Proceedings of the 1964 Seminars on

REMOTELY OPERATED SPECIAL EQUIPMENT

held at
Nuclear Rocket Development Station
Jackass Flats, Nevada
November 4 and 5, 1964

United States
Atomic Energy Commission
Division of Technical Information

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EDWIN G. JOHNSEN - SEMINAR CHAIRMAN

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CURRENT EXPERIMENTS USING PROSTHETIC TERMINAL DEVICES

ON MODEL 8 MASTER SLAVES*

by E. H. Stearns
Lawrence Radiadion Laboratory

Anyone who has worked to any extent on problems requiring remote manipulation has found the most important feature of a manipulator is its ability to hold an object firmly and yet retain sufficient dexterity. If he is not able to hold on, he is in trouble from the beginning. I have read articles such as the one in a recent Scientific American, which explain studies which have been made on basic manipulator movements. I have yet to find anyone who has made a study on manipulator use of the slave tong. For this reason, we have decided to look into the work done by those who have had to develop a human hand replacement, specifically those working on prosthetic devices.

Dr. Murphy⁽¹⁾, in his notes, suggested several terminal devices which might be suitable for use on manipulators. Following the work done by Jerry Leavey⁽²⁾ on one of our manipulators, we decided to try the Dorrance 5XA terminal device. We purchased a right hand version late in September and immediately adapted it to one of our Model 8 manipulators. Two things became apparent immediately after purchase. First the rubber band closing technique was not readily adapted to a Model 8 and it allowed very little, if any, "feel" of the object that was being picked up. Second a new quick change device must be adapted to the Model 8 so that the hand could be easily removed for interchange with either a left hand or some other special tong, such as the ones in present use. We decided that we did not have time to develop an interchangeable type wrist, but we could do something for the rubber band. A special adapter was built which offset the hand approximately three quarters of an inch in order to allow the cable to run out under the ball bearing joint. This made the hand closely coupled to the wrist, which the experiences of Jerry Leavey had shown to be beneficial.

The slave was put into Cell No. 1 last Monday, October 26, 1964, in conjunction with a normal Model 8. On both Monday and Tuesday, it was used extensively for opening a special radiation capsule. After the capsule was opened, the foils which it contained were dissolved, and subjected to wet chemistry analysis. Two persons performed the work; one was a chemist with very little hot cell experience, the other was a chemical technician with extensive hot cell experience. The technician found himself favoring the hand with the Dorrance

*Work performed under the auspices of the U. S. Atomic Energy Commission

(1) Dr. Eugene F. Murphy, Veterans Administration, New York, Memo to E. Johnsen, See Appendix A, Volume I.

(2) Personal communication - Mr. Leavey is employed by Hosmer Corp.

terminal device, especially in the chemistry work. This was quite surprising, because the technician is left handed and this slave was installed on the right hand side of the cell. He did find that in some of the mechanical operations the hand was not quite as convenient as the old set of tongs. This may have been due in part to the fact that some of the equipment has been designed for use with the old style hand. I am sure a certain amount of prejudice is also involved. Many times he tried to use the Dorrance hand in the same manner that he would have used the old style tongs. It was obvious that training would definitely be needed on his part to achieve proficiency. The chemist stated that he felt that for some objects the hand was definitely an advantage. The problem is that at this date, he has not learned the different methods by which the hand should be used. The next step is to equip the left hand slave with the left handed Dorrance hand, which we intend to do. The next step beyond that might be to try other forms of prosthetic terminal devices.

Dr. Murphy pointed out another problem with a standard Model 8 hand. During certain maneuvers the operator's hand is put into a position where it is basically at its weakest attitude. To overcome this, we tried rotating the master wrist at 90 degrees to the slave wrist. We found this to be extremely confusing for the operator, in that when he would move the wrist straight out from himself the hand would go at 90 degrees. We felt this to be an extreme detriment that no operator could overcome. The next approach was to actually rotate the hands at 90 degrees to each other. This again was found to be of no advantage because with the inside hand at 90 degrees the operator was not working a natural position. This again led to confusion which would be hard to overcome. We have also altered our master hands in such a way that all of the motions that are powered are operated without the operator letting go of the handle. This way an operator can truly operate two slaves at once. The motions which are included are the X, Y, and Z on those slaves equipped with extended reach and the brakes.

At this time, it might be well to point out that the mechanical master slave manipulator does have a future. There are many points in its favor; the most obvious one is its cost. There are many laboratories in the United States today that need a manipulator that costs less than five thousand dollars. It must be of the master slave type. It must equal the Model 8 as far as coverage, strength and dexterity are concerned. Many features should be changed; one is the extremely high head room required for the Model 8. I feel the only way this one can be licked is to avoid the telescopic tubes. By avoiding telescoping tubes, the booting problem is greatly simplified. Further, it would be preferable if the size of parts such as the tubes and so forth be decreased so that the manipulator does not take up as much of the cell as does the present Model 8. Another feature which is needed is the ability to reach into a deep hole. On a new model the inertia should be as low as possible.

A feature of the Model 8 which makes it very popular with its users is its reliability. Many of the new expensive manipulators have not been proven due to the very limited number that have been built. I believe this is a result of their cost.

I also am a firm believer that no development can be done without bugs plaguing the first model. I think our rocket technology is a prize example of this situation. I hope in the future that a better liaison will exist between the designer and the user. A point which illustrates the difference between the thinking of operating personnel and design people is illustrated by the following example: I have noted that the ambidextrous master hand of the Model 8 master slave has been criticized because the fingers fit loosely, which prevented a close coupling between the operator and the object. This criticism, I believe, is unjust. The ambidextrous grip was developed by Westinghouse because the so-called close coupled hand was awkward and actually hurt the operator. In the case of the Model 8, the operator must exert a force on the grip for closing and holding, but the opening action is spring operated and is not affected by the operator's action. As a result, no feedback is transmitted in the opening direction. The only feel is on the fingertip pads during the closing and holding operation.

In conclusion, I would like very seriously to recommend that someone design a replacement for the Model 8, and hopefully use some of the technology learned from the prosthetic device field to build a more useful manipulator for the industry.

BRIEF NOTES ON CURRENT TECHNIQUES AND PROBLEMS OF REMOTE HANDLING

AT THE REACTOR MAINTENANCE, ASSEMBLY AND DISASSEMBLY FACILITY

by Don York
Los Alamos Scientific Laboratory

I do not have a new manipulator or new experiment to introduce. However, I have several examples of what can be done with the accumulation of a lot of the existing manipulative equipment. To explain to you exactly what we do, we will relate this discussion to the disassembly of a reactor.

The test car on which the reactor is mounted during a test is moved to and from the test cell using a remotely operated prime mover. The prime mover is under local control before the test, and after the test it is operated from the MAD Building by remote control.

You can get some feel for the magnitude of our remote handling problems by realizing that in the disassembly of each reactor, the number of parts that is handled remotely has been as low as 5,000 and as high as approximately 20,000. The weights of these items have varied from milligrams up to 10 tons, and we have the capability of going on up to 25 tons. The physical size varies from a small wire on up to the entire reactor, or anything that is above the shielded compartment on the test car. To date, we have never remotely maintained a reactor, however, we are seriously beginning to think about it.

The Maintenance, Assembly and Disassembly Building is divided into three areas: the assembly area, the office area, and the shielded area. The assembly area includes a clean room where the core is assembled.

We will discuss principally the shielded area and its equipment. There is a great variety of tools that go along with the manipulators, such as grinding wheels, metal cutters, impact wrenches, and cutting torches. The shielded area is equipped with shielding windows and five individual systems of black and white television.

Our experiences have shown us that all electromechanical manipulators should have a hand extension feature on them. We find that this feature makes the final motion towards gripping much easier, and consequently, we have provided this feature on the Model 700. The time ratio of remote to manual operations varies from about 4 to 1 to 20 to 1.

We are quite fond of the large number of viewing windows. It is our philosophy that a viewing window is superior to TV. There is less maintenance and a much larger view. The communications system

between windows has been quite a problem, which has been recently solved. The intercom stations between windows were not entirely desirable because the operator had to stop to press a button. On the other hand, using only headsets was not a desirable system either, because you could not always find the man. So we came up with a combination of the two. We have an intra building telephone system, with one phone at each window and a headset at each window. The headset is used in operations and the telephone is used to locate operators. The two together seem to work quite well. Presently, we are trying to improve the in-cell communications. Here again, we have tried telephone and intercom units. We think that we are approaching the answer now by using a speaker that you talk back to. We have found that with the speaker system you can talk up to twenty feet away to the speaker through a face mask and be understood.

We have found that a TV boom has been more of a hindrance than an aid. If we extend the TV camera to a point where it can see something, it is in the exact same location in which the manipulator arm should be at that time to manipulate. We have cured this situation by using the boom on the manipulator as a TV boom. We have also come to the conclusion that all TV cameras in that large of a room are of questionable value unless they have a zoom lens on them.

We have found that a paging system is quite valuable. However, it irritates some people. Along with this system we have installed the Bell Telephone key separate system. We have a criticality alarm system which warns the operators when criticality has happened.

After completion of disassembly, the shielded area is decontaminated. The lower and upper disassembly bays can be decontaminated in 2 to 10 days. We have a Decontamination Facility which is located adjacent to the shielded area, and this facility is used for the decontamination of the tooling. It is not shielded. We store all of the spent fuel elements on the test site after they have been returned from LASL. The elements are sent back in the same containers used in sending them to LASL, and they are stored here in the desert on remote railroad flatcars. To date, we have performed post mortem operations on nine reactors, four of the gaseous reactors and five of the liquid hydrogen reactors. At present, the NRX reactors are being disassembled in this facility.

REMOTE OPERATIONS AT TEST CELL "C"

by J. B. Henshall
Los Alamos Scientific Laboratory

You will be conducted on a tour of Test Cell "C" this afternoon so I thought I would give you an idea of what you will see. We, of course, do not have remote manipulating facilities at Test Cell "C". But, in the general sense of remote operations everything done at Test Cell "C" is a remote operation. Because the reactor produces intense gamma rays and neutron fields when it is operating, it is necessary to provide personnel operating the facility with some sort of radiation protection. At Test Cell "C", as well as Test Cell "A", the radiation protection is simply supplied by getting far enough away from the reactor. This distance is two miles in the cases of both test cells. At ETS-1, the new engine test stand that is in the early stages of checkout by Aerojet-General, the shielding of personnel is provided by earth cover, by locating the Control Point underground within 1,000 feet of the test stand. Thus, at NRDS, we have two different concepts for providing radiation shielding.

In the case of Test Cell "C", where the solution to the problem of radiation was distance, remote operations are required. These remote operations are all performed electrically. Since the distance is large, there are no mechanical linkages between the control point and the test cell itself. It could be interesting to discuss in a very general sense, the way in which the remote operations are accomplished. We have a very large number of the conventional types of valve controls of the ON-OFF type operated by switches at the Control Point. We do however, also have a number of more sophisticated control systems.

A reactor cannot be started in the way a chemical engine is started. Starting is one of the problems that is peculiar to the testing of nuclear reactors. For example, in bringing a chemical engine to power, one usually simply opens or closes a binary valve. It is sometimes necessary to sequence several of these valves to a very high degree of accuracy. The chemical engine is then brought up to its full thrust in 10's and 100's of milliseconds. It is very rare that a chemical engine will go from its state of no thrust to full thrust in more than one second. In the case of the reactor, it is impossible to get to full thrust in this kind of time period without introducing almost insoluble control problems because of the neutron kinetics involved. We cannot bring it up to power in a time that is much shorter than one half a minute. Actually, we conservatively take several minutes to bring the reactor to power. Our propellant, which is liquid hydrogen, is also an extremely good neutron moderator. It, therefore, becomes necessary to bring the propellant flow to its full flow value at a rate which is compatible with the rate used to bring the reactor up to design power.

This reactor control has necessitated a completely different control scheme than is used for chemical engine testing. Very early in the reactor program, analog feedback systems were developed. These systems operate in the following way. When a parameter is to be controlled, such as the liquid hydrogen flow rate, one first measures that variable. This is called the feedback signal; it is an electrical voltage proportional to the physical variable. A second essential component is a control element, such as a valve or reactor control rod, whose position can change the feedback variable. The essence of the analog feedback control system is to position the control element in such a way as to cause the controlled (feedback) variable to behave in a prescribed way. This prescribed variation is supplied in the form of a time-varying voltage. One then compares, electronically, the measured value of the signal with the demanded value, and from this difference constructs a command signal to tell the control element what to do in order to make the difference zero. These closed loop techniques are used throughout the major control system of Test Cell "C".

The liquid hydrogen is stored in vacuum-jacketed vessels which are called dewars. The cryogenic temperatures of liquid hydrogen makes it necessary to transfer this fluid through vacuum-jacketed pipes.

The instrumentation and control systems are in a shielded basement in the test cell since these are the components that are most sensitive to radiation.

We do not have remotely operated equipment for connecting and disconnecting the reactors since it is possible to do this manually in this test cell. When it comes to operating other kinds of test stands (such as ETS-1), where one does not have the massive concrete shielding structures, it will be necessary to remotely disconnect piping, hydraulic lines, instrumentation lines, and all of the services that are provided by an umbilical cord connecting the test vehicle and the test facility.

In addition to test operations, there is the whole field of maintenance which we think requires better equipment. So far there has been very little done in this area. As you might guess, these reactors are rather expensive to build, and for the most part, they can only be used one time. We have recently demonstrated the capability of restarting a KIWI reactor, but even with restart capability it will probably never be possible to run one of these engines a hundred times, as one can do in a chemical rocket engine development program. We have experienced some sort of problem with hardware on almost all of our reactors that has either prevented or made us a bit nervous about re-running them. Based on our experience

with servo control systems we wonder if it might not be possible to use the techniques of this very powerful field to solve some of the difficult problems of remote manipulation and repair. It may be possible to unite these systems with their power and controllability and the motor functions of the human body to advantage.

In concluding this description of Test Cell "C", I want to mention the camera bunkers that are generally located some 600 to 700 feet from the reactor. The radiation levels this close to the reactor are so intense as to completely darken any photographic film. The cameras are mounted in a protected concrete and earth shield bunker and the pictures are taken through a mirror which is mounted in a support structure above the shield at bunker.

Semi-radiation resistant TV cameras are used on the reactor pad. Two TV cameras are located on the pad some 30 or 40 feet away from the reactor. Those will generally function fairly well for approximately a minute during a full power operation, but then they experience difficulty. However, the cameras seem to be self-healing and will come back on after the reactor is shutdown to a level which will allow them to operate again. The radiation level at which this occurs is not known because no instrument has been provided which is able to measure the dose rate during a reactor operation. From chemical dosimeters we can measure the total dose and knowing the total run we can get an estimate of the peak dose rates.

REMOTE HANDLING REQUIREMENTS FOR NERVA (E-MAD & ETS-1)

Presented by L. E. White
Aerojet-General Corporation

Coauthors: H. Alexander, R. Field, C. Hall, R. Schaffstall, B. Nausler

The NERVA program provides for the development of a nuclear rocket engine for application as an upper stage of a space vehicle. Before the engine can be put to this use, its reliability and performance must be established; with the demonstration performed during the development test program. The engine test program for NERVA will be conducted at Jackass Flats, Nevada, where facilities are being completed that satisfy the initial planning and unique requirements set forth for nuclear rocket engine testing. Two major facilities are involved--an Engine Test Stand (ETS-1), at which static firing of the engine will be conducted; and the Engine Maintenance, Assembly and Disassembly (E-MAD) Building in which, beyond the scope implied by the title, extensive post mortem analysis on engine component parts will be performed. The E-MAD Building will provide the capability of readying an engine for test, replacing damaged parts of an engine either tested or new, disassembling or reassembling a tested engine. These functions will be accomplished remotely or directly depending on whether the engine is radioactive or not.

This paper will not deal with detailed facility discussions concerning the Engine Test Stand (ETS-1) or the E-MAD Building, nor will it discuss the NRX activities at R-MAD and Test Cell "C". It is intended only to present data related to the ETS-1 and E-MAD facilities that contribute to the development of significant remote handling systems. However, should more detailed information relative to the functions of these facilities be desired, the guides conducting the tours this afternoon will be capable of answering most questions.

Engine Test Stand (ETS-1)

(Figures 1A and 1B) The Engine Test Stand (ETS-1) has been designed and built to provide a facility for the performance evaluation of static test firings of nuclear rocket engines.

This facility provides for nuclear engines to be tested in the nozzle-down position. It provides a test-stand-to-engine interface incorporating remotely operated pneumatic lines and electrical connectors with which the engine counterparts must be accurately mated. Additionally, and since this is a nozzle-down test facility, a method to handle the exhaust gases has been developed called the NERVA Exhaust System (NES). This system includes as a major sub-system, a deflection duct which deflects the exhaust gases down and away from the facility.

Surrounding the engine during test is the Engine Test Compartment (ETC) shield which has three basic functions: to provide a safe oxygen-free operating environment for engine test; to partially stimulate space vacuum environmental conditions operating in conjunction with the NES; and to provide radiation shielding in accordance with safety and operational requirements.

The ETC will include stationary top and bottom shields and two half-cylinder side shields that are remotely positioned and sealed to the top and bottom shields for engine testing. They are remotely opened and removed from the test stand area to provide access to the engine assembly after test.

All drive mechanisms, fluid, instrument, electrical couplings and seal systems are operated by remote techniques. Seal systems are designed for inert gas purge to eliminate air leakage into the engine compartment. These systems are currently in fabrication and are expected to be delivered during 1965.

Since the bottom shield provides an opening for the deflector duct, a duct shield is to be provided to minimize radiation level on the engine compartment area after removal of the engine from the stand in order to facilitate personnel access to the stand area.

The Engine Test Compartment and the engine-to-test-stand interface provide the predominant constraints for establishing requirements involving installation, recovery, on-stand maintenance, and malfunction repair of the engine in relation to the test stand.

(Figure 2) The Engine Installation Vehicle (EIV) carries the engine between the engine test stand and the E-MAD Building in the nozzle-down position. It will position the engine along the direction of the tracks very accurately by means of an inching-drive mechanism. The engine support carriage is capable of moving vertically, laterally or rotationally by means of self-contained drive systems. Attached booms, containing TV cameras (not shown), will provide the capability for monitoring the engine-to-test-stand interfaces as the engine is positioned during the installation phase. The TV system will also monitor engine support carriage relationship with the engine during the removal operations; that is, removal of the engine from the test stand. Control for these systems, positioning drives and TV, can be local or remote, with operations associated with a new or untested engine being local and for a tested engine, the operations being remote.

(Figure 3) Remote control for the EIV emanates from the Manned Control Car (MCC) which is a two-man operated vehicle shielded from the radiation associated with "hot" operations. Additionally, the MCC incorporates control of the prime mover (locomotive) that provides the

prime source of locomotion for the EIV and MCC between the test stand and the E-MAD Building. This unit was developed as the companion piece for the EIV as a result of considerable engineer analyses of the tasks to be performed at the test stand.

All remote operations involving transport of the engine, hot installation of an engine into the test stand or removal of a hot engine from the test stand, necessitates the use of the locomotive, MCC and EIV as a unit. Through radio communications, the operators in the MCC are in constant touch with ETS-1 or E-MAD personnel and the status of the operations is readily determined.

This facility will be "proof tested" in 1966 using a cold flow machine and at this time the remote handling technique of installation, coupling of engine to the stand, and transport system handling will be determined.

Malfunction studies and analyses have been conducted for all feasible emergency conditions and necessary devices incorporated into the design of the Transport System by the engineering-manufacturer to insure adequate safety to the test article and/or operating personnel at all times.

Economic and logistic considerations may suggest "on-stand maintenance" of engine assemblies. Program requirements could necessitate rapid turnaround of assemblies to derive maximum test data. Because of these factors, engineering studies are in progress which may define "on stand" engine maintenance requirements. This data will then determine remote equipment operational characteristics and requirements and define the need for such equipment.

