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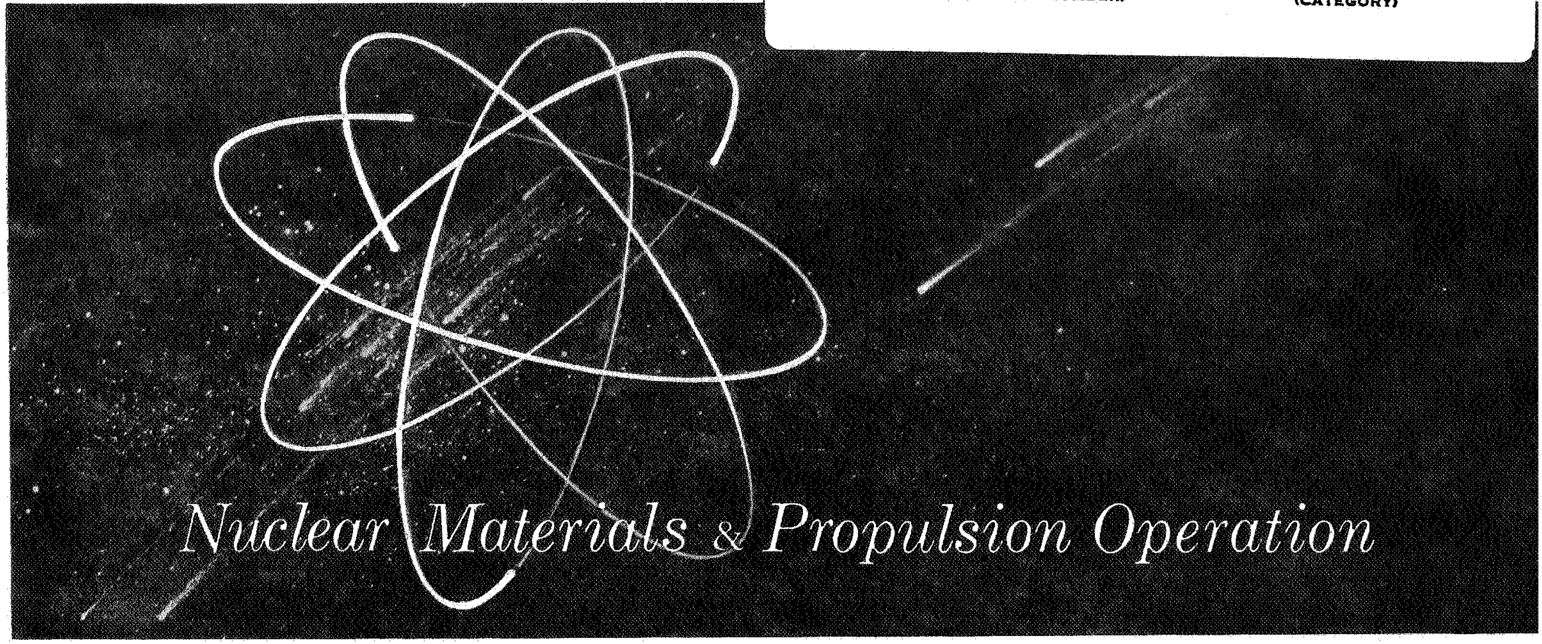

INTRODUCTION TO NUCLEAR PROPULSION

Lecture 15 - NUCLEAR TEST OPERATIONS

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1.0 INTRODUCTION

The test operation of nuclear power plants, specifically nuclear rockets, bears some interesting similarities to the operation of chemical rocket tests as well as, of course, many differences. A significant feature common to both nuclear and chemical rocket tests is that all the fuel for the entire operation is loaded at the start of the test. As a direct consequence of this fact, the operation of nuclear power plants must be surrounded with adequate safety precautions, as is indeed the case in the operation of chemical rockets. A second direct consequence is that in both types of testing a very thorough and complete checkout is made before starting the test.

One of the more obvious differences that exists in testing nuclear power plants is the difference in the environment. Here we have the radiation to contend with in addition to the conditions present in chemical rockets like heat and vibration. In the case of a lightly shielded reactor, such as would be required for a nuclear rocket, it is impossible to approach the power plant without protection after any significant amount of testing has taken place. This is, of course, because of the high radiation field that will exist at this time. In some respects this problem makes the ground testing of a nuclear rocket resemble the flight testing of a chemical rocket in that all the checkout has to be done before the testing begins at all. Once the test has gotten well started, it is then too late to do very much about a malfunction which may occur. There are various steps, such as shielding and remote handling, which can be taken to reduce this problem, but these are not always satisfactory. This will be discussed further later in the lecture.

A second very important difference in the operation of a nuclear rocket is that it is impossible to shut the nuclear power plant off completely after it has been run. A significant amount of power is generated for long times after operation and this, of course, leads to a number of operational problems which we will discuss later on.

Another difference which should be mentioned is that in the case of doing nuclear tests, it is necessary to build a full size reactor, or nearly so, and not, for example, start with a 1/10 scale model. This is because it is necessary to provide a minimum amount of nuclear fuel to make the reactor work at all. Although it is possible to achieve high temperatures by running at low power and low coolant flow, this may not provide a realistic test of the system. This consideration does not apply to very large reactors which are limited by heat transfer area rather than reactivity.

A final significant difference is that after the nuclear test has been completed the disassembly and analysis of the power plant requires the special techniques of remote handling, which will be discussed later.

2.0 PURPOSES OF TESTS

Before proceeding further with the discussion of test operations, it is worthwhile to identify the objectives or purposes for which the test is to be run. One category consists of obtaining research information. This type of test involves a reactor or power plant which is designed with no specific application but which is intended to obtain information in order to guide future design efforts. The Heat Transfer Reactor Experiments which were described to you in Lecture #1 fall primarily into this category, as do the KIWI tests. The second classification of tests is usually referred to as development. Here the purpose is to perfect and verify the design of a power plant which is expected to have a useful mission. This is basically the role of the early NERVA tests. The third test objective is to achieve and demonstrate reliability. Because of the cost it is difficult to pursue reliability with nuclear reactors in the classical way by building and testing a large number of samples. By keeping in mind which objectives are applicable to a particular test, it is possible to get a better perspective of the design and operation.

3.0 TEST FACILITIES AND EQUIPMENT

3.1 Radiation Protection at Test Facility

The facilities required to carry out the testing of nuclear power plants of the general type that would be applicable to nuclear rockets have certain fundamental requirements. The first requirement is protection of the personnel carrying out the tests. Since a mobile propulsion reactor can afford only a small amount of shielding, it is necessary for the facility to provide protection from the radiation generated during the test. As an illustration of one way in which this can be accomplished, we can look at the Initial Engine Test Facility which was used during the ANP program. Figure 1 shows an aerial view of the IET. In this facility the shielding was obtained by putting the entire control and equipment building underground and covering it with 15 feet of dirt. This same protection from the radiation from the reactor also served to protect the operators from accidents such as a nuclear runaway, or a chemical explosion caused from the jet fuel which was used during the tests. An alternative procedure for protecting the operators would be to provide separation between the operators and the reactor as is done in the facilities at the Nuclear Rocket Development Station.

The facility must provide a means for personnel to get in and out both during normal operation and in the event of an accident which might spread radioactive contamination in the vicinity. At the IET, as can be seen from the photograph, there is a tunnel which permits vehicles to enter and leave the facility during all power plant operations. This same approach was used at the Flight Engine Test Facility.

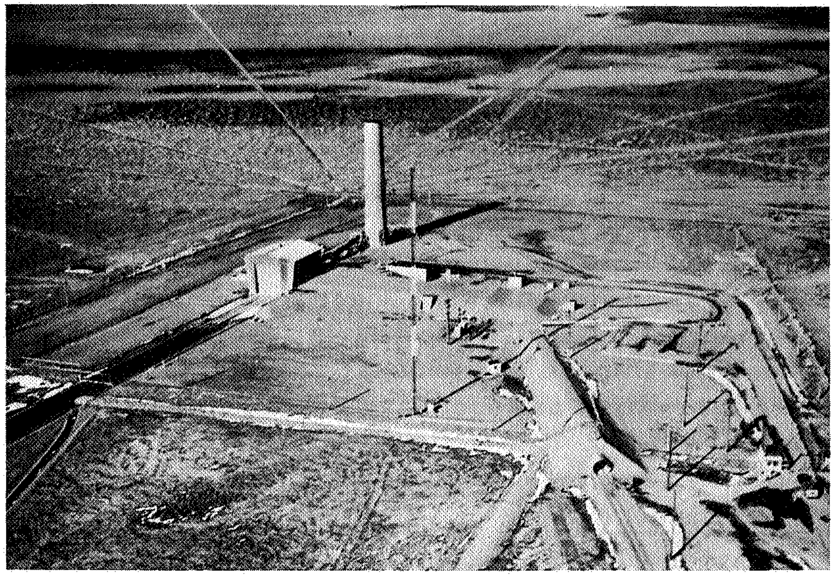


Fig. 1 - Aerial photograph of the Initial Engine Test facility

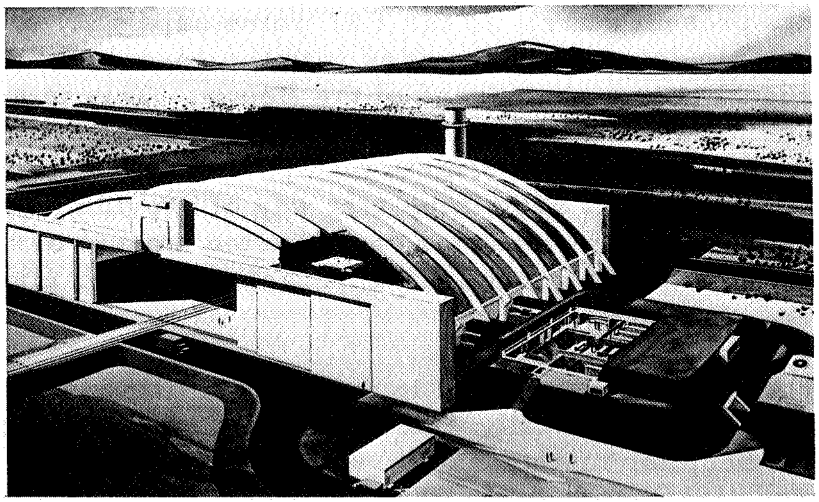


Figure 2 - Artist's sketch of the Flight Engine Test Facility

3.2 Viewing During Test Operation

Now having placed the operators underground, as in the IET, or having separated them from the power plant as is done in the Nevada facilities, it is necessary to provide visual access between the operators and the power plant. At the IET this visual access was provided by periscopes. At the Flight Engine Test Facility at Idaho (Figure 2), as another example, a direct viewing window was provided. This unusual viewing window had to provide both gamma and neutron shielding. Television is the third possible solution to the problem, appropriate for remote facilities such as the ones in Nevada. All these systems have various advantages and shortcomings which must be evaluated during facility design. Fortunately, the reactor itself does not impose any unusual requirements for visual access, which is needed for observation of secondary systems and to watch for chemical fuel leaks, fires, etc.

