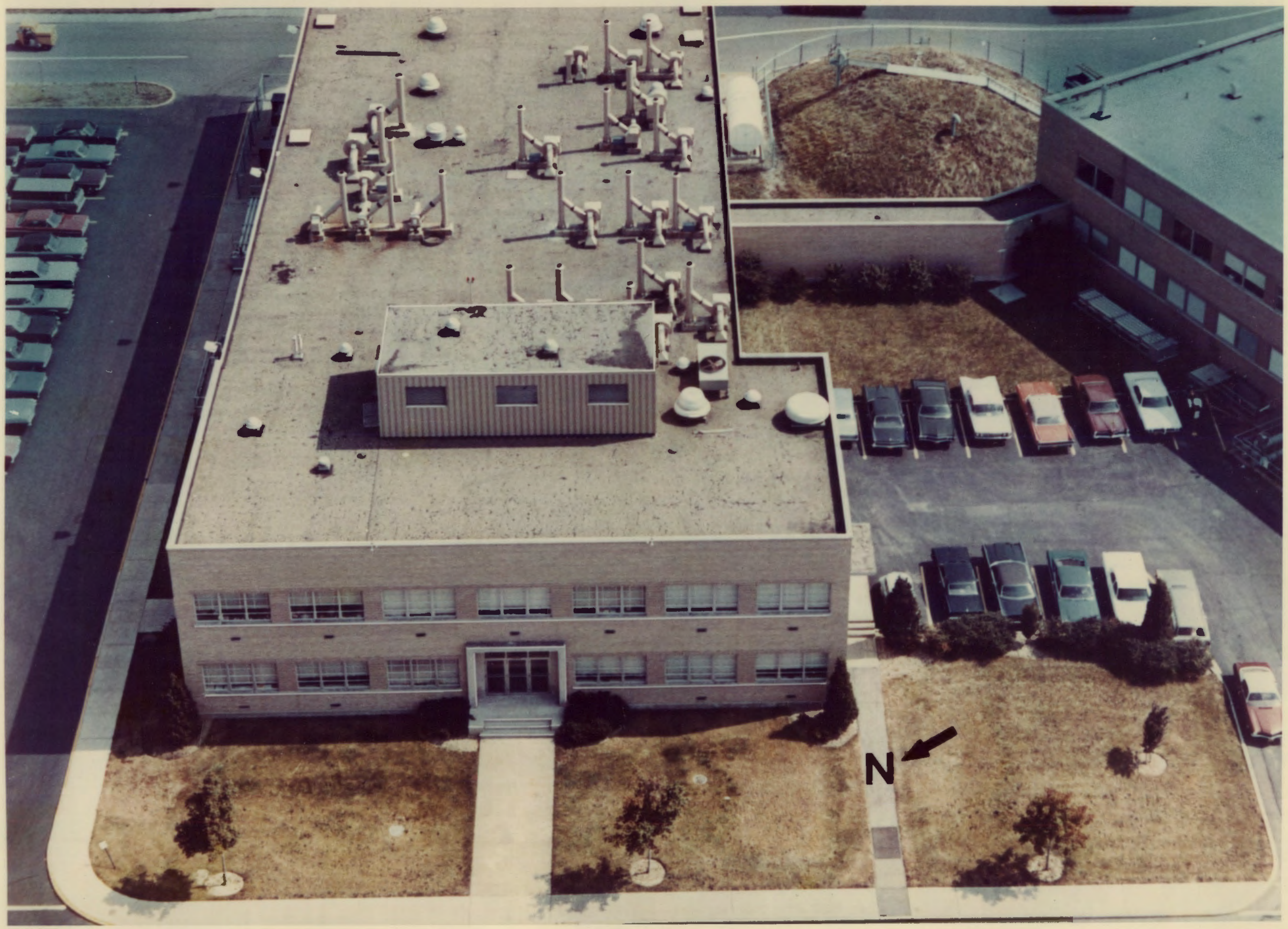


STOP # 7 MATERIALS FOR MAN MPL

1/8" = 1' R.S. 5-17-79

NASA
C-73-1525

MATERIALS PROCESSING LABORATORY



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