It is certainly not anticipated that malfunctions would occur to seriously damage the test stand or an engine; however, malfunction analyses are presently being conducted to establish the need for additional remote handling equipment which would augment the existing equipment in the recovery of a seriously damaged engine. At present, the only remote equipment available includes the MCC-EIV with emergency use of the Beetle as necessary.

Three approaches were considered during the 1961-1962 time period for engine transport and recovery. These were:

- a. Radio control prime mover with Test Stand/EIV hard line control via remote connector.
- b. Radio control prime mover with multiplexed radio control for EIV systems.
- c. Shielded manned prime mover with hard line control between prime mover and EIV.

The criteria used for selecting the present system was based on many factors, a few of which are noted here:

- a. The transport system was to handle engines for all planned and future NRDS engines and vehicle test stands.
- b. The ETS-1 design was frozen and construction status precluded hard line control to the EIV without significant facility modifications.
- c. Reliability, direct viewing, control complexity, test stand economics and economic factors related to the transport system.
- d. System chosen must be compatible with E-MAD and be sufficiently flexible to accommodate engine configuration changes.
- e. A transport system capable of delivering spent fuel materials and radioactive hardware to the graveyard facility.

Engine Maintenance, Assembly and Disassembly Building (E-MAD)

(Figure 4) The E-MAD Building has been designed and constructed to provide the capability to assemble and prepare the NERVA engine for test at ETS-1, to remotely disassemble the engine following the test, to replace critical components remotely, reassemble a radioactive engine and to perform extensive post-operative examinations and tests on the disassembled components. Since the E-MAD Building was described in detail at the last Project ROSE Seminar in May of this year by Mr. Neder, REON, AGC, and J. Colgan, Vitro, the description of the building shall not be repeated except to quickly recall the general arrangement of the building and to provide a brief discussion of the equipment being currently provided.

The design of the integrated remote handling system is an integration of three basic remote handling systems supplemented by an overhead crane, master slave manipulators at the viewing windows, storage stands, dollies, and fixtures.

The primary E-MAD remote handling system concepts in principal were frozen during the design of the E-MAD facility during 1961 and 1962.

The OPS concept evolved principally with the need for an overhead manipulator system (like the O-Man). The telescoping box type rather than the O-Man tubular design was developed primarily due to the height and span dimensions of the E-MAD Hot Bay which dictated the necessity to minimize manipulator whip and provide structural integrity to the system. The design criteria for the OPS was further expanded in order to accommodate disassembly and reassembly of close tolerance engine components.

Working in conjunction with the OPS were two additional systems, the WMHS and the FMHS. The former was developed with the need to have two independent and versatile hands available to work simultaneously on the engine assembly. In concept therefore, and due again to the Hot Bay dimensions, two such independent hands were planned for each side of the bay. The FMHS provided for all floor mounted stands, jigs and fixtures needed for the disassembly, maintenance and reassembly processes. It was decided due to economic consideration, that these stands would provide the variable portion of the remote handling system to accommodate different engine design configurations and other potential changes evolving during the development cycle.

All other facility remote handling systems were planned based on the commercially available equipment existing during the facility design period, recognizing the need for improvements and advancements at a later date when program requirements so demanded.

The three basic handling systems in the Hot Disassembly Bay at E-MAD are the Overhead Positioning System (OPS) (see figures 5 and 6), the Wall Mounted Handling System (WMHS) (see figure 7) and the Floor Mounted Handling System (FMHS). The bridge mounted telescoping mast of the OPS has positioning heads for adapting it to handle the completely assembled engine or its major components or sub-assemblies during disassembly operations. The OPS is especially important in the reassembly/disassembly operations by virtue of its ability to lift the large engine components and position them with the accuracy required by the close tolerances inherent in the engine design.

The WMHS will provide the facility with the means to accomplish the many remote hand operations required during reassembly and disassembly of the engine. The system consists of two trolley mounted booms that traverse the east wall of the Hot Bay via a wall mounted rail system. Each of the booms is fitted with a manipulator at its extreme end. The booms have the required flexibility to position the manipulator hands at most any given location and attitude within the eastern half of the Hot Bay.

The FMHS is composed of a number of assembly fixtures, support stands, portable turntables and lifting fixtures for the engine and its component parts and assemblies. The stands and fixtures are designed to interface with specific components, supporting them in a convenient attitude for assembly on the engine.

Supplementing the engine handling system, a 40-ton bridge crane and auxiliary 10-ton hoist on the same trolley serves the entire Hot Bay. Both hoists have motorized hooks to assist in remotely attaching to the lifting provisions of equipment items and in positioning the stands and fixtures in the proper attitude for use in the disassembly operation.

Master slave manipulators installed at each of the first floor viewing windows in the Hot Bay and third floor viewing windows in the Crane Maintenance Balcony will allow many small engine components to be examined and/or further disassembled.

Components that have been removed from the engine and examined at one of the viewing windows may be transferred to the post mortem area for further detailed examination and analysis. A remotely operated dolly and a mobile carriage, which are part of the FMHS, will allow transfer of radioactive parts from the Hot Bay through the Hot Hold Tunnel into the post-mortem Cell Service Area. A small material transfer rail system servicing both the east and west post mortem cells allows transfer of engine components between these cells and the Core and Engine Disassembly Cells.

(Figure 8) The Cell Service Area is served by a $7\frac{1}{2}$ -ton bridge crane and a rectilinear manipulator installed on a common overhead rail system. The crane and rectilinear manipulator will be used to remove components from the carriage or dolly and place on the cell transfer carts that travel into the cells. The cells will be equipped with a pair of master-slave manipulators at each viewing window. Appropriate cells will be equipped with periscopes, bore-scopes, stereomicroscopes, and equipment such as tensile testers for determining the physical properties of test specimens. Each of the twelve cells will be equipped to perform a specific function for a complete analysis of the engine components.

To expedite the disassembly process and to make it possible to work on more than one engine at a time, it is planned to activate the Core Disassembly Cell and the Engine Disassembly Cell. As planned, each of these cells will be equipped with a bridge mounted rectilinear manipulator and master-slave manipulators at each of the viewing windows. After the reactor is separated from the engine in the Hot Bay, the major components can be transferred to the Core and Engine Disassembly Cells for further disassembly.

In addition to the remote handling equipment just described, many items of ground support equipment (GSE) in the form of accurate holding fixtures for the engine assembly and subassemblies are being provided to assist in the various stages of remote disassembly of the NERVA engine.

Auxiliary Facilities in the E-MAD Complex

ETSMB - The Engine Transport System Maintenance Building is currently under construction in the E-MAD complex. This facility will be used to perform the necessary maintenance pre-run checkout and modification as required on the transport system and rolling stock.

Radioactive Materials Storage Area - A new facility is being provided for graveyard storage of fuel material radioactive metal hardware. This facility has been designed and will be placed in

construction status in the near future. This facility will service the entire NRDS when complete. The material transported to this facility will be housed on flat cars and will be moved using the locomotive/MCC. During transfer of hot materials to and from the E-MAD Building, switching along the main railroad line and onto spurs as for example to the radioactive materials storage area, is controlled from the E-MAD Master Control Room (MCR) and communicates via radio between the MCC and MCR.

Future Conceptual Planning and Design (E-MAD)

Future conceptual planning and design involving remote handling equipment at E-MAD falls into the following general types:

1. Modifications to existing equipment
2. New Manipulator systems
3. New viewing equipment

While little effort has been directed toward these future and anticipated handling problems by NTO personnel, the recent Project ROSE Seminar has certainly and definitely stimulated our thoughts and imagination as well as confirming some of our basic concepts for future remote equipment design at E-MAD. In addition, recognition has been given to experiences by LASL and AGC/Westinghouse in the KIWI and NRX Programs in R-MAD and, therefore, the following represents some of our current thoughts regarding potential improvements at E-MAD.

Modification to Existing Equipment

Using the currently planned and/or existing equipment as a springboard into future E-MAD operations, let us constructively examine some of the modifications that might be made to existing equipment to increase their usefulness, speed up operations, increase the equipment reliability, provide more accurate manipulation and reduce operator fatigue.

Based upon our present knowledge and equipment development, the OPS, WMHS and rectilinear manipulators could be modified to include servo positioning and force reflection feedback to the operator as well as programming systems for controlled motions and automatic positioning.

Accessory equipment in the form of special tools and adapters and refined checkout systems will be added as requirements are discovered. Master slave manipulators may be equipped with special purpose hands and be provided with test, installation and maintenance fixtures and equipment. The turntables may be modified to incorporate a position control system with readout facility at the turntable and at the controller, variable speed controls and interlocked controls for increased flexibility. Hoists may be modified to incorporate appropriate hook configurations and antiswing devices developed for remote operations.

The crane and rectilinear manipulator in the Cell Service Area of the post-operative cells could be modified to allow the crane to pass over the bridge mounted manipulator and allow increased hook and manipulator coverage as well as allowing the manipulator hand to service the crane hook during remote operations. A more compact design of the manipulator bridge trolley would allow increased reach into the cell doorways and provide more effective material transfer operations using the in-cell master slave manipulators.

GSE equipment will be modified to make them more compatible with the total integrated remote handling system as well as to increase production and operator efficiency. Design changes to the NERVA engine will undoubtedly occur to some extent and must be reflected in the GSE design. Experience and operational requirements will dictate further changes to speed up operations or simplify the disassembly procedures.

New Manipulator Systems

The existing facility at E-MAD includes a pair of WMHS units (see figure 6) on the east wall with no provisions as yet on the west wall for similar units. Many concepts have been contemplated for this second pair of WMHS units including a so-called light-duty version of the existing units. Based upon our present knowledge, we feel that this second pair, similar to that described by R Goertz at the last ROSE meeting, should definitely include two armed manipulators having servo positioning and force multiplication and reflection. The manipulator arms, similar to the LASL unit "MINOTAUR" (figure 9) and the Lockheed SCHMOO, should be provided with the means for separation of the two arms as required. Viewing of the operations at the manipulator hands would be accomplished with a dual TV system to provide a three dimensional effect to the operator. A system employing this type of manipulation is depicted in figures 10 and 11. As illustrated, it will provide increased capability and versatility and would be easier to operate. A cantilevered bridge on the present WMHS rails will support a vertical telescoping mast with the manipulator pod attached to the lower mast section. Each manipulator pod will provide two interchangeable manipulators. Attaching the same manipulator pod to a portable pedestal (see figure 12) would provide extra hands in complex operations. Attaching the same pod to a remotely operable vehicle (see figure 13) would provide a completely mobile pair of manipulators for emergency use, for coverage of the crane maintenance balcony in the Hot Hold Tunnel or in any area where manipulator coverage is limited or non-existent.

Future master slave manipulators must be examined and assessed as to requirements for servo positioning and force reflection. For large cells such as the Core and Engine Disassembly Cells, a bridge mounted system of this type would provide master slave manipulation in all areas of these cells plus reduced operator fatigue as a direct result of the force multiplication design.

Remote Viewing at E-MAD

Regardless of how sophisticated the capabilities are of remote manipulating equipment, short of a completely automated operation, its usefulness will be directly related to the ability of the operator to observe the actions being performed. Although direct visual observation of a nuclear engine disassembly operation may be attained through use of lead glass shielding windows, this provision is of limited value due to the distance from the operator to the test article, the distortion of motions, and the limited angle of viewing. These limitations require that direct visual observation be supplemented by other methods of observation. The method which is currently in extensive use and which appears to offer the greatest promise for improvement in the quality of viewing, is that of closed circuit television.

The present design of the E-MAD TV system provides remote viewing by cameras located in the Main Disassembly Bay, the Hot Hold and Transfer Tunnel, the Engine and Core Disassembly Cells, and the Post Mortem Cell Service Area. The video outputs from any of these cameras may be transmitted to any operator station in addition to the Communications Control Center and the Master Control Room. The outputs from any two of the cameras may be viewed simultaneously, using two different monitors, at any of the operator positions located in the galleries adjoining the Main Disassembly Bay.

The cameras will be mounted on booms attached to the walls, portable booms, or portable stands. The booms will permit different angles of viewing to be obtained both horizontally and vertically, by remote control. The portable booms and stands may be repositioned by use of other equipment, to obtain different distances and angles of view. Remote controlled zoom lenses, mounted on each camera, also provide an apparent distance adjustment.

This system provides the operator with black and white viewing of a quality comparable with commercial broadcast television. By proper placement of two cameras and observation of their output on two separate monitors, the operator is able to obtain a crude sort of three dimensional information.

Although the current E-MAD system does provide viewing information not available by direct visual access, it has shortcomings which limit its usefulness. There are several considerations which might be incorporated to improve the quality of viewing.

Possible Improvements in TV Viewing at E-MAD

There are many requirements which could be stipulated for an optimum viewing system. However, the majority of these can be summarized by stating that the viewing, for maximum utility, should approximate that provided by a pair of human eyes, located at a desirable working distance from the operation in process. Some of

the factors involved in this type of viewing are discussed below:

a. Three Dimensional Television:

Possibly the factor which would provide the most noticeable improvement in operator viewing for performing remote manipulations, would be the incorporation of a three dimensional TV system. The three dimensional effect, which can be attained with a well designed TV system contributes to the operator's depth perception, both by presenting two separate images to the eyes (retinal disparity) and through the kinesthetic sense of eye convergence.

To provide the operator with the type of observation which will aid him significantly in performing remote manipulations, the three dimensional system needs to simulate the type of viewing provided by the eyes. It is not sufficient to have the visual information from the two viewing angles presented on two separate monitors which require viewing of first one and then the other to obtain the desired information. Rather, this information needs to be displayed in such a manner that each of the operator's eyes may see the visual presentation of only one of the two cameras or optical paths. There are several different methods of achieving this using various combinations of equipment. Either two cameras or a single camera may be used to sequentially or simultaneously present visual information gathered from two viewing angles. Through use of polarization techniques, the composite picture, obtained from either a one or two camera system, may be separated into the two views obtained from each of the viewing angles, with each eye perceiving only one of these views.

The incorporation of this type of equipment would obviously improve operator performance, both in quality and quantity of work performed.

b. Color:

Another factor which could be used to provide additional clues to the operator, regarding the nature of the object being disassembled, is that of color. To derive the maximum benefits attainable from the use of color, steps could be taken to add color to portions of the assembly which require greater finesse in remote manipulation which would make them stand out in the operator's view. With or without special coloring provision, the use of color viewing systems would provide the operator with additional information regarding the object which would help him in performing remote manipulations on that object. Seeing the object in its natural color would also give the operator a psychological boost.

c. TV Booms:

The ability to change the angle of view is an important consideration. An automobile mechanic in disassembling an engine

will unconsciously move or turn his head many times to obtain spatial information through changes in "over-lap". He will also stoop, stretch and peer upon occasion. TV booms should enable the cameras to duplicate the motions of the human head and provide the mobility of the legs and trunk of the human body. In addition, a three dimensional system when applied to the booms would necessitate boom motions which permit changing of the angle between the two optical paths.

For maximum usefulness, it is not enough to merely have these motions of the boom available through manipulation of a group of switches located on a control panel. An optimum system would allow the operator to at least partially control the boom motions through his normal body motions, such that if the operator stepped in any direction he would actuate a servo-mechanism which would result in the boom duplicating his motions. A control panel would be required to provide a selection of motion multipliers, to allow the operator to change his zero reference position, and to provide motions not readily controllable by normal body motions.

An ideal boom would provide for complete mobility and would not require attachment of power cords.

d. Radiation Resistance:

An important consideration when using TV equipment in a nuclear engine disassembly operation, is its ability to withstand damage or impairment of performance while operating in a radioactive environment. TV systems are currently available which have taken a number of important steps to increase their toleration to radiation. Some of these are as follows:

(1) Intentional deletion and replacement of materials known to be susceptible to radiation damage.

(2) Development of non-browning vidicon tubes and zoom lenses.

(3) Removal of all electronic components, except the vidicon and one stage of amplification, from the camera unit. The one stage of amplification is especially selected for radiation resistance and the preamplifier may be attached to the camera unit through as much as 100 feet of cable. This permits the placing of critical electronics in a shielded area.

It is anticipated that even greater resistance to radiation damage may be attained as radiation damage studies continue.

e. High Resolution TV Equipment:

A basic method to increase the detail of the monitor presentation is to increase the number of lines of scan per frame. The TV system used in E-MAD uses 525 line per frame scan equipment. Equipment

is available which uses almost twice as many lines per frame. Although the increase in detail is of course not in direct proportion to the number of lines per frame, there is a noticeable increase in the detail presented by the high resolution equipment, particularly of fine vertical lines. Although there are factors which tend to offset the benefits gained from increasing the number of lines per frame, it is anticipated that equipment capable of producing even greater detail will be developed in the future.

f. Manipulator Wrist Mounted TV:

The ease of aligning tools or performing certain operations could well be enhanced by the incorporation of a TV camera mounted on the manipulator wrist. Trends toward camera miniaturization make this possible in a manner which would provide a minimum of interference with other equipment. This camera would supplement, rather than replace, the cameras providing an overall view of the operation.

g. Headset TV System:

At the Project ROSE Seminar which took place in May 1964, Mr. Bradley of IDA, described some experiments with a TV system with monitors mounted on the operator's head, such that, regardless of which direction the head was turned, the camera video output was observable. In addition, a servo-mechanism was employed so that turning of the operator's head resulted in swiveling of the camera.

This type of system has the basic ingredients of an optimum viewing system. It was reported that the impression was conveyed to the operator that he was located where the camera was. An extended system of this type would not only provide optimum viewing, and control of this viewing, but it would also psychologically absolve the barrier of walls and distances and permit the operator to feel as if he is inside the hot bay with his work.

An optimum system would consist of a three dimensional headset TV system, using high resolution color transmission, with all camera and boom motions controlled by normal body motions. Turning of the eyes should result in camera motion in addition to turning of the head. The size and weight of the headset and the method of attaching signal and control cables should be such that the operator feels a minimum of encumbrance.

It seems that if this type of viewing were used in conjunction with a mobile remote manipulator which simulates the body arms, wrists, and finger motions, that the operator's projection of himself into the operation would be approaching the ideal in remote manipulation. It is reasonable to assume that a system of this type would result in a significant increase in operator capability and productivity.

In conclusion and as observed by those present, the latter portion of this paper deals with suggested improvements in remote handling techniques and application of advanced concepts of ROSE. The intent is deliberate because of the ultimate future necessity to provide remotely operable systems for the performance of maintenance to and replacement of nuclear engines and/or critical parts in a space environment. While little significant progress or design has been conducted on advanced remote handling systems due to the more pressing problems of activating the facility, it is anticipated that as the NERVA program becomes operational and with operations increasingly more complex that new and advanced concepts such as discussed today will be incorporated into the facility systems.

FIGURE 1A

FIGURE 1B

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

E-MAD REMOTE HANDLING SYSTEM

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

FIGURE 10

E-MAD FUTURE MANIPULATOR CONCEPT
SHEET 1

FIGURE 11

E-MAD FUTURE MANIPULATOR CONCEPT
SHEET 2

FIGURE 13

REPORT ON FMC REMOTE HANDLING VEHICLE

by Robert Tolliver
Kirtland AFB

For those of you who did not attend the last ROSE Seminar, this is a follow-on report on an experimental fullscale model of a remote controlled salvage system described during the previous seminar. Several years ago the Air Force Weapons Laboratory (AFWL) determined what type of equipment we felt was needed for the emergency conditions that were associated with aerospace nuclear power plants. In building up this concept we came up with many ideas on paper. So we decided that we would build an experimental model, which would be a "mobile test bed" to try to prove out some of the ideas of remotely operated recovery equipment. The equipment has two large manipulators, which are individually capable of picking up in excess of 600 pounds. The arms have eight different motions and three of these motions may be deleted by actuating switches in the control console. We have built into this vehicle much more capability than you would put into a vehicle that you would use in an operational situation. We did this because we want to try out various concepts.