3.3 Handling and Maintenance

Another requirement is access to the power plant. Here the principal problem to be overcome is that the power plant cannot be approached after operation, as was mentioned earlier. In all the tests that were actually conducted in the IET, the HTRE series, enough shielding was provided on the power plant to permit at least limited maintenance of the power plant after shutdown. For prototype aircraft power plants, as for nuclear rockets, the shielding would be considerably less, so that manual of "contact" maintenance would be impossible. It is, of course, possible to disconnect the power plant and return it to the special remote handling facilities, or "Hot Shop", a picture of which is shown in Figure 3. Although this may be the best way to handle single rocket firing tests, it is likely to involve undesirable delays for longer test series, for instance, when demonstrating restart capability, as will be appropriate as nuclear rocket technology advances beyond its present state. At the FET some capability for performing maintenance with manipulators was provided with the so-called "Beetle", which is now in Nevada. Figure 4 is a photograph of the Beetle. This is a one-man shielded vehicle carrying manipulators and mounted on an army tank type chassis. It would also be possible to provide remote manipulators as part of the regular facility equipment. A final and very important way of providing access to the power plant for maintenance, at least for very limited amount of time, would be to provide portable shields to allow people to approach the power plant and do small maintenance items.

The operating scheme which was used in the test facilities in Idaho provided that the power plant be mounted on a dolly which could be removed from the test facility and taken to the Hot Shop for maintenance. With this system the facility must make provisions for connections between the power plant dolly and the facility. Typical things that must be connected are: control and instrumentation wiring; coolants, including aftercooling; chemical fuel (turbojet fuel at the IET); samples of various fluids, for example, moderator water or effluent gas; electrical power for the

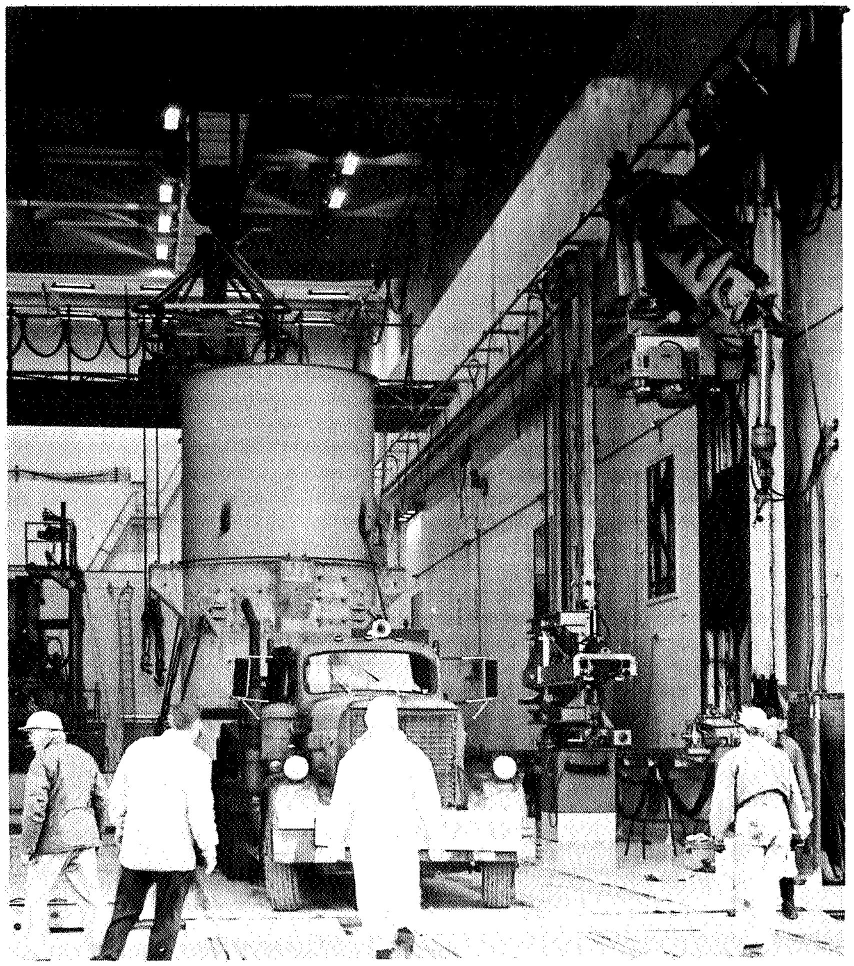


Figure 3 - Typical monitored entry into the Hot Shop

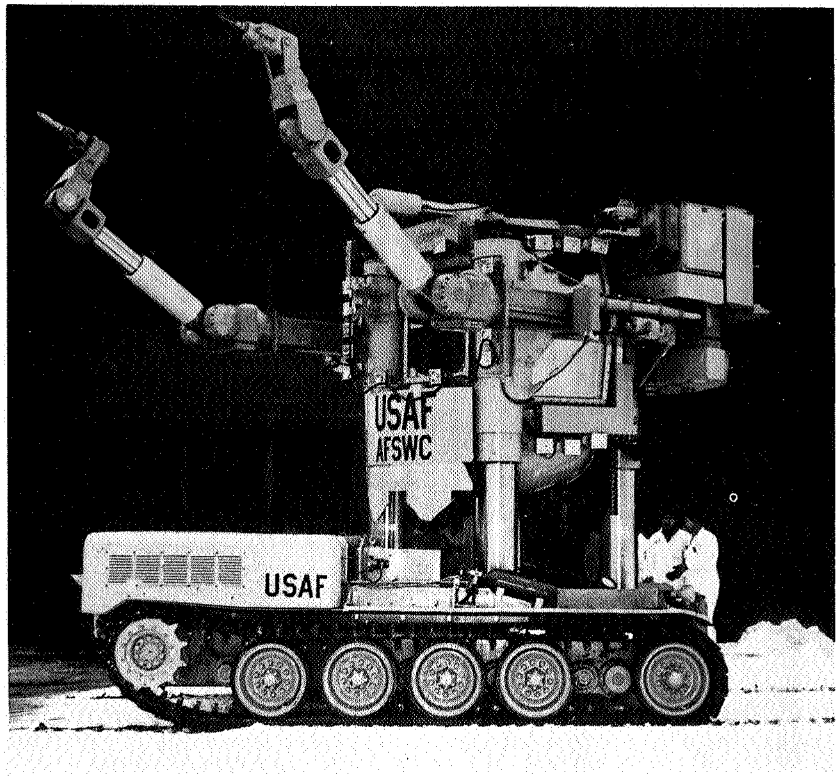


Figure 4 - The Beetle

various auxiliary systems that are mounted on the dolly; lubricating oil; and compressed air. At the Initial Engine Test Facility all of these connections with the exception of the turbojet fuel and some of the compressed air were made up manually in a small shielded room at one end of the test cell, called the coupling station. The turbojet fuel was routed outside the coupling station for safety. The connectors for fuel and compressed air were designed to make up automatically as the power plant rolled into position.

3.4 Control and Data Systems

An important requirement for the test facility is the provision of power plant control and data systems. The time scale of the projected tests largely determines the type of system that is needed. Here there is quite a difference between the testing that was done at IET and that involved in a nuclear rocket test. At the IET tests were carried out that would last for a hundred hours or more in contrast to a nuclear rocket test with a duration of from 5 to 15 minutes.

a) Control System - At IET, during the HTRE tests, it was possible to operate the power plants completely on manual control. That is to say, the power of the reactor could be adjusted by manually driving the shim control rods in and out, and the turbojet engines could be operated by increasing or decreasing the flow of fuel and the area of the jet nozzle. Provisions were also made, and generally were used, for the automatic control of the power plant. In this mode a servo system would adjust the power of the reactor to the selected value and other servo systems would control the temperature and speed of the turbojet engines. During the IET testing, because of the relatively long time involved in operation, the selection of the desired reactor power, engine speed, and engine temperature were made manually by the operator, in other words, he would simply select the conditions at which he wanted to operate at any time. For a nuclear rocket test, in contrast, because of the short test time available, in all likelihood the control system would include a programmer which would automatically select the power level, the coolant flow rate, etc. which was desired in accordance with a schedule which had been determined in advance. This is about the only way in which such a test can proceed, since things will happen a little too rapidly for the human operator to follow and understand them and take corrective action. Nuclear system control was discussed in considerable detail in Lectures 13 and 14 (GEMP 190h and GEMP 190i).

b) Data System - At the IET an automatic data system was provided with capacity for recording some 700 points. These points were recorded in approximately 5 minutes, so that the system was most useful in measuring steady state information. The general procedure was to hold all conditions steady while a data scan was taken. Of course, some transient information was required for special tests, and some information was displayed on Brown recorders, principally for the control of the operation. However, in general, all the testing involved rather slow changes, and requirements for transient data equipment were quite limited. The Flight Engine Test Facility used the same philosophy for its data system, but with advances in electronic techniques provided a capacity for recording about 2000 points in less than two minutes. It also provided increased flexibility in selecting the points to be recorded by using a punched tape input program. Nevertheless, this data system was still designed primarily for steady state operation. Since at the FET the testing was going to involve a very large power plant in a quite early stage of development, it was clear that the operators could not observe and understand all that was happening fast enough to be sure of taking corrective action fast enough. It was planned, therefore, to keep the data system in continuous operation, scanning perhaps 500 points, which it could do in less than a minute. The data would feed continuously into a digital computer which would be programmed to search for off design points, and only these off design points were then displayed or brought to the attention of the operators, whereas data which was coming out as expected would be suppressed. The data system was thus an integral and necessary portion of the power plant control system.