The 3-D viewing that I described in the last presentation has proven to be a real aid. We still have some problems with it, but it is amazingly good. I think the reason that this is better than previously 3-D systems is due to three things: (1) higher resolution cameras, (2) zoom lens, and (3) a common synch. We haven't had a good opportunity to try this equipment out, but we have driven the vehicle remotely, we find that the peripheral TV system is a big aid in driving this vehicle.

Our tests so far indicate that good remote control can be maintained at a distance of one mile. We can probably exceed that distance, but we haven't tried. We are using a radio link with low wattage because we have some problems in this area obtaining clearances, particularly with TV. We have four cameras in this system, and since we want good resolution, we have to utilize a fairly wide band. We are using a band width of something like 120 megacycles with these four cameras.

MR. JOHNSEN: How much problem would it be to change your system over to use a hardwire link?

MR. TOLLIVER: None at all. You would simply take out the radio link, and replace it with a hardwire link. As a matter of fact, we operated this equipment initially using a hardwire, while we were building up to the point of operating by radio.

QUESTION: Is this equipment to be used for the SNAP experiments?

MR. TOLLIVER: I really don't like the operational aspect of this program at this time, although it is necessary in order to provide the background requirements for our research efforts. Maybe I should explain, if we spend all of our time developing an operational plan, we never obtain the opportunity to complete our experimental efforts. However, operational uses are being considered. Mr. Beeston (SNPO-N) has queried us about using it for the TNT test in Nevada. Idaho Falls has requested this equipment for the SNAP TRAN test next year and official request is now in for the support of the SNAP IOA launch. Capt. David Jones is the project officer on this program and is in charge of our participation in these tests.

QUESTION: Who is the contractor on this project?

MR. TOLLIVER: FMC Corporation built the vehicle. They also made significant engineering contributions in addition to the preliminary design that we furnished them.

QUESTION: What are the plans for follow-on work?

MR. TOLLIVER: Follow-on plans include an extensive evaluation program. Mr. Kama from AMD at Wright-Patterson is one of the members of the team and will provide the human factors psychologists for the investigation; the AFWL will provide the engineering evaluation and the Air Training Command will provide the operators. We expect this evaluation program to go on for about 6 to 9 months.

QUESTION: What sort of a climb angle can it negotiate?

MR. TOLLIVER: Like a rock? If you were to come up against a rock about two feet high, it would not climb over it, but the vehicle is capable of climbing 60% grade and negotiating a 30% side slope.

QUESTION: Where is the center of gravity?

MR. TOLLIVER: The center of gravity is in the middle of the vehicle, assuming that the manipulators are stowed. Now this is not true when the manipulators are extended to 19 feet. We are in the process of adding a stabilizing bar, not because there is a serious problem, but we want it there to add to the stability of our vehicle.

QUESTION: Are the actuators hydraulic?

MR. TOLLIVER: No, everything is mechanical-electrical.

QUESTION: What is going to happen to the TV cameras when you get them into a high radiation field?

MR. TOLLIVER: The TV cameras do not have non-browning lenses because of LASL experience in the MAD Building. LASL has stated that lens browning didn't appear to be a significant problem. When their lenses started to brown, they were removed from the radioactive area and after they had been out of the area for some time, the lenses seem to clear up.

DISCUSSION OF PROPOSED TELECHIRICS RESEARCH LABORATORY

by Dr. John Clark
Battelle Memorial Institute

By way of introduction, what I have to say is all in the future tense. As some of you will remember from the previous seminar, we have spent quite some time at Battelle looking at the remote handling technology in an abstract and analytical way. We have made some progress since the last time in carrying out the intended purpose of this analysis which was to provide a framework in which useful research could be done. The whole object is to expedite or clarify the development of the art. One useful aid in this is to have an analytical framework that lets you separate things into small enough pieces so that you can turn them over to somebody in a laboratory. When the work is done you can then put the results into the framework to produce useful information.

It has been said many times that this art of remote control or remote handling, building robots, etc., may well be a brand new branch of engineering and a brand new branch of technology. It is tempting to compare it with cybernetics and sometimes is thought as a branch of cybernetics. My own preference is to say that it is comparable in the sense that remote handling is as promising today as cybernetics was when Norbert Wiener proposed the concept many years ago. The two are parallel. Cybernetics, to a remote handling person, is one of the many tools that he uses, but just one of many.

Our interests today are concerned with remote operations as such, independent of the environment. We are interested in how to do a job in a place where you can't use your own two hands. This problem is independent of the environment, whether it be nuclear, underwater, high temperatures, or outer space. We do not underestimate the importance of environments but these problems are being studied elsewhere.

The analyses and the studies today have been done at Battelle as a part of our internally funded research program. The Battelle management believes that this whole art will become important someday and the results of our work will be of value to the people who, manufacture artificial limbs, or TV viewing systems, manipulator "arms", and similar equipment and to the users of this equipment, whether they be Government agencies or commercial companies who plan to work in hostile environments. So this is the motivation and I would like to discuss the Battelle plan as far as it has gone.

There are, as you all know, numerous ways to command mechanical systems, and numerous ways to see various operations. These techniques have been used by people who have worked in remote control, and as one would expect, some work well, some work not so well. But you find that the operators have strong opinions about the goodness and the badness of certain systems. We propose to avoid reliance upon opinions by generating quantitative measures by which one can tell which system to use in which case. We are attempting to develop a logical quantitative way to measure these things.

The analysis of these problems, the determination of a plan of attack on them is all leading up to the definition of a telechiric laboratory. The laboratory is designed as a place in which to do these particular studies. This is a relatively short term and modest step toward a complete facility in which ultimately all aspects of remote handling or telechiric research can be investigated as well as environmental studies. Mr. Whipp later on in the day will present a discussion which in a sense will be the opposite point of view. He will be looking on a long term basis at what would be desirable to have in the not too distant future. His concept envisages a facility that can be used for a broad study of the many facets of remote control and for environmental investigations. Our concept is for a Telechirics Research Laboratory (TCRL) in which basic experiments in remote operating techniques and methods will be performed. (The remainder of this presentation was accompanied by numerous slides and was not available for inclusion in these proceedings.)

REPORT ON ARGONNE NATIONAL LABORATORY'S ACTIVITIES

by Ray Goertz
Argonne National Laboratory

I want to tell you about some of the work we are carrying out at Argonne and some of the parameters which we believe are important in general-purpose manipulator systems.

We have found it difficult to explain manipulator systems to people by the use of words, diagrams, and pictures. We even find that it is difficult to communicate all the important parameters even when people have had a tour and tried out some of the systems. If you have had some experience, preferably over an hour, in using mechanical master-slave manipulators, it will probably be easier for you to understand some of the ideas I hope to convey here.

I want to refer you to Figure 1, which is just a block in space. This block, like all other solid objects in space, has six degrees of freedom when it is not restricted. No more and no less. The manipulator working arm or slave arm must move this hypothetical object in any one or a combination of these motions. In addition, it must be able to grasp the object.

Grasping of the object needs to be fairly well done for most operations and all the grasping "hands" or tongs of manipulators that exist now fall far short of what is really needed. At present, the parallel jaw system of tongs is the most commonly used. You heard yesterday that one of the terminal devices that amputees use is better for some types of operations.

The human hand, being equipped with numerous fingers and a thumb, has the ability to grasp objects much more readily and faster than any grasping device developed so far for manipulators. Whether or not it will be practical and economical to develop manipulator "hands" with approximately the same number of motions that the human hand has, is a good question. At the present time, it seems that other approaches would be preferable at least for a number of years. One method that we think has merit is to develop "hands" or tongs which have three or four fingers. These fingers would be capable of having their shape changed to accommodate grasping different sizes and shapes of objects. The changing of the shape of the fingers would be an indexing operation which the operator would perform just prior to closing the fingers on the object. This method, we believe, would provide considerable improvement in grasping capabilities without the need for numerous additional servos. Eventually, we believe, it will be desirable to slave several finger movements to the single movements of the operator with force-reflecting servos.

Another important parameter is the friction in a manipulator. The Coulomb friction in each motion of the master-slave manipulator must be kept quite low. Each manipulator has a little bit different friction in each of its seven or more motions. Most of the motions of the Mechanical Master-Slave Manipulator Model 8 have a Coulomb friction of less than 1% of the maximum load capacity of the manipulator. The Z motion, however, has a friction of about 2% of the maximum load capacity when it is in very good working condition. This friction increases to 3% or possibly 4% as the manipulator is used and the tracks accumulate dirt and oxide. From experiences on this manipulator and others, we believe that a master-slave manipulator should have a Coulomb friction of less than 1% for all motions. A small amount of viscous friction, however, doesn't seem to interfere with the operation.

There are numerous other characteristics of manipulator systems that are important. Whenever manipulations have to be done, it is necessary to bring the working arm into contact with the object before the operation can be performed. Thus, a collision is involved at the beginning of each operation. If the manipulator system is designed and used to perform work at a reasonably good rate of speed, the collision forces are important in the design of the manipulator arms. Therefore, master-slave manipulators need to have the inertia as low as possible. This is not necessarily true for unilateral electric manipulators because they move slowly.

The Electric Master-Slave Manipulator Model 3 has a friction in the X, Y, and Z motions of between 1 and 2%. The cutoff frequency response is approximately four cycles per second (this varies from motion to motion and is also a function of the gain setting). For purposes of discussion, we could call the Mechanical Master-Slave Manipulator Model 8 and the Electric Master-Slave Manipulator Model 3 as having intermediate to low fidelity.

We choose this designation of fidelity because we believe that a much higher frequency range fed back to the operator would be useful and, also, a much higher range of static force reflection. The higher frequency and static information would help the operator by giving him additional information as to forces being applied, small collisions being made, or vibrations being set up as a tool passed over an object or some part of it. It would be of only secondary importance as far as controlling damaging forces to the object.

The present master-slave manipulators can be operated at a reasonably good speed. For ordinary hot laboratory types of operations, the speed of performing work with the master-slave manipulator window system is about 10% the speed of doing the same type of work directly with the hands. The rate of performing work with the unilateral electric types of manipulators is 10 to 100 times slower than this. That is, they can be operated to do work at about 0.1%

to 1% the speed of the human hands for hot laboratory type of work. The reason that the master-slave manipulator is as good as it is, we believe, is primarily due to the natural movements of the handle tongs, force feedback to give "feel", and the high reversibility of master to slave and slave to master. We have found that a manipulator operator having several months of experience can concentrate the greater portion of his mental attention on the work that is to be done rather than on how to control the manipulator.

A general-purpose manipulator must be able to do positive and negative work. For instance, if an object is lifted by the manipulator, it does positive work, and if it is lowered, the object does work on the manipulator. In the case of the mechanical master-slave manipulators, all of this work is provided by the operator. In addition, he must supply work to overcome friction and inertia. In the case of electric master-slave manipulators, the operator also must supply either all of the work or a fraction of it. If the force and motion ratios of master to slave are 1:1, he must supply all of the work done on the object plus friction and inertia. If the manipulator is set to have a force boost of 3:1, then he does only $1/3$ this amount of work. Due to the bilateral action and the fact that the operator does positive and negative work when operating a master-slave manipulator, it is possible for these manipulators to be used to steady a load held in a crane. This can be done almost as readily with the slave arms of the manipulators as it is ordinarily done directly with the hands. The electric manipulator is quite good in this respect and can be used in this manner to help handle heavy loads. Getting a good grasp of the object is sometimes a little difficult.

At present, we are working on an electric master-slave manipulator which has a load capacity of 50 pounds in each arm. We call it the Mark 4. You will recall that Les White referred to a manipulator system having a ball with two slave arms attached to it. The general configuration of the slave arms of the Mark 4 is similar to the sketch shown by Les.

Electric master-slave manipulators have numerous advantages over mechanical master-slave manipulators. The most significant of these is that the slave arms can cover a larger working volume. Other advantages are that they can approach work from different directions and different angles, have force boost, and so on. The Mark 4 Electric Master-Slave Manipulator will have better reach characteristics than the Model 3. This is, in part, due to the incorporation of an additional mechanical linkage between the mounting and the slave arms. Two slave arms will be mounted on a single support which will include indexing drives to orient the pair of arms in many different directions.

The Mark 4 should have higher dependability than the Model 3. This is being designed into both the electrical system and the mechanical system. The servo amplifiers utilize transistors instead of

vacuum tubes. The mechanical is being designed in an attempt to avoid some of the problem areas that had occurred in the Model 3. Experience with the Model 3 indicates that it has a reliability of about 1/2 that of the Mechanical Master-Slave Manipulator Model 8. We believe there is a good chance of making the reliability of the slave arms of the Mark 4 equal to or better than the reliability of the Model 8's. The slave arms will be designed to have a load capacity of 50 pounds in any direction with a reasonable safety margin and the servos will be equipped with power limiters. These limiters will tend to protect the mechanical components of the slave arm. No such protection exists in the mechanical master-slave manipulators.

The slave servo drive units use four low-inertia servo motors. The effective combined inertia of these four motors reflected in the X, Y, and Z motions at the wrist joint is about 4.5 pounds. In addition to this inertia, there will be the inertia of the arms, wrist joints, handles, and so forth.

In considering the capabilities of the manipulator systems, all important parameters of the entire system must be taken into consideration and must be developed to a suitable condition. The conditions will be a function of the human-factors characteristics of the operator, the man-machine combination of how the manipulator responds to the operator's commands, and the feedback information that the system provides to the operator. This feedback information is extremely important. The feedback information of the human being working directly with his hands consists principally of tactile information, proprioceptive force information, neurological position information, vision, and hearing. In the case of master-slave manipulator systems, all of these types of information are fed back to some degree except tactile feel. When we use the term manipulator system, we include the viewing. It might be of interest to you to know that large, dense shielding windows were developed almost exclusively for master-slave manipulators to be included as part of the system. They were not developed for other types of viewing although they are used for viewing with unilateral electric manipulators, general viewing, and so forth. The viewing provided by windows is quite good providing the work is at a reasonably close distance. For large facilities, windows do not provide adequate viewing for master-slave manipulator operators. First of all, the distance may be great and, therefore, the apparent size of objects is greatly reduced. Another limitation is that as the distance gets great in comparison with the width of the window, the window provides essentially only one point of view.

In the near future, systems must be developed to provide an adequate viewing system for electric master-slave manipulators for use in large facilities. One method which seems to have promise is to utilize television in a special way. The ordinary television having pan, tilt, zoom, and so forth, is completely inadequate for

providing adequate viewing for manipulator operators. We believe, however, that if the camera and monitor are slaved to properly follow the movements of the operator's head, that a greatly improved system would result. All six motions may be needed. However, quite possibly five will be sufficient. At the present time, we are designing such a master-slave TV viewing system utilizing a commercial 800-line closed-circuit television system. Preliminary experiments on restricting the operator's view to a moderately small angle, say, 10° to 20° solid angle, indicates that work can be done at a reasonable rate with this restriction. In order for the present television systems to give adequate detailed view, a reasonably narrow angle will be necessary.

COMMENT: One of the things that I wish to comment on is your discussion of a 50 pound capacity manipulator. I think we need manipulators of different sizes. One of the advantages of a master-slave is that you can do little jobs that you don't plan ahead of time. For instance, assume an operation where a component is plugged into a reactor. The operator gets the tool for plugging it in and then all of a sudden he finds that he doesn't have the electric cord connected. If you have a master-slave, you know that with action of the hands and with force reflection, you can make the connection. The one thing that I don't think that anybody can overemphasize is that operations cannot be perfectly planned. It is because of the unforeseen problems that the master-slave manipulator is particularly valuable.

MR. GOERTZ: We fully agree that there is need for a variety of sizes. Another characteristic to be taken into consideration, i.e., that two master-slave manipulators can be applied to one load. They can thus work as a team, and since each has 50 pounds capacity, the total capacity is 100 pounds. The next model using this new motor is to have a total capacity of 200 pounds, 100 pounds for each arm.

QUESTION: What did you mean by 100:1 friction force?

MR. GOERTZ: Coulomb friction should be low to give good "feel".

QUESTION: Coulomb friction where?

MR. GOERTZ: In any motion or in any direction of combination of motions with respect to ground.

QUESTION: Between the object and specific terminal motion?

MR. GOERTZ: Oh no, I'm sorry. In the manipulator, when it is unloaded, it still has friction with respect to ground.

QUESTION: Then I presume that when you said that certain of this information that you get is for information purposes and not for control. It is hard for me to conceive that it would not be for motor control eventually, otherwise it wouldn't be as good. I presume that what you mean is a kind of second level of motor control. A strategy decision making kind of thing.

MR. GOERTZ: Yes, it is primarily information of "feel" needed to make a determination as to what the next human motor control should be.

QUESTION: What is the feedback ratio from master to slave of the manipulator?

MR. GOERTZ: The Master-Slave Manipulator Model 3 has a master to slave force ratio of 1:1 or 1:3 for all of the seven motions. In addition, the squeeze motion has an additional force ratio of 1:9. The operators usually prefer to set the manipulator to have a force boost of 3:1.

QUESTION: Is this on the 50 pound manipulator?

MR. GOERTZ: Yes.

QUESTION: On some of the larger systems that you have shown, how far back from the hand do you think it is desirable to have a full force reflection?

MR. GOERTZ: I think there is no definite answer. As we all know, force reflection and reversibility is needed for the work being done in the "hands" or tongs, but it is also sometimes needed to stop the movement of the manipulator when some other part of the arm collides with an object. In the mechanical master-slave manipulators and in the present electric master-slave manipulators, the drives are located beyond the master-slave movements of the arms. For higher fidelity manipulators in the future, it may be necessary to restrict the force feedback to movements near the "hands" or tongs. If and when this is done, auxiliary force feedback or stop switches may have to be added. We have gotten one warning on this from experience on the Electric Master-Slave Manipulator Model 3. The elbow of this manipulator has force feedback in one direction of its motion, but not in the other two. We found it necessary to put on a switch to provide an alarm when the elbow bumped something.

DR. RESWICK: I want to make a comment about John Clark's presentation. The example of the automobile engine makes me mad. Not at John or his talk, but about the injustice of it. I think it is important that our thinking not start with a set of tasks specified by a spark plug hidden behind an air conditioning compressor. I think that in the case of the automobile it is all right because there are people who are willing to skin their knuckles at a low rate of pay to keep things going, but, in the case of a rocket, it seems to me that the recovery of the whole engine may depend upon somebody beating on the heads of the original designers to get them to pay a lot of attention to this problem of remote manipulation. Miracles are not going to be performed with the design of the new manipulators. They are limited by the state-of-the-art as predicted, just as the engines are limited. I think that anybody who sits at a design desk should say, "Now look, think of this from the old world point of view. Make these engines so they can be serviced by presently predicted equipment."

MR. JOHNSEN: I believe that in the nuclear rocket program there is more money going into the design of rocket engines so they can be reassembled remotely than there is going into the design of remote equipment to do this.

MR. GOERTZ: I would like to comment on this because it is a very important point. I agree to some extent with both Dr. Reswick and Dr. Clark, but also there is need to develop manipulator systems having capabilities to the extent that the particular spark plug mentioned could indeed be removed remotely. We believe that such systems can be developed and that they would be extremely useful in the rocket program. Although the devices may cost a considerable amount to develop and build, we believe that savings in designing and building the rocket system would more than offset the cost of developing and building these advanced manipulator systems. Of course, some consideration of ease of remote repair must be included in the design of nuclear rocket hardware.

QUESTION: Is it possible to have a variable ratio of feedback for say 1,000 pounds? Could a real good feedback with a 1:1 ratio be obtained for light loads and a variably different ratio for a heavy load?

MR. GOERTZ: Yes, it is possible to provide a variable ratio of force feedback, but I doubt if this is desirable. First of all, a manipulator that has a 1,000 pound load capacity would necessarily have to have large and heavy slave arms. Because of this, it would likely not be a physically desirable device for performing light work. A better arrangement probably would be to provide different manipulators having load ranges that might normally be within a factor of 100. Thus, a 1,000 pound maximum load capacity manipulator could be used on loads from 10 to 1,000 pounds. For loads less than 10 pounds, or maybe a little higher, it seems to me that it would be desirable to provide smaller slave arms. I further believe that there should be a selection of master to slave force ratios and that once the selection has been set, that it should remain a constant ratio until it is reset to a new ratio. I personally believe this would be better than having a variable force ratio.

METHODS FOR SPINNING OFF NASA MISSION ORIENTED RESEARCH

TO THE LIFE SCIENCES

by Dr. Clinton Hartwig
National Aeronautics & Space Administration

I am pleased to have this opportunity this morning to briefly outline to you a system that has been developed by the NASA Technology Utilization Division to adapt its space reoriented findings to the needs of other technologies. I am a life scientist in this division and participating in the program--a physiologist by training--so when I talk about things in particular, it will be in terms of life sciences. The office has responsibility in the Physical Sciences, as well as the Life Sciences, so they are also interested in engineering, materials, techniques, and electronics.

The Space Act of 1958 states that the activities in space should be devoted to peaceful purposes for the benefit of all mankind, and the Act requires that the NASA Administrator provide for the widest practical and appropriate dissemination of information concerning its activities and the results thereof. So to help carry out this directive, NASA established the Technology Utilization Program. Its broad objective is to be an important tool for national economic progress by speeding general use of scientific knowledge created in the space effort. This is in effect a drive to apply mission oriented science and technology to the needs in other technologies. The Division is now about three years old and has organized a rather complex system for identifying the new and novel ideas that are coming out of the space program and disseminating it nationwide to interested people and organizations. Now the technology utilization organization is comprised of 12 technology utilization offices in the various research and space flight centers as well as several independent research institutes and university dissemination centers across the country.

An innovation which proceeds through the TU system goes through four basic steps, and these steps are: (1) identification, (2) evaluation of the idea, (3) its adaptation to some other technology, and (4) a wide dissemination to all potential users of this information. Identification is generally achieved by TU officers that are at the various space research centers. There is a TU officer in the SNPO program; his name is Mr. Samuel Snyder, and he will work closely with Mr. Edwin Johnsen in looking throughout the whole program to discover innovations in the program which may have application elsewhere. When an innovation appears to have an application in some other technology, the idea is written up in the form of a document which we call the Flash Sheet. Now the Flash Sheet can be anywhere from 1 to 20 pages. It is basically a document describing the idea,

the name of the innovation, and the name of the innovator. The name of the innovator carries through all the publications so that we can always look back and find out who designed the particular piece of equipment in case additional information is needed.

Another paragraph on the Flash Sheet lists suggested applications. It is very possible that a device or an idea that has been designed for a specific space mission may well have application in other fields. The fellow who designed the device works with the TU officer in the field center to think of other applications for the device, and they list the various applications it might have. To cite a particular instance, a Gemini bio-instrumentation simulator was devised to simulate the various kinds of electric potentials that can be obtained physiologically. Suggested applications would be a system to check out electric physiological measurement and recording systems in hospitals and clinics. So, these are possible applications of a device specific in its mission orientation.

The Flash Sheet is sent to Washington Headquarters and is the vehicle for the idea that came out of the center. Once it gets into the system, it is sent out to various institutes for evaluation, which is the evaluation step. The evaluation is the assessment or the worth of the innovation--does it advance the state-of-the-art; does it have application in some other field? The evaluation is accomplished by five research institutes--Arthur D. Little, Battelle Memorial Institute, Illinois Institute of Technology, Southwest Research Institute and the Stanford Research Institute. There, knowledgeable people grade the application in terms of its innovation in other technologies. If it is deemed to be a worthwhile idea or an instrument that should be given wide dissemination, it is written up in the form of a NASA Tech Brief. This is a one-sheet information dissemination vehicle.

An example of adaptation of space hardware to a need in medicine is a miniature bio-telemetry unit. This is a device that was designed to satisfy one of the requirements in the Apollo program. The Apollo astronaut cannot have any hardwire connection leading from him to the read-out system. He has to be absolutely unencumbered by this sort of arrangement. To achieve this, NASA found it necessary to develop a bio-telemetry unit which can telemeter the electro-cardiogram for a period of two days to a distance of 100 feet. The EKG transmitter which is about as big as a stack of four nickles, is simply pasted on the sternum. Since there is less muscle noise at that point, the person can walk around in any way that he wishes, and the signal is picked up and read out in whatever is the most convenient form. The device has been described in a Tech Brief and will be given wide dissemination to anyone who might be interested in using this kind of device. It has obvious application to hospitals, clinics, intensive patient care and so on.

Now, I have discussed two of the four steps--identification and evaluation. Adaptation is the next step that I would like to briefly describe. Many of the things that are coming out of the space program are specifically space mission oriented, which makes it very difficult to look at the object to see where it may have some application elsewhere. So, there has to be some re-engineering done on the device, and sometimes this re-engineering will be done in the center that developed the device. Usually the designer has an idea where it may be used in other applications, and within a very brief time he can do this re-engineering. This actually assists in this transfer process to get a device which will be eventually a commercial item. But more often the adaptation takes place in the organization who will make the device for their own use or make it as a commercial product.

The last step is the dissemination of information and this is done through news media, mailing lists, direct contact, and university programs such as the Indiana University ARAC Program. ARAC is the Aerospace Research Application Center. Now ARAC runs a need profile on surrounding industrial organizations and then ARAC collects all of the NASA information, such as the Tech Briefs and the publications that come out of the TU program, as well as all public reports that NASA generates, and then feeds this information to the various industrial groups wanting this kind of information. A Tech Brief is only one piece of paper, but it indicates several things, particularly how additional information can be obtained. In the particular instance of the telemetering device, a request to the TU officer in Ames Field, will get you the complete design schematics and some data on the device, so that you could either make it or have it made for you. Very often, if there is a requirement, the person wanting further information can talk with the innovator. These Flash Sheets are always about six months behind, just like any other publication. Very often the innovator has some new ideas and new thoughts on this particular device in the meantime, and very often you can get some new thinking in terms of the instrument that he has designed.

A number of contributions have been made in the Life Sciences and I would like to briefly describe one, because it will take you through the various steps involved in making a device available to industry, and secondly, I think this is very important because it demonstrates that a device with a narrow physical science application can, with a little ingenuity, be modified for use in the Life Sciences. When one stops to think of it, the input into the Life Sciences Program of Technology Utilization can come from many fields beyond that of just the Life Sciences itself.

In answer to a space requirement, Vernon Regallo, at the Ames Research Laboratory in Mountain View, California, designed an instrument to measure the impact of micrometeoroids in outer space. It is simply a large shield that is attached to a transducer. The transducer is a piezoelectric crystal. As you know, when the crystal is twisted, it generates a little current of electricity and then by appropriate

amplification you get the read-out in whatever form you want. One day, during lunch, Vernon happened to hear a conversation between a biologist and another engineer. The biologist was lamenting the fact that he couldn't measure the heartbeat of a chick embryo without breaking a little hole in the shell and sticking electrodes into the embryo itself or by the use of a window in which you visually observe the heartbeat. Vernon Regallo made a few quick calculations and said, "I've got a device that can do just that. It can measure those small changes in momentum." So Vernon had then identified a non-aerospace application for his instrument. What he did was to take the big shield off of his test instrument and make a little egg basket and the biologist brought over a Bobwhite egg. A Bobwhite egg is one-sixth the size of an ordinary hen's egg, and to get an idea of the small minute size involved, the heart within that small 6-day embryo is about the size of an end of a pencil. But Vernon Regallo's instrument was very sensitive and when placed in this little basket within an incubator, he measured the small changes in momentum and was able to read it right off on the oscilloscope.

This is a particular instance where the adaptation took place right within the center. This was written up in a form of a Flash Sheet and sent to our office and it was right at the time when we were just getting over the Thalidomide scare and I had remembered reading that the Food and Drug Administration was actively seeking methods to detect the effects of chemicals on developing embryos. We contacted the Food and Drug Administration and since they knew what the problems were in monitoring chick embryos they were impressed. After we described the equipment, we arranged for one of their investigators, Dr. Jacqueline Verrett, to visit Ames three days to evaluate the device. She went out for three days and stayed two weeks. She took a whole kit of chemicals along, various insecticides, adrenalin, digitalis, etc., and found that the device indeed was quite an advancement in the state-of-the-art in monitoring chick embryos. All of this created a certain amount of interest, and Straindyne, an electronics company in California, got the necessary information from the TU office and they are now marketing the device. Where Vernon Regallo's original test device took about two tables for the electronic gear including an oscilloscope, various amplifiers, Straindyne boiled down all the electronic equipment so it could be placed in a small console. The total set-up is now an incubator box, a read-out system, and a small box of electronic equipment.

This briefly gives you an idea of how NASA will look at technological developments and try to adapt them to the use of other technologies. I think that the scientific community will benefit from this program and will adapt much of the remote handling equipment in ways that will fulfill other needs of mankind.

QUESTION: We have discussed the possibility of harnessing bio-electrical impulses as a method for controlling remote operated equipment. Could a momentum-measuring device be used to detect the very small amplitudes and forces involved in muscle flexion so that the muscle responses, when properly measured, could then be used to control a remote device?

DR. HARTWIG: John Lyman of UCLA has a system where he puts strain gauges on the surface of the skin and he has been able to successfully predict positions of the end of the fingers with these strain gauges. This would be one way to take advantage of the muscle responses that you are talking about.

QUESTION: This essentially is already being done?

DR. HARTWIG: On an experimental basis. It still has the same problems that you don't have with straightforward mechanical systems.

MR. JOHNSEN: What are the incentives to start the originator to get a TU report going? Are there any incentives?

DR. HARTWIG: Well, there is the incentive awards program.

MR. JOHNSEN: That is a program within the Government. What about outside of the Government? What are the incentives to people outside of the Government, but who are working on a contract for the Government? Assuming someone has done something along the lines which you have reported, are there any incentives there other than intellectual honesty which will motivate the designer to make the necessary steps to get this information in the TU system?

DR. HARTWIG: If it were a commercial organization, there is the incentive of a commercial product. You can get a patent waiver of title to an invention. Under the Space Act, the NASA takes initial title to all of the patentable information, but then they just turn around and give the information away. In fact, some companies under the new technology clause will take patent rights right from the beginning even before they begin their research. So NASA strives in every way to provide this information, and to provide patent rights that the organization would like to obtain.

QUESTION: How are companies selected to manufacture and market new products?

DR. HARTWIG: Well, when a device is known, its description is given a wide dissemination. The companies that are interested in marketing the device write to NASA and are given licenses. It is generally Government free, but open to commercial utilization.

QUESTION: Now the AEC office has different policies regarding disclosure of Government-sponsored work, AEC-sponsored work. Is there a similar program in the AEC?

MR. JOHNSEN: As you know, SNPO is a joint AEC/NASA office. We work with a Technology Utilization office within the AEC, but the AEC representative was not able to be here today. However, I think the AEC policy is similar to the NASA policy, although I am not absolutely sure.

QUESTION: Who is the AEC representative?

ANSWER: Dr. Donnelly.

QUESTION: How do I get these Flash Sheets? I've never seen them.

DR. HARTWIG: You can get on a mailing list simply by writing a letter to the Technology Utilization Office at NASA Headquarters in Washington. They will send you all of the Tech Briefs that come out of the program.

MR. JOHNSEN: I think the same things apply to the AEC. You just send a letter to Dr. Donnelly. I will be glad to assist any of the people here in getting this information.

DR. HARTWIG: Each device or technique has its own peculiar patent situation. This is always indicated on a NASA Tech Brief. For instance, the Tech Brief on the telemetering device indicates the Patent Status as; "NASA encourages commercial use of this innovation. No patent action is contemplated." So, it is just up for grabs.

QUESTION: I have a question relating to the one asked about when the patent release was given. Is the patent given to me, and then to another company, and then to another one, all on an equal basis or do I get an exclusive patent utilization right?

DR. HARTWIG: There are both non-exclusive and exclusive licenses available under the NASA Patent Licensing Regulations.

QUESTION: Who determines who is going to get the patent if more than one person is interested?

DR. HARTWIG: If an organization develops a device, they are given the right to take patent action on this particular device. On the other hand, if a device is developed in some other organization and then made available to industry, each device will have its own peculiar patent restrictions and this you find simply by writing a letter to the Patent Council at NASA and finding exactly what the situation is.

QUESTION: Are patent rights on a first-come, first-serve basis?

DR. HARTWIG: The first one on the market is the one likely to stay alive longer than the rest of them.

POSSIBLE REMOTE MAINTENANCE AND REPAIRS ON REACTORS AT NRDS

BY Charles Wofford
Los Alamos Scientific Laboratory

19:29740

Detailed disassembly operations using standard and special remote handling fixtures and manipulators are performed almost routinely on radioactive KIWI reactors at the R-MAD Building at NRDS. Disassembly operations on the past two KIWI reactor tests, the B4D-202 and the B4E-301 conducted in May and August of this year were carried out very successfully. We have had, however, a total of nine hot reactors starting in 1959 to disassemble to keep us in practice. These past two disassemblies utilized some newly designed remote handling equipment to speed up the disassembly and to aid in post mortem examinations of the fuel elements and other components. Some of this equipment you have probably seen on your tour, for example, the core disassembly complex in the upper disassembly bay.

We do anticipate new disassembly problems with each reactor, however, and one of these would be an aborted reactor test.

Even though a constant effort to improve the reactor test car and reactor hardware continues, it is probable that a malfunction or failure will sometime abort a reactor test. The present reactor/test car design, the reactor test philosophy, and the existing remote handling equipment at NRDS do not permit remote maintenance, repairs or replacement of components on our reactors. The present philosophy for example, in the event of a hydrogen leak, or reactor/test car component failure during a reactor test, is to modify the Test Experimental Plan.

It is the purpose of this report to discuss some of these past occurrences, to present possible methods of repair or replacement of failed components remotely, and to, also, present malfunctions or failures that are not presently considered repairable remotely. Such remote operations and replacements of components on reactors have never been performed at the R-MAD Building.

Consider, for example, that a hydrogen leak develops in some portion of the test car piping, or in the reactor nozzle, or in some other reactor or test car component during the initial stages of a test. The Test Experimental Plan would have to be modified by perhaps decreasing the reactor run time, reducing its power level, or even halting the test. Any restarts would be unlikely. Obviously, it would be very expensive to alter or discard this several million dollar test. Hopefully, these reactor/test car malfunctions could be repaired or components replaced remotely. This would require a stockpile of spare components. At the present time we have few spare components on hand. A nozzle, for example, costs several hundred thousands of dollars and obviously, this approach would be expensive.

Consequently, much study must be given to a reactor remote maintenance program. What components would be deemed repairable or replaceable remotely? How much new reactor design would be necessary for remote maintenance operations? Would we sacrifice the data lost on an aborted test for the time required for maintenance, the expense for spare components, etc?

If such a program was set forth such maintenance could be performed at the test cell on the unshielded test cell pad, or in the shielded lower disassembly bay of the R-MAD Building. No remote handling equipment is available, however, at the test cell pad.

Pinpointing the location of a malfunction on the reactor/test car is a big problem due to the limited capabilities in viewing the reactor close-up. Run time, power level, and time after reactor shutdown among aborted tests will, of course, vary the amount of radioactivity present. Presently, there are two TV cameras at Test Cell "C" mounted on permanent concrete supports to monitor the reactor/test car from about 200 feet. Pan and tilt controls and zoom lens are, of course, remotely operated from the Control Point (CP). Additional tripod mounted TV cameras are sometimes brought in to this radius for additional coverage. Present mirror system photographic coverage at Test Cell "C" is limited to two photo bunkers located some 700 and 830 feet from the reactor/test car. These TV and photographic cameras have limited locations which are too distant for detailed close-up viewing, and lack the resolution needed to locate and examine a malfunction. High resolution radiation resistant TV cameras are not considered here because of the long one and one-half miles of control cable to the Control Point.

After the previous two tests a Questar telescope was set up for general overall observation a few hundred feet from the reactor/test car. However, personnel using the telescope were limited to a few minutes of exposure time and also only portions of the test car could be seen.

Due to these viewing limitations a shielded vehicle could be useful for a preliminary malfunction inspection.

Three shielded mobile manned vehicles are available at the test site: the Beetle, the Bat and the Masher. I am sure most of you are familiar with these vehicles. Very briefly, the Beetle is a modified track-laying vehicle equipped with two General Mills Model 550 manipulators. Its one man shielded cab can be rotated 360 degrees and hydraulically elevated 15 feet. The Masher is a two man modified version of a T-51 tank recovery vehicle equipped with a bulldozer blade and a 30 ton capacity crane. The Bat is a four wheeled, pneumatic-tired one man shielded tow tractor. It appears that all remote maintenance operations would best be performed in the lower disassembly bay rather than any attempt with these or other shielded vehicles on the test cell pad. These above vehicles, however, could be used separately

or together, for general close-in observation and malfunction inspection of the reactor/test car. These vehicles have never been used to view or to perform any remote operations on a KIWI reactor.

Such vehicles could accommodate portable radiation resistant TV cameras and periscope-cameras within a 100 foot radius of the reactor/test car. These operations would again depend on the level of radio-activity. A TV video tape recorder mounted inside the vehicle would provide monitoring inside the vehicle, or a reel for the TV camera control cables to existing terminal boxes would provide recorded monitoring.

This report will be divided into four categories of different modes of reactor/test car malfunctions.

Category I

This category consists of the repairs that can be made manually in the shielded test cell flow control room, known as the FCR, or remotely on the test pad in the partially shielded privy which supports the reactor on the test car. Some of the items located on the test car plug which could be repaired or replaced in the FCR are:

1. Rod control servo-valves and associated wiring.
2. Rod control pneumatic lock pin control valves and associated wiring.
3. All test car to test cell piping hookups which includes all the piping in the plug, consisting of the 8" propellant line, 4" water line in, 4" water line out, 6" purge line, 6" emergency purge line, and 3" vent chilldown line.

There appears to be few maintenance problems, regardless of run duration, and one of which have to be done remotely once the test car plug is mated into the test cell face and thus shielded from the reactor. Manual disconnection of a hot reactor/test car in the FCR for transportation of the test car to the R-MAD Building and reconnection in the FCR can be accomplished now.

Repairs of items manually or remotely in the privy at the test pad might be accomplished if the reactor test aborted in its early stages. In this case, disconnection of the test car from the test cell would be unnecessary. These items that might be repaired or replaced are:

1. Pressure probe transducers and associated piping and wiring.
2. Rod control actuator assemblies and associated piping and wiring. This wiring is single lead wire and it is unlikely that this wire would need replacing unless a serious accident occurred. In this event, it is

probable that serious damage would have also resulted to the other systems. The actuator assemblies could be replaced only after a short run duration because it seems impractical to redesign for a completely remote replacement capability. The replacement of an actuator assembly could be made using present hardware. A new actuator and an actuator lift fixture could be brought into the privy and placed under the faulty actuator. The electric connector and the hydraulic and penumatic lines would have to be disconnected. Six nuts from the 1/2-inch retaining bolts on the roof have to be removed. The actuator is then lowered and removed. The new actuator must be raised, engaged with the control rod shaft, rotated against the control rod zero stop. It is then resealed and the six nuts replaced. These operations would probably take less than one hour. Pressure checking methods of the actuator to the roof seal would have to be established since the entire reactor must be pressurized to properly check this seal.