For nuclear rockets, the time available to take corrective action is further compressed, so that the next logical development would be to have the digital computer not only reading the data and comparing them with predicted values, but then actually controlling the parameters such as reactor power, coolant flow, etc. in order to bring the condition back to normal, to terminate the test, or to reduce power to a safe point in event of difficulty. As another consequence of the reduced time scale of the tests, a great deal more emphasis would be placed on recording transient data continuously throughout the test.

4.0 POWER PLANT TESTING

4.1 Low Power Tests

The first step that must be taken in the conduct of a reactor test program is, of course, the assembly of the power plant. Here one has problems rather analogous to loading the fuel into a rocket, namely, taking the necessary precautions to make sure that it doesn't go off prematurely. This means that it is not simply a routine manufacturing process to load all the fuel elements in the reactor. For the tests that were run in Idaho a special facility was constructed for this initial loading, called the Low Power Test Facility (shown in Figure 5). Here the fuel elements were loaded into the reactors under controlled conditions. Measurements were made to be sure that the right amount of fuel was being put in and that the reactor did not accidentally reach a critical mass prematurely. This was done by providing a source of neutrons and several neutron counters. Fuel was typically loaded in increments of about 10% of the total. After each increment was loaded the neutron flux was measured. As more fuel was added, approaching the critical mass, the neutron level would rise. By plotting the inverse of the counting rate, or multiplication, it was possible to predict quite accurately the point at which the reactor would become critical. After fuel loading was completed the control elements were calibrated and measurements of the power distribution and other reactor physics measurements were made. In the case of HTRE #3, the power distribution was actually shimmed in a fairly extensive program by putting in boron strips to adjust the neutron flux to produce the desired nuclear power profile.

After these steps were completed, the reactor could be returned to the manufacturing facility. Before doing so, the reactor must be made positively safe to insure that no nuclear accidents can happen during transit or during the final assembly operations. For HTRE #1 and #2 this could be done by draining out the moderator water. For HTRE #3 the control rods which were used for the critical loading were replaced by so-called transport rods. These rods had the characteristic that they would not fall out of the reactor in case it was inadvertently dropped. Other acceptable systems would be to safety-wire the control mechanisms to prevent movement, or to add poison in void spaces.

With the reactor back in the manufacturing or assembly area, it was combined with the remainder of the heat removal equipment and the power plant was then taken to the Initial Engine Test Facility for power testing.

4.2 Power Testing

- Checkout - The first step at IET was the connection of all the various systems which we discussed before and a thorough checkout of the operation of these systems separately, a process completely analogous to preparing a rocket for firing.

- Testing - After the checkout was satisfactorily completed, a carefully planned series of tests was followed, involving a gradual approach to power. During these tests the power measuring instruments were calibrated, the effectiveness of the

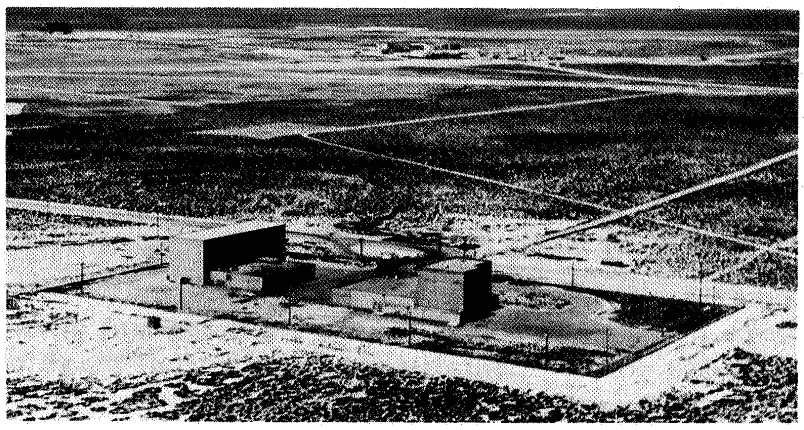


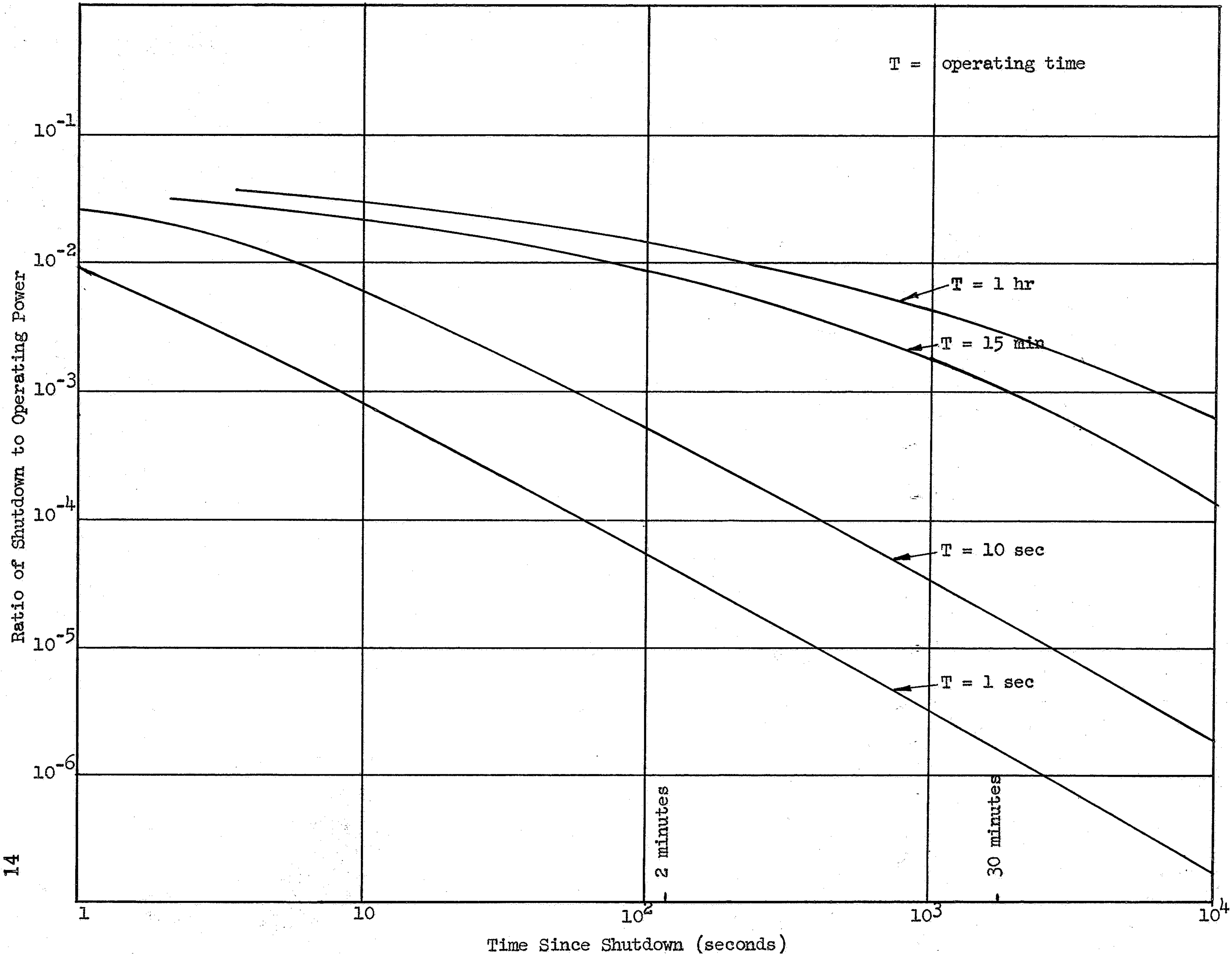
Figure 5 · Aerial photograph of the Low Power Test facility and the Shield Test Pool facility shielding measured and compared with calculations, the nuclear heating rate measured, and other tests of this nature performed. The primary purpose of this part of the operation was to carry out methodical increase in power, checking the operation of all instruments and systems and the stability of the power plant at every step. Typically the power was raised by a factor of about 3 for the steps from a few watts to the beginning of significant temperature increases in the reactor. Power was held constant at each step for 15 minutes, or more if needed to obtain data. When the fuel element temperature started to rise noticeably, new power steps were set for temperature increases of 200°F to 300°F and the duration of operation at each step extended to about 2 hours. Fortunately, during all the HTRE tests this gradual approach to power could be carried out without difficulty, as it was always possible to shut down to make adjustments or correct malfunctions.

For nuclear rocket tests, in contrast, the limited shielding, the high cost of coolant, and, possibly, the desire to avoid temperature cycling combine to dictate a far more rapid testing program. Testing up to a few kilowatts, where temperatures without coolant start to rise, can be carried out as described above. At this point it is necessary to reach the decision to commit the power plant to operation, which will be an irreversible step in many ways, especially since it will thereafter be impossible to do unlimited maintenance around the power plant.

Other considerations than radiation levels can result in an irreversible action associated with going to power. An example of this would be starting the HTRE #3 on nuclear power. In this case it was possible to take the power plant up to low power in the usual manner, using the standard jet engine starters to provide cooling air, but then it was necessary to increase the power rapidly, without turning back, in order to complete the start. This is similar to the situation which might exist in starting a nuclear rocket engine. In this case, it might be necessary to start up quite rapidly in order to provide enough pressure from the rocket chamber to power the turbo-pump, making it impossible to go gradually to full power.

- Shutdown - At the conclusion of a test, a normal, planned shutdown procedure would be followed. An alternative emergency shutdown procedure, called scram, is also invariably provided. In many cases a scram or emergency shutdown is to be avoided if at all possible because it may result in various types of damage to the reactor, particularly from the standpoint of thermal shock. In general, a normal shutdown would proceed much more slowly and methodically than the emergency shutdown. The requirements for the emergency or scram shutdown are set by some very pessimistic assumptions regarding the possibility of a nuclear malfunction. As a rule, the scram system is designed to provide twice the amount of reactivity which is necessary to make the reactor prompt critical, that is, critical on prompt neutrons alone. The philosophy here is that if some accident occurs which makes the reactor almost prompt critical, one wants to be able to compensate with an equal amount of emergency shutdown, which would stabilize the power and also to insert an equivalent amount of negative reactivity to make the reactor subcritical to reduce the power rapidly.

Fig. 6 - Power Generated After Shutdown



4.3 Aftercooling

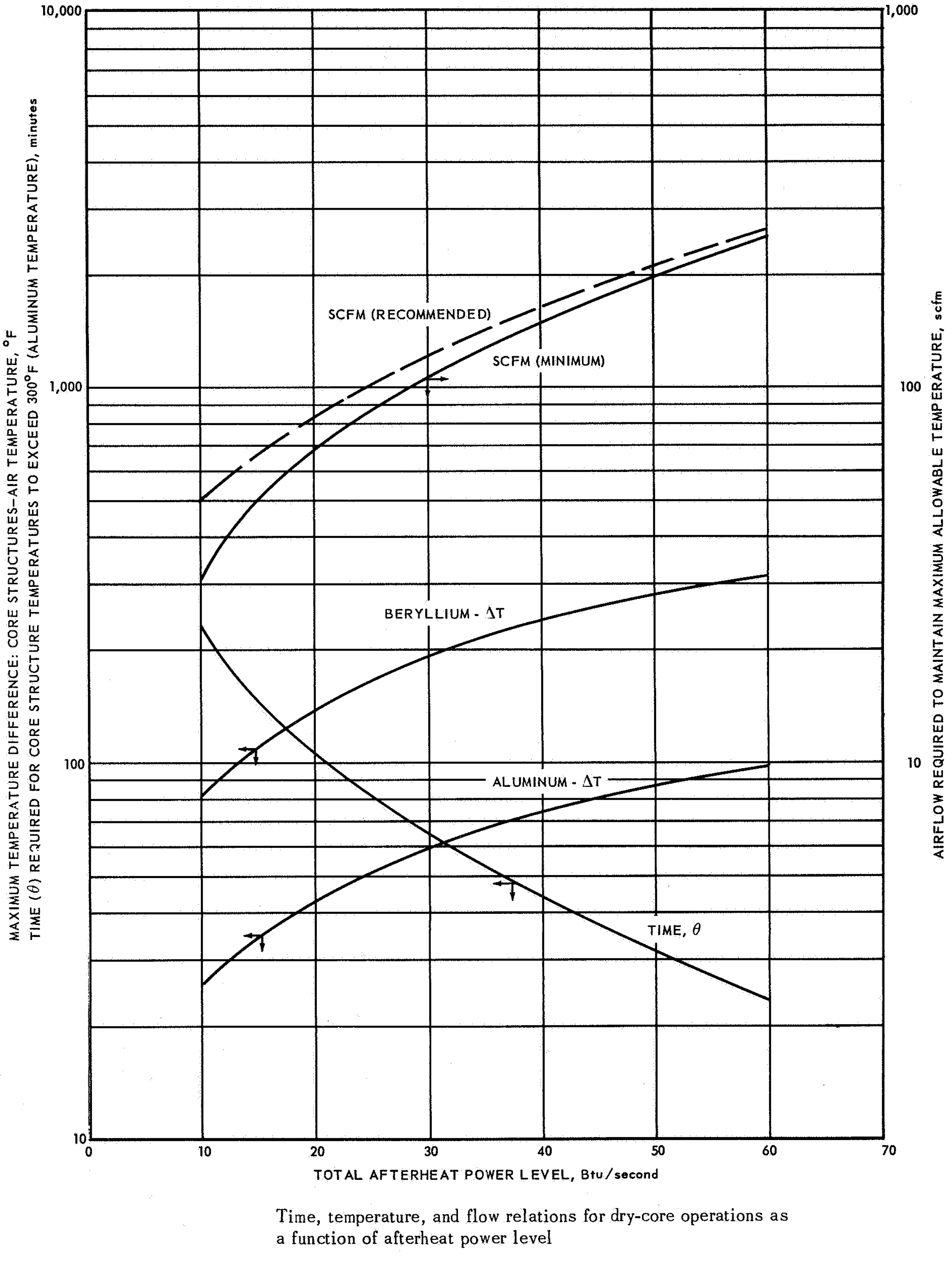
In the lecture #9 (GEMP-190f) there was a discussion of the afterheat generated by the reactor and the temperatures which it caused. The afterheat creates an operational problem in that it requires that some coolant be provided for long periods after operation. The first curve, Figure 6, shows the power generated in a reactor as a function of the time after shutdown. As can be seen, for 15 minutes of operation, a typical operating time for rocket testing, the power 2 minutes after shutdown is still about 1% of full power, and even after 30 minutes it is about 0.1%. For time less than 10 seconds after shutdown, the duration of operation is of little importance. If no coolant is supplied, this power will cause temperatures to rise far beyond safe limits, as is shown in Figure 1.37 of GEMP-190f. From this curve it is clear that the time available to take corrective action before excessive temperatures occur is quite short, and become progressively shorter as the normal operating power is increased.

The problem is aggravated by the change in energy distribution between the normal and afterheat cases. For normal operation the fuel elements receive about 90% of the total energy generated, whereas after shutdown they may receive only 60%. This is because about half of the after shutdown power is released as gamma radiation with great penetrating power. The coolant requirements after shutdown must then be based on cooling the reflector and structural members, as can be seen by comparing Figures 1.39 and 1.33 of GEMP-190f. These show that for the example shown, an aftercooling airflow of 10 lb/sec., or even less, would be adequate for the fuel elements, but that the reflector temperature rises appreciably even with 25 lb/sec.

When the afterheat has decayed sufficiently, it is possible to dissipate it by radiation without furnishing any coolant. This may take tens or hundreds of hours depending upon the reactor design and operating history. Before this occurs, it will be possible to turn off the aftercooling for considerable periods of time, as is illustrated in Figure 7. To use this curve, which is for HTRE #1, the afterheat power is first calculated from the operating history and time since shutdown. The cooling airflow required for steady-state conditions, and the length of time that the reactor can be left safely without forced cooling can be read directly. This information is of particular value for such operations as remotely disassembling the power plant, or moving from the test cell to the Hot Shop, when the provision of cooling might be a problem.

To illustrate the lengths to which designers may go to assure aftercooling, let us consider the HTRE #3 once again. First, a normal shutdown could be made by shutting the reactor off and operating the turbojets on chemical power. Two turbojets were provided, and it was possible to operate either one of them in the event of a malfunction of the other.

Second, it was possible to motor the turbojet engines on their starters, which were run by compressed air from a set of diesel compressors, as long as the turbojets themselves did not have some serious malfunction which would prevent their rotation.



Time, temperature, and flow relations for dry-core operations as a function of afterheat power level

Figure 7

Third, two primary aftercooling blowers were provided, consisting of large axial flow blowers mounted on a separate dolly. These were driven by 450 hp internal combustion engines, each blower delivery 12.5 pounds per second of cooling air. Two blowers were provided for redundancy so that if one blower failed, the other one would be able to deliver the required airflow.

Since these primary blowers were very large and mounted on a separate dolly, it was necessary to provide smaller blowers for cooling the power plant for longer times after operation and while it was in transit to the Hot Shop. To meet this "in transit" requirement, two more blowers were mounted on the power plant itself. These were centrifugal blowers driven by smaller internal combustion engines, providing something like 4 pounds per second of air apiece. Again two blowers were used so that if one failed the other one could carry the load.

Since operation at the IET was not performed around the clock, it was necessary to face the problem of maintaining aftercooling when no one was in the facility. It was felt that the internal combustion engines were not sufficiently reliable for this type of operation and so there were two electric blowers provided for long-term aftercooling while at the IET. These electric blowers were also required to avoid the safety problems involved in operating and refueling gasoline engines in the Hot Shop.

Thus, all told, ten reasonably independent sources of aftercooling air were provided for this power plant.

4.4 Formalization of Test Procedure

The foregoing has described the general procedure to be followed in performing a nuclear power plant test. The actual procedure is, of course, much more detailed. It is necessary to plan the detailed procedure in a manner which takes into account all foreseeable contingencies. For example, much of the data required in the test program cannot be conveniently performed after operation at significant power since the reactor has become radioactive. Therefore, the tests must be carefully scheduled to obtain data in the proper sequence. Furthermore, a well planned and deliberate procedure is necessary to assure safety prior to, during, and after operation.

The documents which must be prepared to satisfy requirements of the Atomic Energy Commission are identified in the subsequent lecture on Safety. In addition, the organization having responsibility for the reactor test should prepare detailed written test procedures for its own internal use. A sample instruction identifying several procedural documents, which should be prepared prior to reactor operation, is included as Appendix A.

4.5 References

A brief summary of testing the HTRE #1, HTRE #2, and HTRE #3 reactors was given in lecture #1 (GEMP-190a). Details of the HTRE #1 and HTRE #3 tests are given in References 1 and 2. A discussion of several aspects of testing and operating nuclear rockets is given in the following articles in the December 1962 Astronautics (Ref. 3).

RIFT	Col. W. Scott Fellows, p. 38.
KIWI Development Testing	Keith Boyer. p. 58
Safety and Operations with Nuclear Vehicles	Lt. Col. Ralph S. Decker, p. 63

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1. APEX-904, Comprehensive Technical Report - General Electric Direct-Air Cycle Aircraft Nuclear Propulsion Program, February 1962.

2. APEX-906, Comprehensive Technical Report - General Electric Direct-Air Cycle Aircraft Nuclear Propulsion Program, June 1962.

3. ASTRONAUTICS, December 1962, Vol. 7, No. 12.

5.0 REMOTE HANDLING

In the nuclear industry, remote handling may be defined as "The performance of a mechanical task using remote manipulating devices, allowing the operator to remain behind a radiation limiting barrier". In most cases, remote handling is thought of as operations involving assembly and disassembly, maintenance, or other operations, performed by remote control devices such as manipulators or cranes.

Remote handling operations are necessary when manual performance or the presence of human beings is prevented by the environment or location of the work site. Environments of this type include high levels of nuclear radiation, high vacuum, high pressure, deep underwater depths, high temperature and others which prohibit manual activity. Nuclear laboratories and research areas are the most common locations of remote handling equipment, but others are presently in use on underwater vehicles, in vacuum chambers and in industries handling toxic materials.

The particular equipment used in remote handling varies widely with the application, but in general the remote equipment is used to engage, grip, and move or position a work piece, tool or item of hardware. This could be performed by a simple remote control crane or by a complex special purpose manipulator. The remote handling philosophy will also greatly influence the type of handling equipment used.