3. Various cathode followers, relays, switches and other miscellaneous electrical and instrumentation equipment. Redesign in a modular type of construction would allow remote replacement. Present hardware such as relays are of plug-in type and can be replaced manually quite rapidly.

4. Replacement of wiring on the reactor/test car would be dependent on the extent of replacement necessary. It is quite possible that certain reassignment could be made in the privy from a damaged channel to a spare channel in a very short time. In any event, each case would require individual consideration for a possible fix.

To consider the manual repair approach mentioned above, one problem is how do we get personnel into the privy safely to perform this maintenance. The induced radioactivity in the privy will limit the working time. One method would be to construct a tunnel under the test cell pad to the bottom of the reactor/test car. With an entrance in the privy floor personnel would be able to enter the privy safely. Another method would be to extend the privy roof shielding containing steel bolts and water and perhaps increase its present 18" thickness such that a shielded manned vehicle could drive up and physically mate to the privy permitting a man to exit the vehicle and enter the privy safely. The privy doors which swing open manually now, could be redesigned and motorized to be opened remotely. The Bat with some modifications might be useful to transport workers and Rad-Safe personnel to minimize exposure.

Category II

This category consists of the reactor/test car maintenance that might be performed by remotely operated manipulators or by shielded vehicles with manipulators at the test cell pad. A special designed pedestal mounted model 2000 PAR manipulator has been recently loaned to us from the Lawrence Radiation Laboratory. It was designed for

Pluto reactor disassembly, but has never been used. We have not checked this manipulator out, but it is very possible that this manipulator could be utilized at the test pad, and in the lower and upper disassembly bays. It has a 21'-7" reach horizontally and vertically, and if placed in the center of the lower disassembly bay could touch both walls. These items include:

1. Replacement of certain sections of low pressure cooling water piping on the test car. Quick disconnects might be considered here. However, by eliminating valves and other connections, this maintenance might never be required.

2. Opening and closing the present privy doors aiding the items listed in Category I above, would decrease the radiation exposure of the personnel involved.

3. Replacement or plugging of holes for instrumentation such as pressure probes and temperature probes in the nozzle, propellant line or pressure vessel might be possible with the proper assembly tools that can be handled by manipulators. These items would have to be readily accessible. Some of these items have failed from heat and radiation on previous tests, but the test was not altered. It appears that the motions of the manipulators on the Beetle are too rough for such operations, but even though this has never been attempted, it might be possible, with some redesign.

4. Replacement of sections of tubing or fittings on pressure probe tubing. This appears to be a difficult operation, as visibility and with limited working space would reduce reliability.

Category III

This category consists of the repairs and component replacements that might be performed remotely in the lower disassembly bay of the R-MAD Building which has the most logical capabilities.

These items include:

1. Replacement of certain items of low pressure water piping that is beyond the capability of the Beetle or other shielded vehicles. It appears that this could be done at the present with existing equipment, with either the overhead manipulator (O-Man) or one or both of the sidewall manipulators in the lower disassembly bay. Again, quick disconnects might be considered here.

2. Replacement of pressure transducer probes beyond the capability of the Beetle. At the present time this can't be done. Redesign is needed for replacement. However, the probes can be pinched or removed with little effort, but this data is lost.

3. Replacement of temperature probes or plugging of their threaded holes in the nozzle, propellant line or pressure vessel again is beyond the capability of the Beetle. Redesign is also needed here, although this might be performed now.

4. Replacement of certain sections of propellant system piping could be possibly performed now with some modifications.

This view of the piping alignment to nozzle and pressure vessel shows the somewhat critical alignment required in connecting the 6" aluminum propellant riser to the reactor. It is connected .400 inches high as shown to reduce stresses in the spider connection. The pipe contracts down to the approximate center line shown. The lower portion of the riser is set back .0625 inches and contraction pulls the riser in to rest against a mechanical stop. The lower end of the riser connects with an 8" triple gimble (not shown). A valve known as OBV-86 in the riser system here has since been eliminated from the test car. There is a vertical adjustment (not shown) which is conducted during the riser assembly. It is not known whether a spare propellant riser pipe would be exact enough for these dimensions. The propellant riser is insulated with Fiberglas, wrapped with Fiberglas tape, painted for moisture proof, and covered with aluminum foil.

5. Minor repair work or replacement remotely of small electrical items in privy, such as solenoids and switches on the control actuators is unlikely due to working space and limited visibility. However, a special manipulator, perhaps the PAR mentioned in Item No. 1, equipped with a wrist mounted TV camera might be able to do minor repair work.

Item 5 might be performed, however, manually, in the privy with special movable shields in the disassembly bay. Perhaps a shielded cage, a lead box with a window containing a man could be moved with the crane in the lower disassembly bay to the test car and placed under a redesigned over-hanging privy roof. This method would allow a man to enter the privy safely. However, one has the problem of gamma scattering here and extensive shielding would probably be required on all sides of the privy. Again the amount of radioactivity is a big factor. For a very early aborted test this might be possible, however.

Category IV

This category consists of those items that cannot be repaired or replaced remotely with the Beetle, or the existing remote handling equipment in the R-MAD Building.

1. Replacement of the nozzle remotely requires the disconnection and reconnection of many items and cannot be done with the present design. Here again is a nozzle view showing the various propellant connections: the 6" diameter aluminum hydrogen propellant riser,

6" flex line connecting the propellant line to the nozzle spider, the static seal, the propellant core screen, the 2" flex line, the clamp ring (belly band) coolant, the 1" nozzle bolt coolant line, the Marman type clamp segments and bolts which fasten the connections. One end of the flex line is joined to the nozzle spider connection with a lead coated seal and eight 1/2-inch Allan head screws which are presently torqued from the spider side, making it impossible to get at remotely with an impact wrench. Reverse direction of these bolts and possibly larger diameter flanges will be required.

To remove the nozzle remotely, the nozzle instrumentation is presently cut with the O-Man grinders from the various pressure and temperature probes which are mounted into threaded bosses on the manifold, the spider and divergent skirt of the nozzle. This instrumentation joins other instrumentation on the instrumentation boom which connects into the privy terminal boards. Obviously, all nozzle instrumentation would be lost as this cannot presently be replaced or rejoined remotely on a new nozzle.

A thin stainless steel nozzle shroud (not shown on this slide) protects the nozzle tubes against a liquid air-hydrogen leak or other possible explosions which have occurred on previous tests. The top of the shroud is welded above the nozzle throat and the lower portion is bolted with a gasket to the aluminum pressure vessel. This enclosed volume is purged during a test. The nozzle bolts are located inside the shroud and cannot be seen or reached for removal. The shroud is presently removed with two cuts with a grinder. Elimination or redesign of the shroud would be required with probably clamps and seals for disassembly and reassembly to the nozzle and pressure vessel. This could be a big reassembly problem for remote handling. Along with the shroud removal, the 6" flex line must be disconnected. A rubber coated stainless steel seal seals this connection. A special fixture would be needed to replace this seal and to hold the line in position. The nozzle bolt coolant line is presently cut with the O-Man grinder, during disassembly operation.

The nozzle bolts, some ninety-six 9/16" x 3" long socket head cap screws are removed next with the side wall manipulator and impact wrench. A redesigned nozzle using segment clamps similar to the clamp ring around the pressure vessel might be developed to hold the nozzle to the pressure vessel. Two different materials, however, are involved here and sealing would be a problem. To replace the present screws would require possibly two or three guide pins spaced around the periphery bolt pattern on the nozzle to orientate the 0 = 0° position. These pins could be screwed in after three of the nozzle cap screws are removed during disassembly. These pins would guide the nozzle onto the pressure vessel. The large diameter lead coated Omega seal has to be replaced in the pressure vessel seal groove.

An impact wrench with a pre-set torque indicator could be used to replace these cap screws.

A special handling fixture would be required to replace this 3/8" wide Omega seal. A small tool to pry it up for removal would be required. Manipulator handling would obviously damage a new seal and a fixture must be capable of placing it in the pressure vessel seal groove.

After these reactor repairs are performed, tests would have to be conducted to assure, insofar as possible, that the repair was successful. This would include pressure checking, continuity checking or just a visual inspection.

In conclusion some remote maintenance is possible with certain modifications of reactor hardware using present remote handling equipment. Additional maintenance might be possible using exotic remote handling equipment and vehicles.

DISCUSSION OF PNEUMATICALLY ACTUATED MASTER SLAVE MANIPULATOR

by Kent Wilson
Autonetics

The first part of this discussion is about the manipulator arm that Autonetics is developing. It is a hydraulic arm that is 6 feet long, with a 50 pound capacity, and does have a rather unusual pistol grip control. For those of you who are interested in an underwater manipulator arm, there was a paper presented on this arm at the ASME meeting, September 23, 1964, in Los Angeles. This paper describes what we call the Beaver Concept. This particular concept is a submarine that would be built to handle mechanical arms and do other mechanical jobs under the ocean. You might call it an underwater bulldozer. The manipulator control may be of interest because the pistol grip control has been controversial as a control device for rate controlled manipulators.

The arm has a total of nine motions. It has an X-Y motion at the shoulder, a hinge elbow, and an X-Y motion at the ball wrist. It has a grip rotation, a grip extension, and a grip open-close. The control consists of two ball joints that simulate the shoulder and the wrist. The shoulder control is in the box. When the operator lifts up on the entire control handle, without doing anything with the little handle that he has hold of, but entirely moves his arm, then the entire shoulder motion can be moved in the desired direction--horizontally or vertically. The arm is extended by pushing on the handle. This operates a hydraulic device that coordinates the shoulder, the elbow and the wrist motions at the proper velocities so that you get a straight line extension motion from the shoulder and the wrist.

We also have two other coordinators--one of which is for shoulder left-right motions, and the other is for shoulder up-down motions. Because of these coordinators, anytime the operator has the grip oriented in a certain direction, he will be able to move the arm at the shoulder or elbow, but the hand will still stay pointed in its original direction.

All of these operations are done hydraulically, although I imagine they can be done electrically. They are quite easy to do hydraulically. The arm itself has turned out to be very reliable. I think I have been involved previously in the manufacture of 20 different arms, some having electro-mechanical actuators and some having hydraulic actuators and control. This particular arm is the most reliable of them all.

I would now like to talk about a servo manipulator that I am working on. There is more than a concept here. First of all, the manipulator is bi-lateral and Ray Goertz has already explained the need for having a force feedback system in a manipulator. After my previous experience with the handyman manipulator that was used on the ANP Program, which had three times more slave force than the master, I thought the best approach would be a 1:1 feedback.

I have some comments on electro-pneumatic systems that differ from the opinions of Mr. Goertz. As you can see, this servo manipulator arm can be fitted into a suitcase. In addition to the arm, there are also two pairs of actuators in a shoulder or cylindrical portion that takes the place of the body. One of the major advantages of pneumatic systems becomes evident when you stop to think about force feedback, the bi-lateral need. Whenever you have a gear train with a high speed low torque electric motor drive, there will be a substantial amount of friction. In order to get bi-lateral force reflection, you have to have a torque generated by the slave, and this comes from the difference in position between the master and the slave. Let us assume that we have an electric motor driving a jack screw or a worm drive and when the arm gets up to a desired position, it is stopped. In this case, there is no signal required to hold that self-locking mechanism there. To me, going through a gear train is not the way to operate manipulators. Also, if you do go this route, it is going to cost you money because of the high priced gears that are needed. The key to a good pneumatic manipulator is a pneumatic actuator that is low in cost, leak proof, and will not have a great amount of friction.

When I was with the ANP Project, I tried to use ordinary piston type actuators that have low friction but they turned out to have high leakage. Because of the large number of motions in a manipulator, it is possible to consume a large amount of power in leakage. The pneumatic actuators I am now using are merely pieces of braid that can be inflated. The braid when it is inflated (and there is a bladder inside) grows in diameter and as it grows in diameter it shortens in length. This gives you then a stable device because it is in tension. It is superior to a bellows, because inflated bellows are inherently unstable columns which tend to collapse.

In this manipulator each actuator for the seven motions is a pair of these braided tension devices known as McKibben muscles. It turns out that the prosthetics industry have been using these devices at working pressures of about 90 to 100 psi. This particular device in this manipulator is built for 500 psi. The advantages of using this system is that it does not use gears. There are some undesirable features with this particular actuator, as it is. In going to the metal braid, I found that I have a spring rate, but I have been able to cancel this out in my electrical circuits.

This manipulator has a 20 pound capacity, which is less than Mr. Goertz thinks is required. I personally don't feel that a capacity above 20 pounds is necessary. An operator has a tendency to get tired just using the equipment. It is a hard job to hold out a load of 20 pounds and most operators don't want much more than this. The capacity is, of course, greater when the arm is not horizontal, and can lift 50 pounds when near vertical.

At the time I set 500 psi as a working pressure limit, I was not using metal, since I thought I could use the nylon braid. Since going to metal, and looking now at the servo valves, there doesn't seem to be the previous limitation, so there probably could be a boost in working pressure. However, I don't think that I would want to make this first manipulator with a greater capacity than the 20 pounds and I wouldn't want to go any higher than the 500 psi.

The range of motions is the next thing I wish to discuss. This manipulator has very good coverage. It has a full shoulder motion--that is, about a 90° conical coverage. This motion is split up in a way that is analogous to the human arm of the operator. This would actually be what you call a neutral position (positioned at 45° from vertical with the demonstrator).

Down in the wrist, we have a total of about 67-1/2° travel each way in one direction and then in the up and down direction we have a total of 45°. Let me say some words about this wrist. This wrist is a demonstration of one of the primary reasons why the handyman manipulator wasn't very successful. It did not have this wrist motion. The operator found it was hard for him to pick up certain objects because of the lack of just this ability. Once you get to a certain location you still want to maintain orientation. With this manipulator, the operator has this ability regardless of the attitude of his arm.

By using two pair of actuators in the shoulder cylinder actually you can get three output motions out of it. We can then swing this upperarm up to 45° each way. So, you can get around an object this way, or this way, or this way. (Demonstrated) The elbow is again a pair of these actuators that fit through holes in here. (Demonstrated). You can see that these are larger holes than those down in the wrist. To get more than plus or minus 90° out of a modified crank device, we are rolling these pieces of braid around a diameter. These two holes in the upper arm are for the only deviation from the human arm--the wrist rotation. To get wrist rotation, a slightly different actuating system is used. This wrist axial rotation takes place through a pair of pulleys. There is a little cable system that wraps around the shaft which gives us a total 360° rotation, 180° each way.

I would like to say a couple more things. The natural frequency of the wrist is around 2 or 3 cycles per second, which is relatively slow. The shoulder has about one cycle per second, but this is not detrimental since it amounts to about 1/4 second delay. I think a man, in going slow, will be able to make normal motions and the thing will follow. When he gets into a tight enough spot to care, I think he can compensate for this. The arm is so lightweight that there is not much counterbalance needed. Also the fact that it is shaped so

the weight of the arm is hanging almost vertically provides an optimum center of gravity. The only thing that we would like to counter-balance would be the elbow. This could be done by putting in a bias pressure, a constant signal which would tend to hold up the elbow. All in all, we try to keep all of these servo loops as uncomplicated as possible. In conclusion, I want to emphasize that in my opinion, a force reflection of 1:1 is certainly easy to put in this kind of manipulator.

STUDY OF REMOTE HANDLING IN SPACE

by Charles Vivian
Lockheed Missiles and Space Company

In May, we presented a conceptual design of a manipulative system that would support a space station in orbital operation. This system was the result of a Lockheed sponsored study to determine the feasibility of such a system. As such, this system was designed to have broad capability for performance of a wide variety of missions. Since our presentation in May we have become contractually involved in two studies that would, at least partially, utilize such a system as SCHMOO. These studies are called SCALE and Orbital Cryogenic Tanker, which are part of a NASA sponsored study package called the Orbital Launch Operation package. For purposes of orientation, I would like to present a summary of this program.

In 1961-62 NASA established the Orbital Launch Operations Study, which was performed by Ling-Temco-Vought. The primary objective of this study was to develop a conceptual evaluation of an Orbital Launch Operation program to provide the earliest feasible lunar base build-up for reasonable costs and compatible with the early accomplishment of initial manned lunar mission. The advanced Orbital Launch Operations Study (Phase A) was established in 1963-64 to define a feasible approach to orbital launch operations and to identify in more detail specific problem areas. The recommended support concept evolved during the study involves the use of an Orbital Launch Support Facility (OLF), as an orbital base of operations, providing C/O, countdown, receiving, maintenance and repair services to the Orbital Launch Vehicle. This facility would be periodically supplied with logistics and personnel would be rotated on a regular schedule.

As I said, the OLO follow-on studies were begun this year. The basic objectives and the development of an operational concept for all orbital launch operations and to develop a program framework for achieving an initial overall capability. This study package will finalize the need for an orbital launch facility and will develop the design for such a facility. It will also develop systems requirements for the Orbital Support Equipment (OSE) and provide the design criteria for this support equipment. The major contributors to studies of the OLO study package are the Systems Checkout and Launch Equipment (SCALE), the orbiting Launch Facility (OLF), and the Orbital Cryogenic Tanker Studies.

Maybe I should describe the operational concept of an orbiting launch facility. The typical orbital launch vehicle (OLV) is a vehicle like the Saturn V, which would be launched from Cape Kennedy and put

into a rendezvous orbit. The OLV would rendezvous with the orbital launch facility and the orbital launch crew and OSE would be dispatched to the launch vehicle to prepare for orbital launch. This would include checkout of the vehicle, refueling, and upon determination of fault isolation and repair of that fault. Finally, after a complete satisfactory checkout and refurbishment, the vehicle would be launched.

The expected results out of the SCALE study are as follows:

- o Orbital checkout and countdown procedures
- o Design concepts of checkout and launch equipment
- o Orbital launch vehicle design criteria peculiar to orbital checkout
- o Ground support equipment requirements to support an orbital launch
- o Relationship between earth and orbital base checkout and countdown operations
- o Tools, spares, and maintenance requirements of the checkout and countdown equipment of the OLV
- o Checkout and countdown crew size
- o Total time required for checkout and countdown through orbital launch
- o Reliability factors influenced by checkout and maintenance capabilities
- o Research and testing engineering program for initial launch capability

Man in space will experience extreme changes from his normal earth environment such as zero or artificial gravity, vacuum, and confinement. It is obvious that changes directly affecting sustenance of the basic biological processes will have to be overcome from mere survival. The problem is not only survival, but also performance and the effects on performance of other environmental factors are less obvious and certainly less well defined. For example, confinement in space for long periods could result in a decrement in man's performance due to boredom. Involvement of man in performing meaningful tasks could reduce this possibility. The presence of an ever threatening environment could result in a performance decrement as man under stress often will concentrate on primary tasks and neglect secondary ones. Another factor affecting performance in confinement is that of the work-rest cycle. One which does not have a deleterious effect physiologically and psychologically on performance must be provided. Crew sizes and the necessity to operate twenty-four hours a day may not, however, allow conformance to a normal earth work-rest cycle. Performance of monitoring tasks for long periods would lead to a decrement in performance while crew structure may tend to relegate this type of activity only to a few crew members. Performance of extravehicular tasks may not allow completion in a normal work day period; therefore, a change from a normal cycle or variations in cycles may not only be desirable but necessary. Polaris submarine crews are one source of information for determining the effects of a four on-four off cycle in a closed environment. Additionally, studies,

such as have been conducted by Lockheed-Georgia on the effects of different work-rest cycles on confined crew performance, must be conducted to detail the effects of various cycles. All of these in turn interplay with the fact that men chosen for space work will be highly motivated and trained and can increase the reliability of space systems. The reason for his inclusion is to both improve reliability and perform tasks which cannot be performed by equipment alone.

Normal locomotion is not possible in zero gravity. While adaptation could allow for adequately controlled movement, a need does exist for aiding self-movement. Hand holds or a fixed rail could be used by the unencumbered astronaut. In addition, the elimination of all sharp surfaces and protection of controls would be required to prevent accidental injury or operation.

A need for controlling movement of equipment will also exist. Studies by Kama using air tables showed that for a fixed subject while changes in mass produced no pronounced effect, changes in distance and direction led to significant changes in performance. Response time increased and accuracy decreased with distance. For tractionless subjects performance also decreased in that:

1. Differences in mass produced significant differences in response time - larger masses resulting in longer response times.
2. Positioning was less accurate.

For small items, transport could be accomplished by direct attachments to the astronaut. A study by Mueller indicates the problems which would be experienced in attempting to control movement by the use of tetherlines; therefore, for larger items a positive control means would have to be provided - i.e., a pulley or electrically operated cart or conveyer belt with means for physical attachment of the item.

The application or receipt of any force will displace the astronaut from a stable position and Dzendolet indicates the limitations on the applications of force by a subject anchored by a single handhold. Consequently, it would be necessary to mechanically fix the astronaut in position prior to performing maintenance activities. The means used would have to close the force path through the restrained astronaut. Another approach in opposition to complete restraining would be the use of tools which close the force path in all degrees of freedom.

A similar problem would exist for controlling tools and parts during maintenance activities. Tethering or clipping to the worker or the maintenance area are possible solutions. Certainly the intensity of these problems will depend on the size, number and complexity of the tools and repair parts; and maintenance philosophy must reflect consideration of these problems.

In addition to these problems, the addition of the pressure suit would have the following adverse effects on man's activities:

1. A decrease in gross movement and functional arm reach capability.
2. An increase in the time required to perform a desired movement.
3. A decrease in finger dexterity.
4. A decrease in tactual sensitivity.
5. A decrease in work time due to fatigue resulting from increased exertion required to perform.
6. A decrease in visual envelope.

The reason I am going into so much detail about these aspects of manned operations in space is to point out that man has limited capability in this environment. The application of special remotely operated equipment should become more attractive because of this limitation.

There is one more subject upon which I would like to comment. That is redesign of the work task item to permit the task to be more readily performed. This became apparent during the SCALE studies. The vehicle equipment and black boxes are sometimes located in areas that are hard to reach by a man in his natural environment let alone by a man in a space suit or with remote manipulators. We will be required to perform a large variety of maintenance tasks in orbital operations; therefore, consideration of a space suited astronaut or remote manipulator will be required when the vehicle equipment layouts are made. The design approach and the extent of this consideration is not yet defined, but it appears to be a great deal like the problems we have faced in remote handling operations in nuclear facilities over the past two decades. Modular design of components and/or subsystems with quick disconnects that are readily accessible to man or machine may very well be the solution.

The comment has been made that the user organizations must use whatever equipment is available for design of his facilities. This most certainly is true. However, as past experience has shown, the use of mock-ups to develop the disassembly and assembly procedures, techniques, tools, jigs, and fixtures has proven an invaluable tool to those who use it, and is as important as selecting the best available manipulative equipment. In addition, the mock-up operations determines accessibility and actual design modifications required to the test article to permit the remote operations to be performed.

At the Georgia Nuclear Laboratories which is operated by Lockheed Nuclear Products, we found that the hot cell mock-up was one of the most important phases of our engineering and test operations. In the design of the mock-up we were able to simulate the exact physical dimensions, the viewing capability, including the hot cell window index of refraction and TV system. This permitted the development of the aforementioned items under handling conditions that were the same as the final operation with the exception of the nuclear environment. Based on this experience we heartily recommend this approach to the solution of remote operation problems.

INTRODUCTION TO WORK AT THE CASE INSTITUTE OF TECHNOLOGY

by Dr. James Reswick
Case Institute of Technology

About four years ago a group at the Engineering Design Center at Case started a program which has since become to be called a Research Program on Cybernetics Systems for the Disabled. We like the use of the word cybernetics, because according to my definition, a cybernetics system is one which involves a man, a machine, feedback and feedforward. Systems which are being used in manipulators for disabled persons involve all of these elements and fit this description very well. Our work has been supported by the Vocational Rehabilitation Administration of the Department of Public Health, Education and Welfare, and it has been printed at the recovery of physical function of paralyzed people. I said a few words about this at the last seminar and I don't propose to go into detail about the background of the research. I do want to say a word about the Engineering Design Center since it is rather a unique place. It is in an engineering school because it operates under the assumption that the way to educate young engineers is to involve them in real engineering problems. We try to provide an environment and we try to provide problems for them to work on.

Some of the groups in the Engineering Design Center have banded together in this medical engineering program. They involve the Digital Systems group of Dr. Mergler, the Control Synthesis group of Dr. Taft, and a group in Bio-telemetry Solid States Electronics. Dr. Mergler and Dr. Taft are here today, as well as three graduate students who, for their graduate work, are going to be working on the program that we are undertaking for the Space Nuclear Propulsion Office. This program is to apply some of the background of techniques that have been developed for research on disabled persons to the remote manipulation problem. We have coined a turn of phrase that says that "research for disabled people in a normal environment has a great deal in common with research for normal people in an alien or dangerous environment."

The movie we are going to show features a bonafide quadraplegic patient who is paralyzed from the neck down. We will see an arm-aid system operating on 500 psi carbon dioxide in an all pneumatic and electronic system. We faced many problems such as the design of an anthropomorphic structure which would follow the human arm, the study of the anatomy of the joints, and so on. Dr. Mergler will say a few words about what we hope to be doing in the new program. It is very new, and we are just getting started, and our main reason for being here today is to test some of our assumptions against some of the needs. Finally, Dr. Taft in his basic research area is interested in pure fluid amplifiers. It is our feeling that the pure fluid amplifier, possibly

operating from a gas system, is one of the most promising kinds of control and actuation systems for highly radioactive and remote environments.

The movie shows a device that we call the Case Research arm aid because it is a research device. It is not a prototype for a clinically useful device for paralyzed people. The machine and the electronic computing mechanical systems were designed by graduate and undergraduate students at Case. What they lack in experience they make up for in enthusiasm and just plain daring. We have worked together with groups of therapists and medical doctors from the Western Reserve University and the Highland View Hospital. The most important part of the research effort has been the problem of working on a creative enterprise with people from many different disciplines. We spend as much time solving in our personal and communication problems as we do technical problems.

If you have any questions, we can talk about them later. I would now like Dr. Mergler to say a few words.

REPORT ON STUDY OF GENERALIZED, PROGRAMMED MANIPULATORS

by Dr. Harry Mergler
Case Institute of Technology

It has been previously mentioned that our Arm-Aid Control System operates from incremental data. I believe this comment requires further amplification. The structure contains five articulated axes, each of which is independently controlled (within the limits of movement of the human arm) and each of which contributes to the generation of a spatial locus. Command data is transmitted to each axis in incremental form over two algebraically-signed lines. That is, pulses on one line represent unit changes of that axis variable in one direction; pulses on the second line represent unit changes of that axis variable in the opposite direction. By controlling the relative rates of the command pulses between the axis as well as the total number of pulses generated per axis, a specified spatial path may be generated. At present, command data is stored on a multiple track magnetic tape. These data are generated by physically moving the splint structure through the desired physical path and recording the algebraically-signed pulses generated by the incremental transducers (pulse generators) associated with each axis. On play-back these transducers act as the feedback signal generators in the individual electromechanical digital servo loops associated with each articulated axis.

In retrospect, this system has two obvious disadvantages; one, the storage of incremental pulse data demanded the use of an expensive memory system, and two, the nature of the command data did not readily lend itself to automatic or computer generation. These two limitations serve as the primary starting-points for the next phase of our study in the problem of generalized, programmed, remote manipulators.

In my laboratory, we have two gross areas of interest. One area has to do with the design of multiple axes recorded information control systems. This activity began in the area of multi-axis machine tool control, and I think you can see the obvious similarity in problem type to this splint structure. The second area is in the actual logical design of the computer hardware, that is, the digital hardware, in order to implement information handling systems. Therefore, under the context of the grant that we have through Mr. Johnsen's office, we have a number of goals that we would like to achieve. We will first study this data problem with an objective of minimizing the total data that we must necessarily process in order to communicate to these axes. In the process of minimizing these data, we must develop sophistication in the manner in which we interpret the data. This means the development of interpolation routines on special purpose digital logical constraints, so that we may operate with a minimum amount of data. We would like, however, to go beyond simply minimizing hardware and looking at interpolation schemes. Generally, I can say that this whole activity can be categorized as studying optimal control strategies.

I will enumerate a few of them although we do not have any real data on which to defend them at present. We will investigate control strategies which may be automatically implemented such that the sums of all the velocities, of all the articulated axes at any instant of time, is a minimum. More specifically, our studies might direct us to minimize, within bounds, the velocity on any one of these axes.

Secondly, we will make the same studies with respect to acceleration, that is, minimize or bound the acceleration of any of these articulated axes. A third avenue of study will be an attempt to minimize, or possibly I should say optimize, the spatial path length in going from one point to some destination. Another study area will be directed to minimizing energy trajectories, that is, develop trajectories which have a minimum total energy expenditure. Lastly, we will investigate minimum time paths, taking into account velocity, acceleration, and special limits.

To implement these studies we will do two things. First, we will carry out initial strategy investigations in expanded time utilizing our Univac 1107. When we have developed the strategies which we think show the greatest promise, we will then employ them in real-time on a data processor operating as an integral part of a digital servo loop. This processor will not be the Univac, but will be a device whose arithmetic rates are so high that we can carry out all of the necessary computations, the optimizations, coordinate transformations and so forth in real time within this data processor. The user of such equipment will then specify his goal, and with the data processor programmed, one or more of these control strategies will be implemented to articulate this multi-axis device from one point to the goal. I would like to make it quite clear that we do not feel that we would like to be bound by the human model as necessarily being our ultimate objective for this type of operation. That is, if it is going to work on a skeletal structure like the one in the movie, it must respect these bounds because there are severe bounds that cannot be exceeded or there will be harm to the patient. But, if the same techniques were extended to a multi-axis system for some remote handling problem, then we don't have to limit a wrist rotation to 180° . We can operate it through radians and we don't have to put limits for return. Therefore, our strategies for this type of application may be totally different from the strategies that we use for the human operator. This is all I can tell you of our program at this time, for we have only recently been awarded this research grant and we are in the most formative stages at the present time.

REPORT ON STUDY OF APPLICATION OF FLUID AMPLIFIERS

IN REMOTE CONTROL OPERATIONS

by Dr. Charles Taft
Case Institute of Technology

I am going to briefly discuss a new concept in fluid control. We can use fluid to transmit power or information. When I speak of a fluid, I am speaking of a liquid or a gas, because at least in the eyes of the fluid mechanics people, the differences are not particularly great.

I am sure you are all familiar with the conventional ways of controlling a fluid. You do it every time you open a water tap. You vary the area of a restriction from some source of fluid under pressure and this restriction determines the amount of energy that you deliver to a load. This can be illustrated by a simple system where we have a source of fluid under pressure, flowing through a pipe. If we have a plate that covers the end of the pipe, and we can vary the amount of flow which goes through the pipe by changing the size of the opening between the plate and the pipe, this flow will also vary with downstream pressure. We might represent this control by plotting flow versus downstream pressure for various openings. Obviously when the plate is closed there is no flow, when it is open there is the maximum amount of flow, and the flow depends upon the downstream pressure.

There is also another way in which we can control a fluid--we can steer it. Essentially, expand it into a jet and shoot it into either one receiver or the other and in this way accomplish much the same thing.

About 1959, civilian scientists at the Diamond Ordnance Fuse Laboratory hit upon the idea of accomplishing this steering action by using another fluid jet. Thus they evolved a way of controlling a fluid with a fluid.

In the process of this development it was discovered that a bi-stable device could also be made by using the same principle. If we bring the boundary walls up relatively close to the jet we find that the following thing happens. As the jet moves downstream it pulls particles of fluid along with it. Finally, it begins to pull fluid up from downstream and bring it along with the jet. The very slightest disturbance, for example, if the jet were to be disturbed to the left, makes it more difficult for the fluid to get into the left hand area between the jet and the wall. The pressure begins to drop in this area, and the jet has developed a pressure gradient across it. The pressure drops, causing a pressure difference across the jet;

this snaps the jet over against the boundary wall. Units using fluids have been used for proportional amplifiers and for a digital amplifier, operating in two different kinds of modes. That is, the same digital element can be used for a memory element as well as a gating element.

Work at Case is concerned with the role of these elements in control. In order to find this role and develop design methods, we are working on a pure fluid digital feedback system very similar to the one that is used on the arm aid. The difference is that all the information on the system is carried by fluid signals. The only mechanical part of the system is the actuator, and a disk which serves to interrupt two fluid jets, to provide digital feedback. This system accepts a pulse of fluid. This pulse will command the system to change the output by one increment in our system at an angle of about 15° . The pulse is counted in a fluid counter which is capable of counting up or down. The state of the output is determined digitally by a pure fluid encoder which emits a pulse in two lines depending on whether the output is increasing or decreasing. This pulse is emitted when the output takes on values which are equally spaced and fixed. The counter then sees two pulse trains, one representing the input and one the output. It sums these algebraically to produce a difference or error. This difference is converted using fluid elements into an analog fluid signal which is amplified. The fluid signal is then used to drive two turbines, which in our system, are just air grinders. These two turbines drive a combination of a worm gear and differential to produce the mechanical output that is used to operate the feedback element.

These fluid elements have several advantages. One of them is reliability. There is no sliding contacts, or sliding parts in these valves, and the clearances are rather large. In addition, they are not made of materials which are likely to deteriorate in a radioactive environment.

COMMENT: I would like to point out here that Moore Products of Springhouse, Pennsylvania, has a dandy little demonstrator that you attach to a garden hose, sent to you free of charge, which will convert the strongest skeptic into a real believer.

DR. TAFT: Yes, this is a little element that you can fit on a faucet and it is a good demonstration device. I believe that the role of these devices is going to be in the actuator and in the data handling. They present the possibility of handling data on the manipulator in both analog and/or digital form. In addition, they offer the possibility of smaller actuators and smaller control elements.

QUESTION: What is the theoretical limitation on rise time?

DR. TAFT: This depends on what kind of fluid you are working with. If you want fast rise time the best fluid seems to be air. The best rise times that have been measured so far are in the order of about 10-15

microseconds. Now this is by no means the theoretical limit. The size of the device and the length of the lines between elements are some of the factors influencing the operating time. The other thing that these elements appear to offer us is the best of both worlds in our system. Namely, we can use them in our feedback, circuits and again on our manipulator. These devices can measure digitally to provide advantages from the accuracy standpoint, and at the same time manipulate information in analog form for presentation to our actuators. Now, I would postulate that the same kinds of things that we have done controlling the axis on the arm aid can be accomplished using pure fluid devices.

COMMENT: There are no real limitations as far as amplification is concerned.

DR. TAFT: Amplification is rather funny. We have a little power amplifier that we used to drive the actuators and in the course of the evolution of this power amplifier we had a design that had an infinite flow gain but it was only infinite over a range. The gain itself almost becomes an academic question and it is more significant to talk in terms of power gain. The incremental gain can be quite high.

Some fluid elements have been made by Corning Glass, using a process which they call photoceram. I have a sample on my tieclasp which you could run at a couple thousand degrees because it is a ceramic. I show you this because it represents just about the limit of what we can do today. We have the ability to make the channels and elements all in one big sheet, and then laminate the whole thing together. This allows us to make a control circuit and put in a block.

QUESTION: Is it cheaper than a printed circuit?

DR. TAFT: It depends on how much piping you have to do on the outside but there are no parts to insert.

QUESTION: What advantages does this have over some sort of electronic gadget?

DR. TAFT: Well, radiation immunity is one. Temperature tolerance is another. I think one advantage it doesn't have is speed but a lot of the systems we are talking about are not very fast.

QUESTION: Are there any applications for auto pilots?

DR. TAFT: Yes, Minnesota Honeywell, I think, is doing something on this. There are a number of people working in this area. One of the reasons that we are engaged in it is our interest in control systems design. The way these systems are designed today leaves much to be desired. I think we can contribute in this area.

PRELIMINARY CONCEPTS FOR A CENTRAL TEST FACILITY

by James Whipp
C. F. Braun & Company

Research and development of ROSE systems, subsystems and components is now being accomplished at a low-funded but productive rate in many laboratories and shops, scattered over the country. The number and variety of efforts is important to a healthy, balanced program. But the limitation of funds which can be mustered at each point of investigation leads to some problems. These problems may handicap the total progress toward our specific goal, which is the production of practical, versatile, reliable and economical ROSE systems. Some of these problems may be reduced by establishment of a central test facility for ROSE systems and elements. If, on further study a central test facility does seem desirable, the following are considerations relating to the purpose, feasibility and nature of such a facility. The concepts are necessarily generalized. It is hoped that this discussion will elicit some critical response from those of you who are closely involved in the problem areas treated.

Scientists and engineers of our generation are firm advocates of the philosophy of testing and it is apparent that any test is certainly more valid if performed in carefully simulated, service environments. Viewed in this framework, three requirements of our test needs are likely, in greater part, to be satisfied by the availability of the ROSE Central Test Facility. These are: high cost of test facilities, need to test in complete environmental systems, and need for standards of reference. Let's look at each of these.

By its very nature, ROSE equipment is needed to cope with a special situation or a special environment. Testing therefore calls for simulation of these situations and environments. As environmental chambers become more complex, their cost becomes quite significant. Often when they are considered as development tools that are required separately by each organization by somewhat limited repetitive use, their costs cannot be justified and consequently few organizations can afford them.

A graphic presentation of remote operations is presented in Figure A. Most current ROSE studies tend to concentrate on elements of a single subsystem: (1) the human operator; (2) the link, or man extender; or (3) the task. As a matter of practice the link is generally studied in subdivisions. For example, the mechanical subsystem, the optical subsystem, etc. Up to a point such specialization is natural and unavoidable. But unless investigators can periodically correlate their work with advances in other parts of the total field of endeavor, the tendency is to accept the interface components as invariable. The possibilities for effective optimization may be missed.

Optimization of the total system is then a fundamental requirement and this includes the interplay between the operator and the link, and the link and the task. Some work has been done at these interfaces. But there is still no wide agreement, for example, as to the merit of training operators versus designing systems to minimize the need for training. And very little has been done to redesign tasks to suit the system. We tend by habit to accept the anthropomorphous approach. Prosthetic researchers have gone much further in altering tasks to accommodate the device to suit the operator.

Now, some of you have probably thought, particularly those in flight hardware, that redesigning a task to accommodate the ROSE system may be kind of upsetting. I think we should remember though that optimization has to consider the whole system in a literal sense. For example, one would hardly add new restraint to the configuration of flight hardware to suit the desire for simplicity in ground test manipulating devices. On the other hand, if the remote device is meant to function aboard the vehicle in flight, it also requires space configuration and in this situation, trade-offs in design between the vehicle and ROSE systems become the logical and absolute or mandatory.

The need for standards of reference may also be satisfied by the central test facility. Perhaps it is only because our field is new that no sufficient body of statistical data has accumulated to provide solid correlation bases. More likely the reason one finds it more difficult to compare results in a meaningful way lies in the difficulty of observing elements tests under full-system and real-task conditions. So far as we can tell, there is no organized catalog of task-to-hardware parameters. Certainly, quantitative data is limited.

Standards of reference also has a more human connotation than is implied by data alone. Cross pollination of ideas from various sources is needed and this is what we are doing here. This interchange would not be limited to work in closely related areas. It would likely include the interplay of developments among diverse fields of efforts; for example, efforts at medical applications and man amplification, as well as remote operation and maintenance.