5.1 Remote Handling Philosophy

The two extremes of remote handling philosophy with regard to the type of equipment used are:

- Super Manipulator Philosophy - This philosophy involves the use of an extremely sensitive and dexterous manipulator which effectively replaces a human hand and arm. Conventional hand tools could be used by the manipulator, without modification, and few if any special tools, fixtures, or special hardware are needed. Any job which could be performed by a man's hand could also presumably be performed using this manipulator. Of course such a manipulator would be very expensive, with the complex motions, small delicate parts, and very sensitive force feedback system which is necessary. The state of the art has progressed only partially toward this point today.

- Simple Manipulator Philosophy - A very simple manipulator, with coordinate control, can be used to accomplish most remote tasks when aided by many special fixtures. For some operations the necessary fixtures might be extremely elaborate, greatly exceeding the manipulator in complexity and cost, while for other operation little or no modification to existing tools would be necessary. This philosophy makes use of the manipulator as a positioning device to locate and orient special tools and to transport other items of equipment.

While the relative cost of manipulators and supporting fixtures might be used as a basis for a reasonable decision as to which philosophy to follow, there are other factors to be considered. When using manipulators capable of only simple motions, many limitations are placed on the freedom of the product designer. Experience has shown that remote operating time, reliability, and product weight generally suffer when extensive fixturing is necessary for a remote operation. Ultimate cost to complete the operation will rise rapidly with deficient manipulators and complex fixtures.

The practical compromise on which type of equipment to use and which general philosophy to follow nearly always falls somewhere between the two extremes. Most experience has been in the region nearer the "simple manipulator" concept, as development of the super manipulator is very costly and the reasonable limit of its potential is not as yet apparent. Development work is generally carried on only to the extent necessary to satisfy the requirements of a particular project, with advancements in the state of the art being incidental to the main goal.

For most remote operations a manipulator with adequate capacity and a reasonable amount of motion capability can be utilized, aided by power tools and special devices as necessary for particular requirements.

Some of the techniques used to enable manipulators to accomplish various tasks which do not fall within the capability of the manipulator itself are as follows:

- High torque requirement for large fasteners - the manipulator holds and positions an impact wrench to provide the desired function with reaction torque on the manipulator.

- Engagement of a delicate electrical connector - a compliant wand is used between the connector and the manipulator hand, allowing the connector to be engaged without damage by the crude, noncompliant motions of the manipulator.

- Lift of a load exceeding manipulator capacity - the manipulator can be used to engage slings or lifting devices for high capacity lifts by cranes or higher capacity hoists.

- Hammering or high impact operations - requiring rapid response exceeding that of the manipulator may be accomplished by use of a pneumatic hammer or chipping gun held and positioned by the manipulator.

Many tools are used including, jacks, vises, shears, power saws, torches, power wrenches, abrasive cutters, vacuum cups and many other specialized devices to enable the relatively simple motion capability of the manipulator to accomplish more complex tasks.

5.2 Manipulating Equipment

1. Mechanical Master Slave Manipulators - The most common type of manipulator is the Argonne type master-slave mechanical manipulator. These units have been in use at various laboratories and hot cells for many years. Relatively small, simple and low in cost, they can be installed through or over the walls of most hot cells. They provide a 10 pound force capacity within their limited reach and provide the operator with a mechanical linkage force feedback. Larger units are now available, capable of forces up to 50 pounds.

Mechanical manipulators are inherently limited (by their mechanical connections) to a very small work volume coverage and relatively low capacity due to friction and inertia.

2. Electro-Mechanical Manipulators - The electro-mechanical type of manipulator (see Figures 8 and 9) which is very common in larger cells eliminates the work volume limitation, since the only connection between operator and manipulator is a control cable or possibly a radiolink. Size range is also greatly expanded to essentially any size needed. This type manipulator is generally driven by electric motors or hydraulic systems, is moved about a hot cell or work area on mechanical boom systems or in some cases by vehicles. Commercially available systems are available today in capacity ranges from 10 pounds to 500 pounds. The large units exert forces of up to 2-1/2 tons in certain directions.

However, the freedom from mechanical linkages which allows the unlimited volume coverage and high force capacity is obtained at the virtual complete loss of force feedback and response rates. In order to allow safe control of these larger force machines by operators using switch type controls, the speeds must be reduced to far less than that of the human arm and hand. The sturdy manipulators are in general noncompliant and can exert large forces in unknown directions without the awareness of the operator. Delicate items are difficult or impossible to handle without a great probability of damage. Conversely, large and heavy items can be handled with ease over long periods of time without operator physical fatigue.

3. Servo-Manipulators - Combining the freedom of mechanical connection of the powered manipulator with the rapid response and force feedback (or feel) of the mechanical master slave manipulators is possible using a servo system of power and control. Smaller sized servo manipulators using electric motor servo systems have been made for use at the Argonne National Laboratory. A relatively sensitive 10 pound capacity manipulator and a less sensitive 50 pound model have been developed. Both of these machines essentially duplicate the mechanical master slave manipulator capabilities in size, capacity, and configuration of the hand and control grip.

A larger more radical servo manipulator of about 125 pound capacity was developed by the General Electric Company during the ANP program for use at the Idaho Test Station, and is shown in Figures 10 and 11.