The CTF then should attempt to achieve these basic goals: (1) it should provide a means of convenient and efficient sharing in the use of high cost, high precision environmental test facilities. These should be designed with reasonable flexibility to suit the needs of our field of activity. Incidentally, the availability of CTF would minimize our need to compete with operating functions for facility time. (2) The second basic goal would be to provide the total environment of the task-oriented system. (3) And finally, the CTF should promote development of standard reference conditions, a standard reporting base and a central repository for data--unofficially it should be of great value as a communication exchange. This does not assume any invasion of the privacy of proprietary information where this is a factor.

Expanding further on these main lines, one can set forth some additional criteria for the central test facility. Whether the CTF is to be used solely for this work or whether it is an addition to an existing complex, certain features seemed to be required in either case. It should meet certain minimum requirements, and be capable of assuring certain standards of task work. It should have an array of ROSE systems, data reduction equipment, personnel facilities and a special library dealing in all aspects of ROSE related research and development. It should be expandable for future growth and must provide unit privacy. It would need a central economic and geographic location and accessibility by road and rail and possibly by air and water. It should have a minimal resident staff, which would chiefly consist of administrative and support personnel to provide health and safety functions, to provide station personnel for utility systems operations, and maintenance and to provide a cadre of technicians to assist in the set-up of experimental operations and probably to provide some trained operators.

Certain guides in the operation of the CTF are clearly indicated. It should be available to all ROSE investigations on a first-come schedule basis. It should provide for multiple occupancy or staggered occupancy. Actual experimentation should be accomplished directly by the client groups using a package or mobile test set-up.

Facility concepts which emerge then center around a multi-user community bringing its relatively mobile experiments to the central test facility. This concept is not new, it has been successfully used at the AEC Materials Test Reactor in Idaho and has been more recently developed for commercial applications by the New York State Atomic Research and Development Authority in connection with its planned nuclear pulse reactor facility near Schenectady.

The kind of tests that would like to be performed in a CTF will vary according to the in-plant facilities of the user. A firm policy should be established that the basic development work will continue to be done and should continue to be done in the present laboratories and shops whenever possible. Here you have the variety of motivations that are typical of the science oriented group, user oriented group and the producers of hardware and components. Development work including testing which can be satisfactorily done separately from the complete system is likely to be best done in the specialized surroundings of the home laboratory or the home shop. However, the presence of any of the following circumstances would indicate the use of the CTF as an invaluable test environment: (1) if the test requires full-scale authentic environments, (2) if the test requires complete in-system checkouts, (3) if the test requires correlation with standard performance data, (4) if the test purpose is the development of standard performance data, or (5) if there is a requirement for service center type testing. I think the first three of these circumstances are self explanatory. Here it is enough to note that the terms "environment"

and "in-system" include the task and the operator as well as the hardware. We might look a little further into the last two circumstances.

The first of these has to do with the development of standard performance data. This implies an interest, not so much in rating the test objects, as in the accumulation of fundamental data. Such work could be done using standard systems available at a facility and it would be directed toward basic improvement in quantitative understanding of the element to element relationship. For example, it could be used for the development of performance efficiency parameters acquired in-system under standard reproducible conditions.

The service center function is a little different from these others but it is quite straightforward. Unlike equipment intended specifically for remote handling use, ROSE systems may utilize a wide variety of shelf item hardware such as gears and bearings and valves, etc., produced for normal trade outlets. Because manufacturers of these items may have only rudimentary laboratories for testing these special applications of their goods, additional quality control tests would be made by the CTF. This would likely be a resident staff function. The objects to be tested under simulated operating conditions would include task units, end tools, command controls and feedback elements and feedback arrays, barrier penetrations and the man himself. These classes can be expanded in detail; one might conceive that the test objects will include any and all elements of a great variety of systems. To determine which should be considered, the CTF testing would require balancing the cost of several test provisions against the factors of frequency and urgency.

What other facilities now in existence or planned might serve the purpose of the Central Test Facility? The AEC operates engineering in materials test reactors, NASA plans the Boston Electronics Center, the Air Force and NASA operate a variety of simulation facilities at various centers all over the country, Nuclear Pulse Reactors are planned by the New York State Atomic and Development Authority and also by the Army in Aberdeen. Looking at work going ahead in hydro-space, several of the Navy's laboratories are planning deep submergence test chambers. For instance, the David Taylor Model Basin is acquiring a six-foot vessel that will handle pressures up to 12,000 psi. Larger, high pressure chambers are also being studied, and this sort of study is going on in many of the Navy's laboratories. All of these facilities have special purpose requirements which tend to make them either unsuitable or unavailable for ROSE testing.

A survey of existing facilities which might be converted should be undertaken at some stage, but for now, it appears difficult to visualize the assembly at one convenient location of the indicated variety of facilities units or even a major share of them at any one of the existing facilities. None the less, certain work that is valuable to this program

will be performed in other test centers. This will include environmental qualification of materials and components. The data accumulated at other laboratories, although sometimes difficult to acquire, will be of value to the ROSE program and care should be exercised not to duplicate efforts. Data which is not likely to be adaptable to the work of other laboratories includes the following: basic system compatibility studies, trade-offs among subsystems, and components. This data would also include system or component efficiency factors, time versus cost studies, and the establishment of response profiles over a range of conditions. Response parameters for example include time precision, space precision, load versus position, inertial effects, wherein all of these are related to ROSE systems. Some additional factors are reliability and reproducibility of the activities of the hardware and systems that we put together. In-service time ratio is important, along with maintenance costs, and we need an analysis of failures by type and frequency. Before we can conclude this survey of the functions and demands upon the CTF and proceed to examine its form, we should consider one more mode by which the test systems to be studied will differ. This is in the required versatility.

In the foregoing, we have discussed possible uses and how the CTF might fit into the overall scheme. We have also examined the kind of systems and elements to be tested although not in complete detail, and we have also looked into the nature of the tests and of the required environments. Now let us postulate a general description of a test facility that falls out of this examination.

It could be a modular array of environmental cells, administered and supported centrally. Each functional cell unit could be designed as a self-contained operating entity. Each one of these self-contained entities would be capable of accepting sequential incoming experiments. Typical cell units might be such as those described below. The numbers used here are not necessarily definitive. First, the facility should include a large atmospheric bay for testing remote operations of heavy rated equipment and systems. This may be the heavy disassembly bay of E-MAD. It would simulate operating conditions except for the absence of a special environment. The simulation then becomes primarily geometric. This would be a typical heavy shop layout with walls to simulate the isolation features which would duplicate the limited viewing under service conditions; it might have a labyrinth layout with portable walls and ceiling units to allow variations in layout and ROSE approaches.

Secondly, it might have one or more small atmospheric bays in hot cell arrangement for cold testing of light and medium duty equipment and systems. These cells would be structurally variable and the conditions are geometrically environmental but again they are atmospheric.

Third, a radiation cell. Let us assume that materials compatibility and exposure tolerance of materials have been tested at other facilities. Here, the facility's spatial relationships are simulated for attenuation from a radiation level resulting from, for example, 10^7 mw seconds propulsion reactor test, let us say, after 72 hours of decay time. Maximum possible mobile flexibility should be designed into barrier sections. Provision of a moderate strength portable isotope source allows checkout of operational procedures when desired and its removeability during other periods would facilitate access to the test phase for rapid adjustment and changes.

Four, a space simulator. This is a manipulation environmental chamber. It would be equipped to provide solar radiation, liquid nitrogen temperature, direct and remote viewing, and would have full diameter access. One can certainly appreciate the need for information for designing for a much harder vacuum, so as whether you can grab hold of something without welding to the surface at real space vacuums. However, this is a typical case of the need to balance cost against the value of these refinements and how often they are needed and whether or not such uses of highly specialized environment might not be handled separately in smaller and less complex facilities.

Five is a high pressure, hydrospace cell. Certainly trade-offs are required among pressure rating, dimensions, utility and cost. The features would certainly include indirect viewing. Here a full access diameter opening is a must, and the facility must be equipped to maintain water temperature and control of composition. Test pressures could range up to let us say 30,000 feet submergence, depending on the size of the test chamber required.

Six, a human engineering laboratory. This would be an uncomplicated arrangement of work areas, all primarily designed to measure manned capabilities and responses. Here would be studied the techniques for overcoming problems which are imposed on the man by the system restraints. Data developed here would be directly applicable to full system tests and environmental units. This work is closely related to developments in prosthetics and man amplifications. Other cells should be considered as candidates, for example, a surface and below submergence hydro service tank. This might measure wave action and other water movement effects. Another possibility is that of a sterile cell designed to develop and test techniques for operating remote systems through barriers. Each of the above cells would be provided its necessary auxiliary systems such as pumping, filtering, evacuating, etc. Each would also be provided necessary utility supplies, access docks, handling equipment, non-resident office space, etc, equipment assembly areas and several shop capabilities. When I say some mechanical shop capabilities this is with regard to the individual environmental cells. The total system would have rather expensive shop capabilities as part of the central reinforcing operation. Signal conditioning and data handling equipment

would be made available at the facility but standard transducers would normally be provided by the facility user as a part of his experimental apparatus. Real time display, computer storage and analysis would also be provided by the CTF. Normal administrative and personnel support facilities, a central data center and complete mechanical shops would serve the entire complex. Other central support features might include such items as clean rooms, decontamination areas, photography services, a screen room, materials testing laboratory, chemical and biological laboratories, and these are all meant to be available for the clients use.

The most tangible conclusion that can be drawn from the foregoing, is that some specific studies must be made before a more detailed design is likely to be worthwhile for this generalized central test facility. Two studies are of particular importance: (1) a study covering perhaps the next ten years should be directed at a forecast and analysis of those tasks which will require ROSE systems. This study would seek data on loads, versatility, special environmental limits. It should consider demand frequencies and should give some insight into the important unit handling costs for various applications. (2) Also needed is a survey covering potential interests among probable CTF users. To be meaningful, this will require some assumptions as to the physical location and administration and the source of funding. Although location has been mentioned, we have made no attempt to select one. The concept of the central test facility has many things to recommend it. Further study is necessary. We think the concept has sufficient merit that serious consideration should be given to undertaking the suggested studies.

RAY GOERTZ: I think the central test facility would technically be desirable, but I question when you should start thinking about it. The problem is that today nobody has been able to fund the fabrication of the equipment which you are proposing to test in this facility.

MR. WHIPP: Let me respond to that. I don't want any misconception here when I say that I think the timing is now. I am not proposing the designing and construction of the facility itself, but I believe it necessary to gather enough information to build up some base upon which to build a plan. We are suggesting that it is none to early to think about the problems, and to draw some boundaries around the things when we do get to this phase.

MR. JOHNSEN: I would like to comment that usually nobody thinks about the facility criteria until it is needed, and then there is never enough time to do a really thoughtful study.

GENERALIZED REMOTE OPERATIONS

For our purposes it is not needed to go into the infinite variations that can be identified within this framework. Just to illustrate this variety, the optical system could vary all the way from direct viewing, or use of a window in the barrier to a complex sub-system involving stereo-vision television, flexible as to location and orientation; and with high resolution, including separately adjustable object and background lighting. Other major elements in the system are capable of similar diversity.

REMOTE OPERATIONS IN THE SNAP-8 FACILITY

AT ATOMICS INTERNATIONAL

by William Henoach and John Burton
Atomics International

MR. HENOCH: This presentation is given for two purposes: First, to provide you with some general background information about the SNAP Programs at Atomics International. Secondly, to describe to you the complex task of disassembling a SNAP reactor system without visual access after the reactor had been operated in a windowless test vault for a year and a half.

The SNAP program has been pursued at Atomics International for about a decade now. It has at this time evolved into three major reactor system programs. These are the SNAP 10A, SNAP 2, and SNAP 8 reactor systems. The SNAP 10A and SNAP 2 reactors are identical. The reactor is comprised of a cylindrically shaped pot which is 9 inches in diameter and 12 inches high and which contains 37 fuel elements in a hexagonal array. The volume in between the sides of this hexagon formed by the fuel elements and the cylinder formed by the container is filled in with pieces of beryllium that provide for the reflection of escaping neutrons back into the core. The reactor is reflector controlled rather than absorber controlled. That is, the neutrons which escape from the vessel are either permitted to leave the environment or are reflected back into the vessel by the beryllium hemicylindrical reflector devices. The reactor is cooled by NaK, an alloy of sodium and potassium, which is an excellent heat transfer material and freezes at a less inconvenient temperature than sodium. The SNAP 10A system differs from the SNAP 2 system in that heat is converted to electricity in the former case by thermoelectric elements and in the latter case by a turbo electric conversion system. The NaK which is heated by the reactor passes behind the thermoelectric elements transferring its heat in the process. The thermoelectric units are comprised of a hot and a cold element. The hot element receives its heat from the NaK and the cold element radiates its heat to space. This temperature difference is used to create a potential difference in an entirely analogous fashion to the common thermocouple, which creates an electrical potential when its two legs are at different temperatures. This SNAP 10A system will provide about 500 watts of electricity. The turbo electric SNAP 2 system will generate about 5 to 20 kilowatts.

The fuel elements consist of fully enriched uranium zirconium hydride. The uranium zirconium alloy is massively hydrided in a furnace. The entrapment of very large numbers of hydrogen atoms in the fuel itself provides a high degree of neutron moderation. This results in a lower average neutron energy than would be found in a fast reactor. That is, the average fission neutron energy is less

than it would be if the reactor were without the moderation provided by the hydrogen.

The SNAP 8 reactor is an advanced version of the SNAP 10A or 2 reactor. It has more fuel elements. They are smaller in size, operate at a higher temperature, and the power conversion system is a turbine which puts out from 35 to 100 electrical kilowatts.

In support of these SNAP reactor developmental programs, an aerospace safety program is being conducted by Atomics International. The SNAPTRAN-1 machine is being used at the National Reactor Test Station in Idaho in the conduct of nuclear transient experiments which provide information on the behavior of a SNAP reactor when it suddenly experiences an extremely high input of reactivity. The reactivity input is imposed upon the reactor by the sudden rotation of two reflector drums from a position of low neutron reflectivity to a position of high neutron reflectivity. Several months ago the first experiment in this series was conducted. This experiment was performed to determine what the consequences would be of the sudden immersion of a SNAP reactor in water. A reactor core filled with fuel elements and NaK and protected against achieving criticality by an annular sleeve of high neutron absorbing material was placed in a tank of water. The neutron absorbing sleeve was suddenly removed by lifting it with an explosive charge. The reflection by the surrounding water of vast numbers of neutrons which would otherwise have been absorbed in the sleeve caused the reactor to go highly supercritical. This reactor excursion resulted in the disassembly of the reactor. Essentially no release of radioactivity was experienced since the reactor had not been operated and there was no fission product build-up. This experiment proved that in case of a launch abort in which a SNAP reactor landed in the ocean, it would simply disassemble itself with the release of essentially no radioactivity.

A number of SNAP 10A systems are currently in production. One is to be sent to Vandenberg Air Force Base for a flight test. One will be operated in our nuclear ground test facility at Santa Susana in order to qualify the SNAP 10A system for flight. Others will be used to iron out interface problems between the reactor system and the launch system.

The SNAP 8 Experimental Reactor is currently in operation at the Atomics International nuclear field laboratory at Santa Susana. This reactor is in a pit in the ground. Above the reactor is a shutdown shield and the control drive mechanism.

The first nuclear power experiment conducted in the SNAP program was the SNAP Experimental Reactor. This experiment was conducted in order to verify the calculations which predicted the nuclear behavior of the core. It provides a neutron's view of the inside of the core. Except for the core, this reactor does not resemble the reactor which is going to fly. There is no power conversion system associated with

it. The test is simply a nuclear demonstration of the reactor core. The second nuclear system in the developmental sequence is what we call a developmental reactor or a DR. The S2DR or SNAP 2 Developmental Reactor will be discussed in more detail later. This reactor looks as much as we can make it look like the flight reactor. There is, however, no power conversion system. The heat is simply thrown away. If there were a power conversion system associated with the heat source, it would be laid out in a bread board fashion and we would call that a developmental system (DS).

The S1OFS or the SNAP 10 Flight System is the third and final step in the developmental sequence. This Flight System (FS) resembles the actual system which will fly as closely as we can make it.

In the remote systems engineering business, we are faced with either of two alternatives. If we are fortunate, we will be called in during the design of a reactor system so that we can include design input which will permit us to maintain and disassemble the system remotely. Sometimes, however, we are simply handed a system and told to take it apart. In recent years it has been apparent to all concerned parties that a great deal of time, effort and money will be saved if the people who are going to be asked to maintain or disassemble a system like this are called in during its design.

The following is a summary of the SNAP nuclear operating test program to date.

The first SNAP critical assembly went critical in October 1957. The SNAP Experimental Reactor (SER) started up November 1959 and was shutdown in November 1960. It operated at a power level of 50 thermal kilowatts with a coolant outlet temperature of 1200°F.

The SNAP 2 Developmental Reactor was started up in April 1961 and was shutdown in December 1962. It operated at the same power level and coolant temperature as the SER.

The SNAP 8 Experimental Reactor started up in May 1963; it is still operating today. It has operated at power levels of 450 kw (this is its design power) and at 600 kw. The coolant outlet temperature of this reactor is 1300°F. It has generated at this time almost three and a half million kw.

The SNAP 10 Flight System, which is now about to be installed in the power test vault in our SNAP test facility, is expected to start up soon.

The specific subject of pertinence to our meeting is our experience in the remote maintenance and disassembly of a reactor system. The SNAP 2 Developmental System was designed to permit remote maintenance

without direct visual access. This involved the modification of hardware on the reactor. Besides this, human capabilities and equipment were developed to disassemble the reactor system by television in the windowless test vault in which it had operated for one and a half years.

At this time John Burton will describe some of the more interesting features of this program with you. Mr. Burton is Supervisor of the Remote Handling and Viewing Unit in the Nuclear Operations Department of the Compact Systems Division of Atomics International.

MR. BURTON: Two means of viewing are used at Atomics International on the SNAP program to observe in-cell operations. They are: the traversing closed circuit television system, or traverse TV (the basic viewing means), and a center cell shielding window.

We have developed techniques in the use of closed circuit television equipment (the traverse TV) not only to remotely observe the conduct of a SNAP experiment, but also to direct remote manipulators in the performance of extremely detailed and complex operations such as maintaining a system during its period of operations and disassembling it afterward. The test vaults were made windowless because windows cannot withstand the high neutron flux generated in the vaults during reactor operation. Operations in the test vaults are carried out using the traverse TV system tracks permanently mounted on the cell walls. The camera systems are set on these tracks after reactor shutdown. Viewing requirements during the disassembly of the reactor and/or the removal and transfer of reactor components into a transfer cell are furnished by the traverse TV system.

The traverse TV system was developed at Atomics International to answer the need for the unique viewing requirements of the SNAP Environmental Test Facility (SETF). Part of the development of the traverse TV system involved demonstration of the system in a mockup operation prior to specification of the equipment to be used in the various nuclear facilities. The system has proven so successful in its present form that manipulator operators familiar with the system have shown a preference to TV in those instances when direct window viewing is a possible alternate.

Figure 1 shows a traverse TV unit mounted on a cell wall. The unit consists of a camera with ZOOM lens and pan tilt unit, mounted on a motorized dolly, which rides on the wall mounted track.

Two or more traverse TV units mounted on adjacent walls of a vault generally are used together. In the test vaults in the SETF basic traverse TV units are mounted on both side walls and across

the inside front face of the cell. A fourth traverse TV unit can be set on a camera stand which is moved around by the manipulator as required. The camera stand mounted unit cannot traverse; however, a stationary camera with only pan and tilt is useful in some viewing circumstances.

The camera dollies are all interchangeable. The dollies and tracks are so designed that the dollies can be put on or taken off at any point along the tracks. If desired, two or more cameras can be set on the same tracks and cameras with different lens focusing ranges can be interchanged when required.

In operation generally two cameras mounted on adjacent walls, pointed at right angles to the walls, are traversed to that point where each camera is aligned on the object being observed. The right-angle views so obtained are displayed on adjacent monitors in the television control console. By means of such a display, it is possible to first align the manipulator on the object being observed in one picture and then in the second picture, thereby placing the manipulator on the object. The traverse TV system presents a rectilinear display which has proven to be ideal for use in directing a rectilinear manipulator. As experience has been gained with television viewing, it has been found that two-camera viewing is not an absolute necessity. Satisfactory results can be obtained using one camera.

In order to plug in and unplug the in-cell cameras with the manipulator, a remote television plug was developed. The plug can be operated by the manipulator hand, hand-hook or shoulder hook. The pins in the connector are self-aligning and self-holding. The pins are available commercially and have been standardized for all in-cell remote electrical connectors with the exception of the manipulator-tool power takeoff.

The signals from the various television cameras terminate at television control consoles located in the operating galleries. The television control console serves two purposes: (1) to display the signals from the various cameras to the remote handling operators and to the reactor control room, and (2) to direct (point) the cameras. As with most of the remote viewing and handling equipment used on the SNAP Remote Handling Program, the console was built to specifications developed by mockup operations. An example of the special features developed by the project is the adapting of a manipulator control handle to the controlling of a TV camera. Figure 3 illustrates the functions controlled by what has been called a unitized TV joystick.

The center cell viewing window of the SETF is a conventional hot cell type shielded window. The window is constructed of slabs of high density lead glass with the spaces between slabs filled with minearal oil. The heaviest slab of glass in the window is composed

of 6.2 density glass. The total weight of the window and frame is ~ 7.5 tons. The primary use of the shielding window is to observe the operations conducted by the master-slave manipulators which penetrate the cell wall above the window. The efficiency of the window in transmitting light is only 13% and some distortion exists because of its optical properties, but it is useful in the direct viewing of operations being conducted with the master-slave manipulator.

A typical example of the type of operations undertaken by the SNAP Remote Handling and Viewing organization is described in the S2DS reactor system disassembly account which follows:

The successful disassembly and clean-up of the S2DS system demonstrated that a complex reactor system, otherwise unshielded, could be operated in a hot cell structure, if properly designed, and then disassembled and the cells cleaned to the point where a second reactor could be installed in the same cell. It was demonstrated that techniques can be developed to allow "television only" viewing of complex remote operations and that such operations can be conducted smoothly and in a reasonable length of time.

Following shutdown of the S2DS reactor on December 20, 1962, and subsequent draining of the NaK coolant, disassembly of the system commenced. The initial disassembly involved removing the test auxiliary components of the primary (radioactive) heat transfer loop and portions of the secondary heat transfer loop located in the center cell (transfer lock). Removal of the equipment in the center cell was accomplished by direct contact. The piping system was cut into a minimum number of pieces small enough in size to fit through the roof opening of the cell, thus requiring a minimum number of cuts of NaK piping. Severing of NaK piping was accomplished by first crimping or flattening the pipe by means of a hydraulic ram capable of exerting 60 tons of force, followed by cutting the pipe across the flattened area and then sealing the severed ends by welding. The heat transfer components were removed through the cell roof opening to the high bay floor above where those components to be saved, were removed and the remainder packaged for disposal. All material removed from the center cell were surveyed for radiation. The average radiation level detected was approximately 3 mr/hr. A maximum level of 5.5 mr/hr was measured at the throat of the primary EM pump. Radiation detected was attributed largely to activation. Surface contamination of the equipment was determined to be less than 30 d/m.

Removal of the heat transfer equipment from the center cell permitted installation of remote handling and viewing equipment to commence. Equipment previously developed and proven in mockup operations was moved from the remote handling laboratory to the center cell. A work station consisting of the necessary equipment for opening the core vessel cleaning fuel elements, canning fuel elements, and removing

the elements from the cell in addition to utility equipment such as hand changing fixtures and hand tools, was set up under the slave ends of the master-slave manipulators. Equipment to support the operations in the test vault was staged in the remainder of the cell space. This included impact wrenches, circular saws, band saws, drills, television cameras, tool stands, etc. A table was provided in which seven containers holding six (6) fuel elements each, could be stored at three-foot intervals.

A camera stand holding a traverse camera carriage with TV camera, pan-tilt unit, and zoom lens in addition to radiation detectors and a flood light was set up and all components plugged in. This camera was to be the first camera moved into the windowless test vault. The camera had sufficient cabling so that the unit could be moved into the vault while still plugged into the center cell.

When the equipment set-up was completed and the equipment checked out, the center cell was sealed and the air atmosphere replaced by nitrogen.

Two remote handling crews were established to provide around-the-clock operations, each crew working 12-hour shifts on a seven day a week basis.

On February 7, 1963, the corridor door between the center cell and Vault No. 1 (containing the reactor) was opened and the first camera moved into the vault. Observation of the vault by means of television revealed, (1) that all vault lights were working, (2) that except for darkening of some materials such as glass tape, the reactor and vault appeared to be as was observed prior to startup in June 1961. Comparison of the view obtained by the first and subsequent cameras moved into the vault with photographs taken just before the vault was sealed, verified the normal condition of the vault and contained equipment. The only change observed was the cracking of some insulation "mud" on the top of the core vessel. It was decided that this was due to improper installation.

Using the first camera for viewing, three additional camera-traverse units were moved into the vault and placed on the vault wall tracks. Using the cameras as the only means of viewing and various manipulator supported tools, the S2DS control and reflector assembly was removed from around the core and transferred into the center cell on February 12. A radiation survey revealed the level of the assembly to be in excess of 25 r (limit of instrument). Visual inspection of the assembly by means of the shielded window and periscope disclosed no visual change other than the material darkening previously mentioned. Following visual inspection, the control and reflector assembly was set aside for later disassembly.

Operations resumed in the vault with the stripping of lagging from the NaK coolant lines. Several pipe cuts were made using a supported circular saw with an abrasive blade. Following severing of the coolant inlet and outlet piping, the core was unbolted from the support table and moved into the center cell on February 18. As the core was carried into the center cell by means of the manipulator, radiation measurements were taken in the operating area. The core was placed on a modified welding positioner approximately three feet from the shielding wall. The maximum radiation measured in the access area with the core mounted on the positioner, was 1.7 mr/hr.

With the core now located in the center cell activities were discontinued in the vault so that attention could be concentrated on core opening and fuel transfer.

The welding positioner supporting the core was tilted until the core was in a horizontal position resting on rollers. With the core in the horizontal position, a modified pipe cutter was clamped in place around the vessel. The pipe cutter modifications included addition of a lathe cross-feed with a remotely changeable tool holder. Using techniques developed in mockup operations, the core was rotated at approximately 4 rpm by the welding positioner and the specially ground tools applied in the vicinity of the upper grid plate. The cutting operation required four hours. Following completion of the core vessel cutting operation, the core was tilted back to a vertical position. The vessel lid at this point was still attached to the remainder of the core structure by thermocouples which penetrated the lid and terminated in four of the fuel element end caps. The thermocouples were cut using the master-slave manipulators and modified wire cutters. The vessel lid was then removed, followed by the grid plate which exposed the ends of the fuel elements. Processing the fuel elements involved removing the elements one by one from the core vessel, identifying each element, verifying position of each element, cleaning with alcohol, photographing through the periscope and visually inspecting by means of the shielded window and periscope. The elements, after visual inspection, were loaded into inserts designed to hold six (6) elements. As each insert was filled, it was placed in a storage container or "can." Tops were placed on cans and the cans sealed. Sealed cans were returned to the storage table in the rear of the cell.

Following canning of all of the elements, preparations were started to remove the fuel and transfer it to the storage facility. The means of transferring the fuel was a cask equipped with a self contained hoist and grapple. The cask was placed over an open periscope port in the roof of the cell above the work station. The grapple was lowered onto the top of a can, which was automatically engaged, and then the loaded can was hoisted through the roof and into the cask. A rotating gate in the base of the cask was then rotated, thus closing the cask.

A fork lift truck was utilized to transport the cask to the storage facility where the cans were inserted in storage thimbles. The first can was transferred on March 1, and the operation was completed two days later. With the fuel elements removed from the building, the around-the-clock operation was discontinued and all further work accomplished on a 40-hour week basis.

Following the removal of the fuel, attention was concentrated on disassembly of the control and reflector assembly. As the assembly was disassembled, some components were placed in special casks for eventual further examination in other facilities and the remainder contained in shielded waste casks. Following disassembly and containment of the control and reflector assembly, the remainder of the S2DS system was disassembled using similar techniques and procedures. As casks were filled, they were removed from the cell through the roof opening. Following disposal of the reactor components, the remote handling equipment was disposed of either as expendable scrap in waste containers or as equipment destined for eventual decontamination.

The center cell was decontaminated first to allow a means of access to Vault No. 2 and following initial clean-up of the vault, to Vault No. 1. Decontamination of the cell and vault were accomplished by a combination of processes including vacuum cleaning, hand washing and washing with spray guns. The principal contaminant is believed to have been dust from the activated lagging on the NaK piping in the vault.

FIGURE 1

FIGURE 2

JOY STICK AND CAMERA

FIGURE 3

REPORT ON MANIPULATOR CONTROL WORK

AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

by Dr. Thomas Sheridan and Dr. Russ Ferrell
Massachusetts Institute of Technology

DR. SHERIDAN: There is a group of a dozen or so people who over the past ten or 15 years have concerned themselves with how you apply servo theory to characterizing how people chase dots around oscilloscopes. Our laboratory has been associated with this august group, and I guess we can take pride in the fact that one can now use differential equations of fairly low order to predict within a few percent how people do certain simple control tasks. Most of this, of course, applies to flying airplanes and driving submarines and so on. Several years ago, we began to get a little discouraged with the fact that the tasks for which one could write these nice differential equations were the very same tasks for which one can build little \$50 packages that can do the job just as well as the human and much more reliably. We asked ourselves what is a control task which is uniquely human, and it became evident fairly quickly, by looking at manipulators and remote manipulation tasks that will be important in space and under-sea operations, that remote manipulation was such a task. About that time we got a grant from NASA, in this case the Guidance and Control Group in NASA--not Ed Johnsen's group--to work in this area, and we presently have a lot of fun involving students from freshmen to doctoral candidates in this program. This project has involved us in a variety of things, some of them abortive. Here we want to talk about two aspects--Dr. Russ Ferrell will say something to you about some studies in remote manipulation with long transmission delays from about 3/10 of a second up to many seconds. Then I am going to say a few words about a somewhat more recent interest in tactile feedback.

DR. FERRELL: I would like to say a few words about a project, funded by NASA, which was done in the MIT Man-Machine Systems Laboratory.

It was decided that it would be interesting to study a situation in which there is a long delay between the time a person moved a remote manipulator master control and the time the person could observe the new position of the slave. We made a manipulator, using an x-y plotter having x and y degrees of freedom and a grip. The operator controlled an isomorphic master. We delayed the control signal going from the master to the slave and this is exactly analogous, from the operator's point of view, to having half of the delay to the remote unit, and the other half to this visual display.

At first, the question was whether the person could in fact do the manipulator task under these circumstances. There had been some earlier studies by psychologists with delayed sensory feedback, particularly delayed visual feedback, which suggested that people's movements would become unstable, and they would have emotional difficulty. We found that people devise strategies to get away from this and one of the strategies is, of course, to move very slowly. You can envision that I move the master and after three seconds, the slave follows suit. You can see that if I want to go through a path and have the slave following closely, I can move very slowly so, although I will be three seconds behind, the distance will be very short. Another strategy which appears to be optimum because it doesn't call upon the operator to predict, is simply to do as much of the task without visual feedback as you can, wait until the slave catches up, see what remains to be done and repeat the process.

It turned out that although operators had never used the delay before, they very quickly adopted this strategy completely on their own, without coaching. Seven operators went through a sequence of experiments and six of the seven choose this strategy and were able to describe it afterwards. The seventh operator used a combination of moving and waiting and also moving very slowly at times.

We found that even with a delay of $3/10$ of a second, the move and wait strategy is much quicker than trying to predict ahead. I would expect that at some point with less than $3/10$ second delay continuous movement would be better. It also turns out that because the strategy is so consistent you can also predict the time it takes someone to manipulate when there is a delay even for a fairly complicated task. Of course, I am still speaking about position control, and about two dimensional task situations. But you can predict quite accurately the average time it takes to do a task from measures you take in the case where there is no delay.

We are interested in continuing studies of this kind in relation to applications in which you have, not position control, but rate control and here I would expect that again there would be a kind of move and wait strategy. We have an indication of this from undergraduate studies that have been done in positioning an x-y plotter using a rate control. We are also interested in the possibilities of using a predictor. You can't use a predictor for every task. You can't, for example, predict where the end of a tool is going to be if you are not sure quite how the tool is going to be picked up. You can use a computer, or another manipulator, to see where the hand itself is moving. We also have a thesis study of using delayed force feedback. The manipulator I was using didn't have force feedback. You can imagine having a remote manipulator on the moon picking up a bucket, and because of delay, suddenly having the control pulled down. I had originally been rather skeptical of the usefulness of delayed force feedback but I have since become convinced that there

may be some very interesting things we can learn from it about people's manipulative ability, and about using a manipulator with a delay.

There are operators who have used the manipulator for 12 to 15 hours, although they have actually been experimenting with it for a longer length of time. They do improve their performance considerably with practice but the improvement you can get by using the strategy of moving slowly is practically negligible if there is a long delay. It just becomes impossible to remember what you have done, and everything that you have done in the past three seconds will be duplicated. It must be remembered that this isn't a lag, it is a delay, in which a mistake cannot be corrected.

QUESTION: You wouldn't be aware that you have a mistake until it is manifested?

DR. FERRELL: This is usually the case. You thought that everything was just beautiful and you found everything was completely a mess.

I would like to explain two of the experiments that we did. One of them was a position and grasp experiment, which was the simplest possible experiment you can imagine. The other experiment was an extremely complicated task in which you pick a tool, slide it over, push another tool out of a block, move around the block, grab the other tool, bring the tool out and rotate it (even though you can't rotate the hand, you can rotate the tool by pushing it), regrasp it, bring it around the other side of the block, and turn off a switch. This was a complicated task. People got so that they could do this in about 4 or 5 open loop movements, that is, they would move and wait, move and wait, about 4 times, which is quite good. The greatest improvement with practice is in the time, and with a long delay the waits are a significant portion of the time.

QUESTION: What is the maximum delay time that you use?

DR. FERRELL: 3.2 seconds. The shortest was .3 seconds.

QUESTION: Do the manipulator fingers touch a flat surface, the surface that the tool is resting on?

DR. FERRELL: No, they didn't touch it, but were just about 1/16 an inch above the surface.

DR. SHERIDAN: Let me say I was particularly delighted with the results that Russ got because they flew in the face of predictions of some high placed Government people who were very skeptical that we could operate with this kind of delay, and secondly, the results were somewhat contrary to what linear servo theory predicts. Everybody knows that when you put a delay in a servo loop it goes unstable if you are working at high frequency. Of course, people are too smart for linear servo theory.

I have been personally interested in the tactile sensing problem for a number of years. Dr. John Lyman, who was at the last Seminar, and I did a little experiment at the VA hospital in Los Angeles ten years ago in which we achieved partial nerve blocks in our fingers. It is difficult to block the cutaneous skin senses and not block the motor nerves. John Lyman succeeded in getting a fairly good block, and from his experience it was quite evident that when you lose tactile feedback, you've pretty well had it, unless you take it very slowly and concentrate on what you are doing. You really lose the ability to grab something or to handle small objects.

When we talk about tactile feedback, let's define what we mean, and what we don't mean. One of the things that we don't mean is force reflection, in the sense of force reflecting servos. In other words, we don't mean the integral of force over the finger or over the terminal device, which is normally mediated by the muscle and tendon senses in the human body. The second thing that we don't mean is proprioception which is literally "an awareness of self." In the case of a position servo, you have proprioception with your own normal limb. In the case of a rate servo, a TV picture of the whole scene will provide a form of proprioception. Finally, you might ask can you feel or touch things with other sense organs than your skin? I think that for the immediate future at least, this approach has the most payoff.

Let's look at the other end of the telemetry link, at the sensor on the remote hand, which is picking up the signals. Should this be a reticulated device, a lot of little solenoids or a set of miniature contacts? Some studies have indicated that to do the kind of job that is even worth doing you would need say 30 x 30, 40 x 40, even 100 x 100 miniature elements; to convey a proper pattern you need a very large matrix of separate little sensors, per finger. What you would really like, of course, is a pattern that is continuous, and the question is how to get a continuous pattern. A student a few years ago did some experiments using air jets--an array of small jets of air. The advantage of this, if it were to work is that you might have some glove that the hand fits in and which would transmit your motor actions to the manipulator and still permit a sort of modulated pattern of air jets to play on the skin. If the air jets could be kept together in one stream, the distance from the source of the jet might be variable down to a small fraction of an inch. We tried this with a 3 x 3 matrix, and found that the thermal problems of cooling the skin interfered quite a bit with the ability to sense pressure, but we were still able to get up to about 5 bits per second transmitted from stimulator to skin. I won't go into how you make this measurement. Another technique that was tried abortively was that of spark machining a surface and then feeling over the machined surface, which, if it could be done cheaply and quickly, might provide a sort of tactile TV.

A more promising technique is to pick up an optical indication of pressure which then relays its signal back to a TV display, thus enabling the eyes to sense pressure. There are various ways that this can be done. There is also the Moire pattern which some of you know about--essentially an optical interference phenomena. There is also the possibility of having imbedded in an elastic material many little blobs of something like mercury which when you push against this material changes size and shape and color as individual little particles, and you see the pattern of these. Finally, there is a technique that has been developed by other people for stress measurements; so-called photo stress techniques. In this case, a very soft material is spray painted with silver one side, a piece of polarizing material is put over it, and when the light shines in through the polarizer, it bounces off the mirror on the back side of the elastic material. If you deform the material in certain regions, the polarized light on the outbound trip will interfere with that on the return trip, and you will get interference patterns which you can see. The material is usually used in a way such that the force applied is at right angles to the travel of light. One student did a little study where he used a sandwich of this kind. He had blindfolded subjects feel a number of everyday objects, like coins, buttons, etc. with their own skin and noted that the accuracy of identification. He then used the photo stress sandwich, and he found that they could recognize objects as well by seeing stress patterns with this as they could using blindfolded touch. We have built a device which we can attach onto the end of a Model 8 manipulator and which has material like this in it. The image is picked up, goes through some optics, and is relayed back through a coherent fiber optic bundle, since you can't very well hold a TV camera on the finger end of a manipulator terminal device. The image is picked up by a TV camera and sent back to a monitor. The system doesn't work right now, because although your eye can pick up that image with no trouble at all, a TV camera is not very good unless you can get better contrast. This is what we are in the process of trying to remedy.

We have done some other experiments with electrical contact sensors on a Model 8 manipulator, where we had no vision at all. We were manipulating metal objects and we had just a number of electrical touch spots on the terminal device manipulator. One of the things that this experiment proved to us was that the relaying back of parallel information is far from the whole story. It looks like if you could take certain patterns of information off of those artificial touch sensors, and process the latter, you could tell the operator something that you can't get from the simple parallel telemetry of sensory signals although it may be a technique that he is not accustomed to and must learn. For example, you could have short sub-routines that sensed certain position information and told the human operator in symbolic form whether an object in grasp was slipping.

There is plenty of psychological evidence to show that if you put something down on the skin, so that it remains in one position, you are not going to get very much tactile information; the cutaneous sensors will adapt. Whereas if you're allowed to move your hand around, and get new areas of skin to make contact, you can get a lot more information. We know that much of this kind of motor control is mediated through local spinal arcs in the nervous system. There is a lot that we don't know about this, but I think that some form of tactile sensing using either a visual feedback or some processing right at the site of the sensor is promising. We are trying to get this latter development to the point where we will have something workable and demonstratable.

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