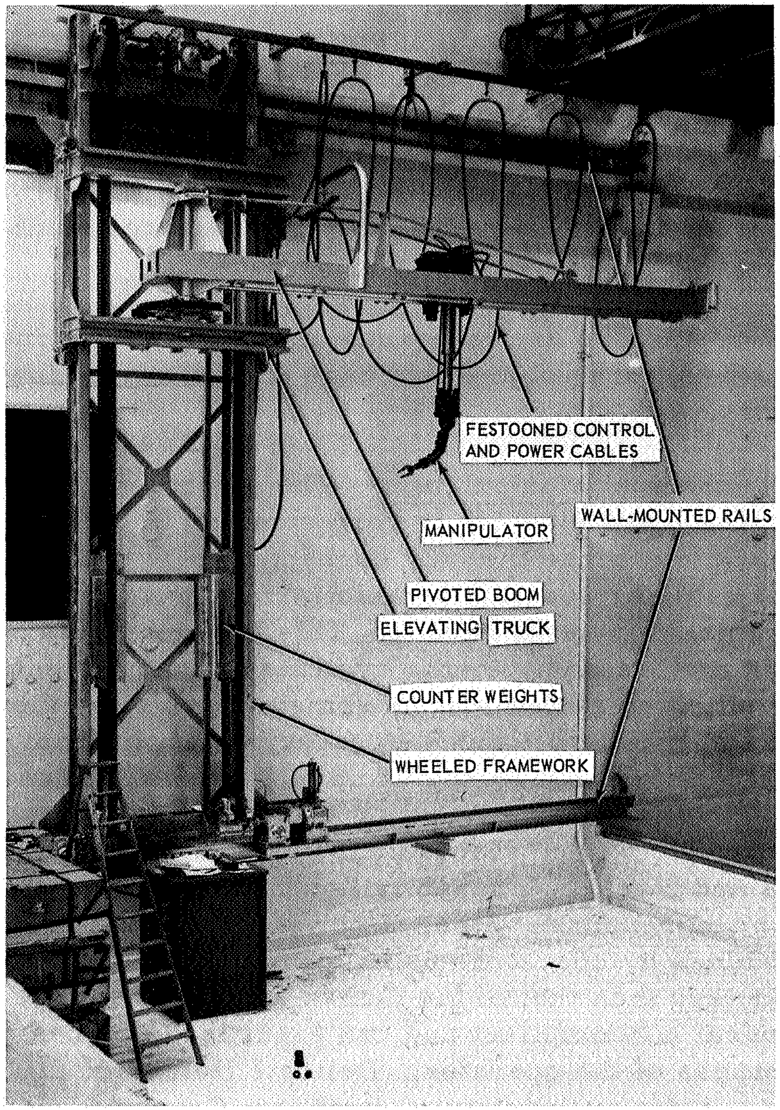

Figure 8 - Stiff-boom wall-mounted GM model C manipulator

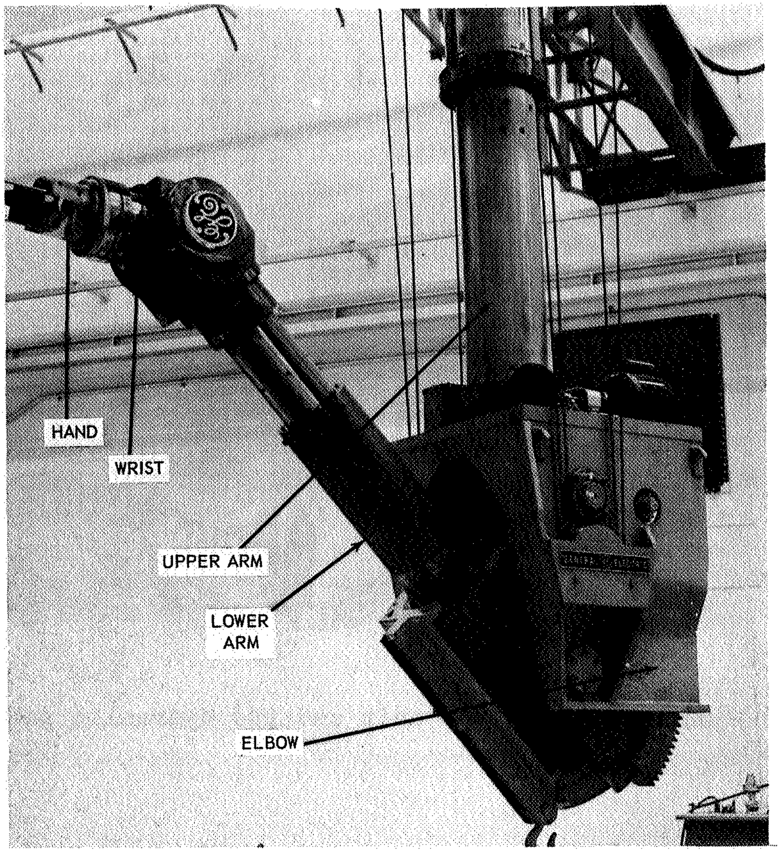

Figure 9 - Arm and hand assembly of the overhead manipulator

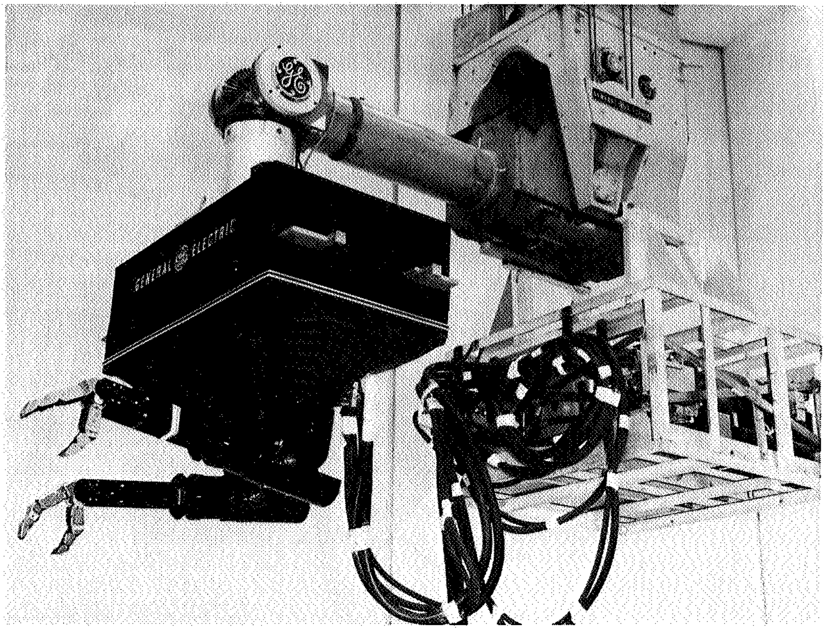

Figure 10 - GE Handyman slave unit and its hydraulic power supply

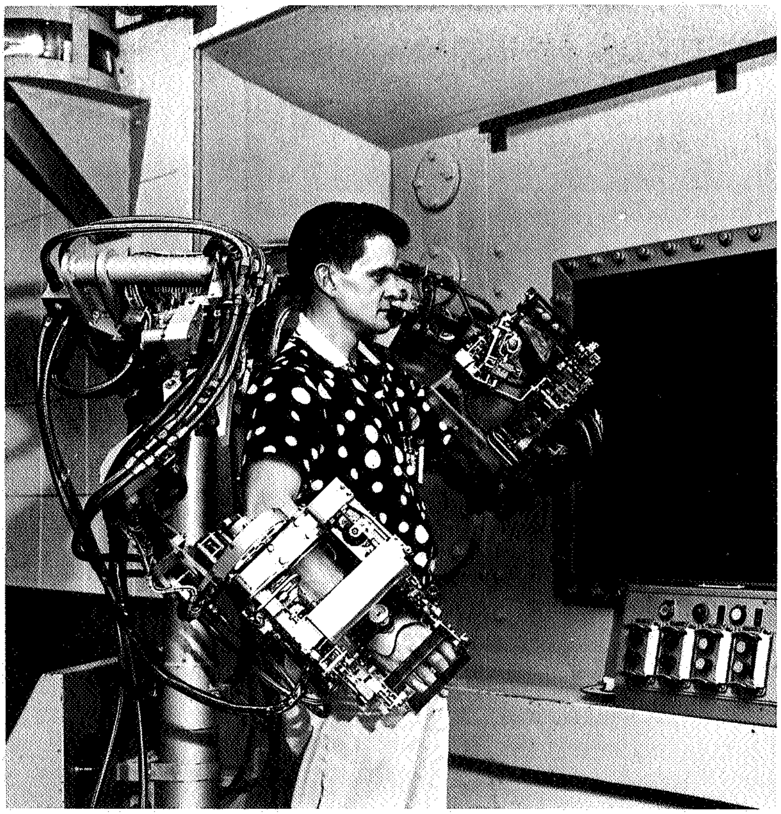

Figure 11 - GE Handyman master unit

It is an electro-hydraulic machine with two arms, controlled by the physical motions of the operator's arms and hands. The operator's motions are sensed by the master control unit attached to his arms and hands and the slave unit moves correspondingly. Forces on the slave unit are reflected to the operator by the master unit. Electronic controls provide counterbalance without the use of counterweights.

All servo manipulator systems are very expensive, many times more so than a conventional manipulator of the same capacity. Servo manipulator use is therefore limited to special applications where their unique combination of work volume coverage, rapid response and force feedback are essential.

5.3 Manipulator Mounting Systems

The manner in which the manipulator is mounted for positioning at the work locations is a very important factor in the over-all capability of the manipulating system.

Manipulators are generally mounted in one of three ways in a hot cell or hot shop and can also be mounted on mobile vehicles.

- Through-wall Mount - Master slave type manipulators being fixed in position either through a hole or over the top of the shield wall, are immobile and therefore limited to the reach capacity of the manipulator itself.

- Overhead Bridge Mount - The most common type of mounting for an electromechanical manipulator is hanging it from a telescoping tube on an overhead bridge and trolley as shown in Figure 9. In this manner the bridge moves along the cell, the trolley moves across the cell and the telescoping tube provides the vertical positioning. This system, however, is restricted in the horizontal reach beyond the telescoping tube and is limited in access to the underside of work objects. Multiple units of this type in a cell will interfere with one another as well as with bridge mounted cranes.

- Wall Booms - By providing manipulator mounts on wall booms, multiple units can operate in conjunction with overhead cranes and manipulators as well as units on the opposite wall as shown in Figure 8. This system is employed in larger hot cells where many items of equipment must use the same work volume with the maximum utility.

These wall booms traverse the length of the shop in both the Idaho and Nevada hot shops and can also travel vertically and swing through 180° in a horizontal plane. The bridge type manipulators traverse the length of these cantilever booms operating in a manner similar to bridge mounted units. Figure 12 shows the layout of manipulators in the Idaho Hot Shop.

An articulated boom, which has the manipulator attached to its tip presents some advantages. One unit in use telescopes, swings through a vertical arc, rotates about its own axis and swings the manipulator telescoping tubes through an arc. This is an extremely versatile system, allowing access from nearly any direction on the workpiece.

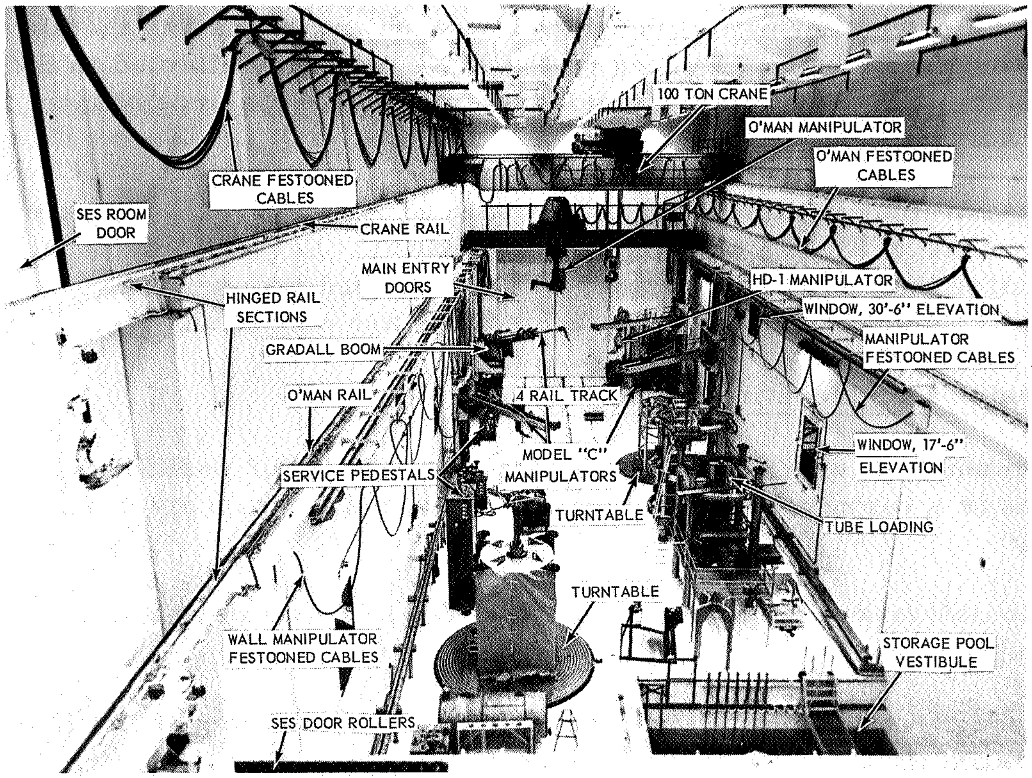

Figure 12 - Interior view of the Hot Shop, looking west

- Vehicle Mounting - Another manipulator mounting system which has become available in recent years is the mobile or vehicle mount. Small vehicles, such as the electric fork-lift truck type may mount the manipulator solidly on the chassis, or on the elevating fork mount. Larger vehicles are equipped with boom mounts to allow greater height and volume coverage.

The very large "Beetle" shielded cab vehicle is equipped with two GM-550 electro-mechanical manipulators on telescoping boom mounts. The booms and entire cab can also be rotated about a vertical axis and elevated on telescoping cylinders to increase the work volume. (Figure 4)

Small vehicles such as the Hughes "Mobot" have the manipulator arms located such that they can reach the floor and cover the design work height without the use of booms. In this type of system there is a question of nomenclature - where is the manipulator and boom dividing line?

(A more complete and detailed coverage of manipulators is found in REMOTE HANDLING OF GE-ANPD DIRECT AIR CYCLE NUCLEAR SYSTEMS, Chapter 5, Section 2.) (In preparation)

5.4 Viewing

One of the most limiting factors in remote handling operations is the viewing problem. At best, the operator must be located a considerable distance from the work point, particularly in the larger hot cells or when utilizing remote control vehicles.

- Viewing Windows - A common and probably the best over-all viewing device is the high density shield window. A high quality window allows the operator to view the operation in his normal viewing manner, with full advantage of his natural stereo depth perception, with high resolution wide angle coverage, and with a minimum of distortion. Where necessary viewing aids such as special lighting for shadows, binoculars, mirrors or other aids can be employed. A number of observers may monitor the work as well as the operator, at the same time and with both detailed and overall visual coverage.

Monochromatic light is used with the thick shield windows to eliminate the color effect of chromatic aberration which destroys good resolution. The loss of color is a disadvantage of this system. Windows also represent a sizeable investment when installed in adequate numbers to provide viewing angles and coverage.

- Periscopes - Periscopes are often used as viewing aids in a hot cell. Since they are limited to a single viewer, have a relatively narrow field and do not afford stereo vision their use is not suitable as a primary viewing system. Variable power eyepieces, excellent resolution, full color and adaptability for photographic uses makes them very useful for general hot cell inspection work. Periscopes are less expensive than windows, can be turned for full hemispherical coverage and can be moved to different locations without serious difficulty.

- Television - Television is used as a primary viewing system in certain types of operations. Where direct vision is impossible, such as guidance for radio controlled vehicles, television is often the only viewing means possible. The major advantage of television is the mobility of the viewpoint; cameras can be positioned in practically any location for viewing at various angles. It is very useful in hot cells for providing a view at right angles to the operator's normal line of sight, providing good triangulation. Inspection or manipulator guidance is also possible in difficult locations such as inside tanks, pipes or behind various obstructions.

Characteristics of television, which limit its usefulness, are poor resolution, sensitivity to high radiation levels, maintenance requirements and vulnerability to physical damage. Relatively high costs are more a function of maintenance rather than initial investment. Systems which provide color and stereo pictures are available but have proven to be of only limited value in improvement of overall visual effectiveness. (See Remote Handling of GE-ANPD......, Chapter 5, Section 6.)

5.5 Remote Handling in Support of Nuclear Rocket Testing

Ground testing of nuclear rocket systems will involve remote handling procedures that parallel those used in the ANP program. The size of test vehicles and radioactive components is quite similar, as are the radiation levels, and the cyclic nature of work loads is comparable. The hot cell which was built on the NNRDC was to some extent modeled after the Idaho Hot Shop and is very similar though slightly smaller than the Idaho Hot Shop. General size, shape, layout, manipulators and booms are very similar or identical to those in Idaho. It seems reasonable, therefore, that the remote handling philosophy for servicing the nuclear rocket systems will also be similar to that which evolved during the ANP reactor service operations.

A point of significant difference, which has not yet received much attention, is that the final product, the nuclear rocket for a one-way space mission may not need to incorporate remote handling provisions, assuming that no orbital "Hot Shop" is built. Since the remote handling provisions on the power plant tend to increase weight and cost and may decrease reliability, they should be eliminated from the final product if possible. The problem, of course, is to do so without invalidating the reliability estimates resulting from the ground test program.

Some basic points or guidelines which seem appropriate for remote handling of mobile reactor systems are listed below. They will generally apply to nuclear rockets as well as to the nuclear aircraft engine test systems from which they were derived.

1. Perform fully remote operations only when necessary.
2. Design the product (nuclear rocket engines and components) to stay within the limits of present day "state of the art" of remote handling.
3. Plan service and remote handling operations into the product design at all stages.

4. Plan and TEST all remote handling jigs, fixtures, manipulators or other equipment prior to "hot" operations (on actual hardware).
5. Utilize jigs, fixtures and supporting equipment to reduce the demands on the general purpose handling equipment, and to reduce the weight penalty on flight type hardware.
6. Utilize semi-remote operations where possible and advantageous.
7. Use personnel shields and special equipment to permit manual operations where feasible and advantageous.
8. Provide remote handling facilities with a "family" of manipulators with the size range covering small and large tasks to be undertaken.
9. Use standard proven equipment and tooling where possible; avoid developing special equipment except when necessary.
10. Remotely subdivide assemblies into components which can be decontaminated and serviced manually.
11. Perform remote operations which can eliminate other remote work (e.g., make a remote adjustment on a component rather than remove the component from a radioactive assembly for a manual adjustment).
12. Design "package" systems for remote handling with automatic and group connections rather than many separate small components.
13. Group connectors, lines, latches, etc., for ease of remote viewing and equipment access.
14. Provide adequate and generous clearances for the remote assembly of parts.
15. Provide guide pins, guides and other assembly aids.
16. Provide captive hardware (bolts, nuts, miscellaneous fasteners, pins, etc).
17. Avoid "blind" operations and those where it is not possible visually to check, inspect or test fit-up and connections.
18. Avoid critical components which cannot be replaced (e.g., threaded holes in a flange).

5.6 General

Remote handling operations are time consuming and difficult, compared to normal manual operations of a similar nature. Depending on the complexity, it may take many times the normal manual time to perform a relatively simple job. Installation of a standard bolt and nut in a flange may require as much as 10 to 20 times as long to perform remotely. Extracting a broken stud from a flange is probably impossible remotely. Some operations such as loosening a bolt on a flange or a number of bolts, may be longer by a factor of only 2 or 3 compared to manual times.

Due to the lack of physical contact with the operating hardware it is necessary to perform tests or checks on various remote operations more closely than for similar manual operations. Components may be damaged by the manipulator, or items which are already unserviceable may go by undetected without human contact.

Disabled handling equipment can often delay operations and may require extensive repairs as well as delays due to removal of the radiation source so that repairs can be made.

Remote operations and equipment are relatively expensive. A complete 100 pound capacity manipulator, articulated boom mount, controls and necessary support equipment costs about $250,000.

Extensive planning, careful design and tremendous patience are all requisites of a successful remote handling operation.

6.0 POST OPERATIONAL EXAMINATION

At the conclusion of the test series many of the test objectives will have been fulfilled. Much more valuable information can be obtained, however, from the laboratory examination of the power plant.

To illustrate the extent of post operational testing which may be applicable, the following section is quoted from a proposed examination procedure for a SNAP reactor following tests in the STEP (Safety Test Engineering Program). This is a particular interesting illustration since it was prepared with virtually no informatio as to the construction of the reactor. It, therefore, accurately reflects the wide range of general purpose laboratory tests without getting into specific details.

Laboratory Examination

General:

"Photographs at appropriate magnifications will be taken covering each point of special interest throughout the entire laboratory processing operations. The magnifications available range from 1/2X to 30X during the macro examinations and from 25X to over 2000X for microstructure studies. Two new fuel pins will be set aside and used for laboratory controls throughout the examination. In addition, it is assumed that a complete inspection report on the pre-run condition of all fuel pins will be available.

Non-Destructive Testing

"Following the static and limited kinetic experiments the following tests will be applied to assess the extent of damage and to certify fuel pins for reuse during the destructive tests.

- The core assembly, including the upper and lower tube sheets and all fuel pins, will be removed from the can, examined to locate any geometric trends in damaged areas, and disassembled. Each pin will be given an over-all examination for obvious material failures.

- The can will receive a careful surface examination and over-all dimensional checks at several points to measure deformations due to high or uneven temperature zones. Instrumentation that failed during the initial test will be examined and the cause of failure determined.

- The length and diameter of each fuel pin will be measured at several points to an accuracy of 0.001". The weight and density of each fuel pin will be taken to measure both over-all material losses or gains and over-all dimension changes.

- Zyglo, magnaflux or dye penetrant tests will be used to detect cracks in metals and welds. Tests should be made on several of the pins before irradiation to establish which method would be the most suitable in this particular case and to verify the initial condition of the pins.

- Ultrasonic testing may be used to detect separations between the cladding and fuel-moderator material (or any hydrogen barrier) that may be present, as well as to measure the cladding thickness itself. It will likely be performed only on pins considered for re-use and would be carried out semi-remotely (shielded dry-box) or by direct handling.

- Radiography can be performed in all cases where the pins are of sufficiently low radioactivity to avoid film fogging, and would be of considerable value in assessing the quality of the end welds and the physical integrity of the moderator-fuel bodies.

- Each fuel pin will be gamm-scanned to determine relative power distributions in the core during the reactor tests. These data will later be correlated with fission product analyses in cut samples to determine absolute power distributions.

"Fuel pins which successfully pass all of the above examinations and tests will be set aside for re-use.

Destructive Testing

"Following disassembly of the reactor, the following tests will be applied to pins failing to meet re-use integrity requirements and to all pins at the conclusion of the final destructive test:

- Free hydrogen gas in capsule will be determined as a measurement of moderator hydrogen loss on fuel pins having no holes or cracks in the cladding. The pin would be inserted into a vacuum system, the cladding punctured remotely and the hydrogen collected and measured.

- The cladding will be stripped from each pin and any hydrogen barrier which may be present examined and sampled for any further testing which migh appear appropriate. The barrier will then be removed from the fuel body. Each pin will be checked dimensionally, weighed and given a microscopic surface examination for flaws and cracks.

- Small samples will be cut at various radial and longitudinal positions from one radial set of pins. Each sample will be analyzed for total hydrogen (and, by inference, temperature) distributions in both the individual pins and the whole reactor.

- Samples taken adjacent to those listed immediately above will be analyzed for those fission products usually used as a measure of integrated fluxes, such as Co^{144}, Zr^{95}-Nb^{95}, Cs^{137} and Ba^{140}-La^{140}. The gamma scanning data discussed above could then be normalized, using these absolute determinations, to obtain absolute power distributions in the entire core.

- A third set of samples, cut adjacent to the above listed sets in a few selected representative areas, will be mounted and studied metallographically to determine the condition of the uranium-zirconium hydride matrix and assess radiation or temperature damage to its structure.

- Typical clad and clad weld areas (if any) in which cracks or other physical defects were found during the Zyglo or dye-check tests will also be mounted for microstructure study in order to determine the cause and degree of failure.

- Several selected fuel areas could be sampled for crystal structure study by x-ray diffraction, in those cases where the film would not be fogged excessively, as a back-up to the metallographic work in identifying phase changes in the matrix. These changes would be particularly likely to occur at the interfaces between uranium and zirconium particles."

7.0 SUMMARY AND CONCLUSIONS

As a means of summarizing the operation of the nuclear power plant, I would like to sketch out a possible sequence of steps that would occur in the preparation of a nuclear rocket for launching. The first step would be the assembly of the reactor and engine. This operation would require a separate facility, presumably isolated from other facilities so that in the event of an accident, a nuclear runaway of some sort, the number of people and the amount of equipment which would be subjected to damage would be minimized. This facility would contain one or more critical experiment cells which would essentially be heavily shielded concrete rooms in which the fuel would be loaded to achieve the desired critical mass. In these cells also various checkouts of the reactor systems would be carried out to make sure that the actual configuration was consistent with the one desired. Following the assembly of the reactor itself and the functional checkout of the reactor controls and instrumentation, the remainder of the engine components would be attached, such as the nozzle, turbo-pump and associated plumbing. The various components such as shielding and other stage hardware which might affect the criticality of the reactor would be mocked up. At this point, still at the engine assembly facility and in a critical experiment cell, the control rod positions would be calibrated for the desired startup position. This is in accordance with the present philosophy that the rocket startup would be accomplished by moving the control elements to a pre-determined position rather than by a closed loop servo. When this calibration of control elements and reactor instrumentation has been completed, the reactor control drums would be secured by a mechanical device such as a pin, which would make it impossible for any of the control elements to move. At this point the reactor is essentially as harmless as any other piece of hardware, and has a negligible radiation field surrounding it.

When completely assembled and checked out at the engine assembly facility, the nuclear engine is ready for a shipment to the stage assembly area. In certain types of reactors a danger is involved in this transfer in that the reactor might accidently be submerged in water or other moderating fluids. Appropriate precautions must be taken to insure either that there is no water around into which it might fall, or that the reactor will not go critical if it is dropped in the water, such as by the basic design of the reactor or by adding poison placed temporarily in the coolant passages. Aside from this the reactor in the safety condition represents no hazard to the operation at all.

At the stage assembly area, which is part of the regular vehicle assembly complex, the engine will be assembled to the stage tank. At this point the actual engine controller will be connected to the reactor instead of the facility control system used in the engine assembly facility. Therefore, it is pertinent to check the operation of the engine controller to make sure that the correct polarity, continuity, and so forth exists from the engine control system down to the reactor control drum. To accomplish this, one drum at a time would be freed and operated with the engine controller. This is again a step of negligible danger since properly designed reactor is incapable of going critical on a single control element.

The stage would then be transferred to the vehicle assembly area. During this operation, of course, the previous comments about immersion in water apply. In the vehicle assembly area the nuclear stage is then assembled to the booster stages and is completely checked out and prepared for launch. It will probably not be necessary to remove the mechanical safeties on the reactor at this point, since the function of the control system has been checked out from the stage controller down through the control elements previously.

The entire vehicle is then moved to the launch site and here a new hazard arises; the hazard of a chemical explosion and fire. It is unlikely that the reactor would in any way add a significant nuclear hazard to the very extensive chemical hazard. Although it is hard to insure that the reactor could not melt down into a more critical configuration, the possibility is sufficiently remote that it probably does not require any significant changes in the operating procedure.

At the launching site, finally, the mechanical constraints or safeties on the control drums will be removed as a final step. Here a nuclear hazard is conceivable in that malfunction in the control system might cause the reactor to operate prematurely. However, this type of malfunction can probably be precluded by the use of redundant systems and electrical safety systems, or it is possible that the reactor would be safetied by poison wires in the coolant passages which would be pulled out at stage separation. Thus, by one system or another, the safety of the reactor at this point is assured.

This sequence of operations is rather generalized, but it does serve to illustrate the considerations that would be involved in establishing detailed procedures. It is probably sufficiently accurate to permit the conclusion that preparing nuclear rockets for launch would not materially add to the existing hazards at the launch site.

APPENDIX A

Sample Instruction

This is a sample instruction identifying actions to be taken and documents which should be prepared for internal use at the reactor test station prior to reactor operation. The sample instruction is based on an instruction used in the GE Aircraft Nuclear Propulsion Department. The instruction assumes an over-all organization identified as the "Department" within which there is a "Reactor Project" and a "Test Station".

Department

Reactor Project

Test Station

- Test Engineering
- Test Operations
- Shops and Facilities
- Security, Health, and Safety

Other

The Reactor Project is assumed to have designed and built the reactor or power plant and has delivered it to the Test Station together with requests for test data. The Test Station is internally organized into subordinate organizations designated as Test Engineering, Test Operations, Shops and Facilities, and Security, Health and Safety.

PROCEDURES PRELIMINARY TO REACTOR OR POWER PLANT OPERATIONS AT TEST STATION

I. Policy

It is the policy of the Department to operate all tests in such a way as to minimize the possibility of events hazardous to personnel or property or which might unintentionally damage or destroy a test device with consequent delay to the programs of the Department.

II. General

A. In keeping with the above policy, this Instruction outlines certain actions, documents and approvals to be completed prior to the operation of any test involving a nuclear reactor at the Test Station. These are formalized in such a manner as to provide for full pre-analysis and review prior to operation while still maintaining the direct line responsibilities of personnel involved.

B. Documents required prior to the operation of any specific power plant or reactor at the Test Station are:

1. Facility Operating Manual
2. Standard Reactor or Power Plant Operating Procedure
3. Test Program and Procedures
4. Permission to Operate

C. Approvals required for these documents are specified below.

III. Document Procedure

A. Facility Operating Manual

1. For each facility in which reactors are to be operated, a Facility Operating Manual will be prepared. This Manual will include such items as the following:

   a. Description of and procedure for operation, calibration, checkout, and maintenance of facility equipments for reactor or power plant operation. These equipments include: data system, radioactivity monitoring devices, communication, ventilation, power, air, fuel, etc.

   b. Description of the organization of the operating personnel, defining responsibility, authority, and the work of all personnel.

   c. Regulations regarding security, access, safety, and evacuation.

2. The Facility Test Operations Supervisor is responsible for the preparation and issue of the Facility Operating Manual. This Manual shall be reviewed and approved by the following:

   Manager - Reactor Test Operations
   Manager - Security, Health and Safety
   Manager - Shop Operations and Facilities Services
   Manager - Test Engineering
   Manager - Test Station

B. Standard Reactor Operating Procedure

1. For each reactor to be operated in a facility, a Standard Reactor Operating Procedure will be prepared. This Procedure will include such items as the following:

   a. Explicit start-up and steady power operating procedures, both manual and automatic as applicable.

   b. Maintenance, calibration, and checkout procedures to be followed at the facility for all components and systems comprising the reactor or power plant assembly.

   c. Calibration and checkout procedure for reactor or power plant as it relates to the facility or installation.

2. When a Reactor Operating Manual is provided by the Reactor Project, it will be used as a reference in the preparation of the Standard Reactor Operating Procedure. There shall be no conflicts between the Standard Reactor Operating Procedure and the Reactor Operating Manual. Should any such conflicts arise, they must be resolved, and all pertinent documents accordingly revised or suitably noted.

3. The Facility Test Operations Supervisor is responsible for the preparation and issue of the Standard Reactor Operating Procedure. This Procedure shall be reviewed and approved by the following:

   Manager - Reactor Test Operations
   Manager - Test Engineering
   Manager - Security, Health and Safety
   Manager - Reactor Project
   Manager - Test Station

C. Test Program and Procedures

1. For each specific test or test series to be performed involving a nuclear reactor, a Test Program and Procedures document will be prepared. The test program will be based on a test request in writing from the Reactor Project. This test request shall be addressed to the appropriate Test Station project programs unit within Test Engineering.

2. Test request must include the following:

   a. Purpose and objective of test, with list of data and information required.

   b. Expected operating characteristics or data based on pre-test analysis.

   c. Special comments pertaining to special notice that should be taken and special limitations that may exist.

3. Based on the test requests, the Test Program and Procedures will be prepared. This will contain:

   a. A detailed description of each test and expected test data.

   b. The detailed procedures to be following in each test, including list of instrumentation and test equipment necessary to obtain the data.

   c. Wherever, in the conduct of the test, discretionary action is intended for or provided for the reactor operator, it will be so stated. In the absence of any statement as to discretionary action, it will be understood that no discretion is provided the operator, except to shutdown.

   d. A list of any tests included in the test requests and not included in the test program with a statement as to why.

4. The following Test Station organization components are responsible for preparation of portions of the Test Programs and Procedures Document as below:

   a. The Facility Test Operations Supervisor, for the facility involved, for the specific test procedure.

   b. The Supervisor - Health and Hygiene for the special health and hygiene monitoring and measuring procedures applicable.

   c. The Supervisor - Analysis for expected key data and special limits as applicable.

   d. The Supervisor - Instrument Engineering for special calibration procedures as applicable.

   e. The Supervisor - Project Programs for the specific test program and for compiling and editing the final document and initiating the approval sequence.

5. The Test Program and Procedures shall be reviewed and approved by the following:

   Manager - Reactor Test Operations
   Manager - Test Engineering
   Manager - Security, Health and Safety
   Manager - Reactor Project
   Manager - Test Station

6. When a reactor operator finds he cannot operate a test in conformance with the Test Program and Procedures, he will discontinue the test until after the resolution of the problem.

   Resolution of the problem may be made by the Facility Test Operations Supervisor, Supervisor - Analysis, and the Supervisor-Project Programs. The agreed upon solution, revision to procedure, or revision to program shall be documented and signed by the above. Copies shall be filed in the suitable facility test log or records and shall be sent to all individuals who reviewed and approved the initial Test Program and Procedures Document.

   The Supervisor - Project Programs, in accordance with assigned responsibilities, is responsible for consulting with and representing the cognizant Reactor Project organization.

7. After each test or each test period, the data and operating results shall be reviewed by the Facility Test Operations Supervisor, Supervisor - Analysis, and the Supervisor - Project Programs. Indicated desirable adjustments to procedure or program, as agreed upon, shall be documented and signed by the above. Copies shall be filed in the suitable facility test log or records, and shall be sent to all individuals who reviewed and approved the initial Test Program and Procedures document.

D. For each test, test series, or group of tests and test series, the Manager - Test Station will issue a document granting permission to operate. This will be based on the completion and availability of the following documents:

   1. Operating permission for the particular reactor involved and planned general test program from the Department General Manager.

   2. Facility Operating Manual for the facility in which the tests are to be conducted.

3. Standard Reactor Operating Procedure for the reactor involved in the facility involved.

4. Test Program and Procedures for the tests planned.

5. The permission to operate will also state any other special limitations.

IV. Review or Inspection Procedure

A. For each facility and/or reactor a Review Board, appointed by the Manager - Test Station, will review the facility and/or reactors as follows:

   1. When any major change has been made in the facility.

   2. When any reactor not previously operated in the facility is installed therein for testing.

   3. At other times to provide a review at approximately three-month periods.

   The Review Board will operate in a consultative or advisory capacity. Each review will be reported on to the Manager - Test Station in writing.

B. The Manager - Test Engineering is responsible for maintaining a schedule of required reviews and advising the Manager - Test Station.

C. The Manager - Reactor Test Operations is responsible for conformance to approved operating procedures, and through him the Test Facility Supervisor. The Manager - Reactor Test Operations and his Supervisors are responsible for training, knowledge, and competence of the test organization and reactor operators.

   The Manager - Reactor Test Operations and Test Facility Supervisor are responsible for operating at all times in a safe manner, and are responsible at all times for shutting down, or not operating, when in their judgment operations would not meet the Department policy on safe operations.