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Pacific Northwest
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U.S. Department of Energy

Interim Report
Spent Nuclear Fuel Retrieval System
Fuel Handling Development Testing

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Summary

Fuel handling development testing was performed in support of the Fuel Retrieval System (FRS) Sub-Project at the Hanford Site in Richland, Washington. The Spent Nuclear Fuel Project will retrieve K Basin Spent Nuclear Fuel (SNF) from existing storage locations in the basins, clean and remove the fuel from canisters, repackage the fuel into baskets, and load the fuel into a multi-canister overpack (MCO) for hot and cold vacuum drying and eventual interim dry storage at the Canister Storage Building (CSB). The FRS is required to retrieve basin fuel canisters, clean the fuel elements sufficiently of uranium corrosion products (or sludge), empty fuel from the canisters, sort debris and scrap from whole elements, and repackage the fuel in baskets in preparation for MCO loading.

The purpose of fuel handling development testing was to examine the systems ability to accomplish mission activities, optimization of equipment layouts for initial process definition, identification of special needs/tools, verification of required design changes to support performance specification development, and validation of estimated activity times/throughput.

The structure of the test program was set up to accomplish this purpose through cold development testing using simulated and prototype equipment; cold demonstration testing using vendor expertise and systems; and graphical computer modeling to confirm feasibility and throughput.

To test the fuel handling process, a test mockup that represented the process table was fabricated and installed at the Hanford 305 Building Equipment Testing Laboratory (ETL). The test mockup included a Schilling HV series manipulator that was prototypic of the Schilling Hydra manipulator. The process table mockup included the tipping station, sorting area, disassembly and inspection zones, fuel staging areas, and basket loading stations.

The test results clearly indicate that the Schilling Hydra arm cannot effectively perform the fuel handling tasks required of it unless it is attached to some device that can impart vertical translation, azimuth rotation, and X-Y translation. These additional degrees of freedom are needed since each joint of the arm is restricted to travel in a radial path about a pivot point. Picking and placing fuel from a horizontal position to a horizontal position is easily performed with the jaw, and the translation capabilities (in X, Y, or Z) of the trolley and mast assembly. Picking fuel from the horizontal and placing it vertically into a fuel basket can also be performed with the motion of the trolley and mast assembly assuming an efficient end effector tool is available for acquiring the fuel ends. Tasks were most easily performed with all but the wrist joint of the manipulator locked out. Without any translation capabilities, the manipulator does not work well for handling long objects that are close to surfaces or obstructions.

The control system of the carriage-mounted arm needs to be greatly improved to achieve reasonable process throughput rates without operator "burnout." In the arm tests addressed in this report, the operator had to carefully plan how to individually position each joint of the arm, as well as the amount of vertical translation and mast rotation. This is like having to stop and think about how to position and move each joint in your fingers, wrist, arm, and shoulder in order to reach out and pick up a pencil. The

control system of the Basin equipment should allow the operator to concentrate on the task to be performed, without having to think about how to move each movable element of the system; those functions need to be automatically performed by the control system. It is recognized that the advertised philosophy of the Schilling control system seems to address this need, but frequent "re-calibration" of the control system to the actual joint positions was found to be inefficient, inaccurate and annoying.

Tests indicate that color video cameras and lights should be placed at opposite ends of the traveling bridge to effective observation of the handling operations. Each camera should be equipped to pan, tilt and zoom. The zoom at wide angle must be able to provide simultaneous viewing of all moving elements and joints of the arm, its gripper, and the arm base; and at telephoto must provide close-up views of the gripper, at the operator's discretion. The wrist-mounted camera should not protrude in such a manner that it interferes with the fuel being handled by the gripper. The wrist-mounted camera should be enclosed in a housing that will protect it from damage when bumped against an obstacle.

For picking up fuel lying horizontally on a surface, the V-block end-effector jaw worked better than the standard Schilling flat end-effector did. Further studies should be conducted to make it easier to fully engage the jaws with either outer or inner fuel elements. The current V-block jaw often gripped fuel with the tips of its jaws instead of grasping the fuel firmly within its V-block.

The Characterization Sub-Project tools, used to acquire fuel ends during inspection in the Basin, were difficult to use. Tight tolerances made it difficult to insert the tool into the fuel ends. A Schilling-proposed design for acquiring fuel ends was effective, but requires an activation method that is difficult to provide with the manipulator.

The process of repackaging spent nuclear fuel in the K-basin storage facility was simulated using the Deneb IGRIP® 3-D modeling program. An IGRIP® model was prepared to analyze process table layouts and manipulator configurations in support of the design efforts by British Nuclear Fuels Limited, Ltd. (BNFL). Results from these simulations have shown that the handling of fuel elements/assemblies can be performed using the modified Schilling Hydra manipulator in coordination with a bridge/trolley assembly. The simulations have indicated that arm configuration is a significant factor in fuel handling. Based on simulation results, the recommended Schilling Hydra manipulator configuration is with the base mounted vertically and with all the joints pitching in the same plane of motion. Again, it was demonstrated that the trolley and mast assembly translation performed the majority of tasks in fuel handling. The arm is used only for activities that require motion that is not in a linear path.

In conclusion, tests have demonstrated that manipulator improvements are required to pick, move and place fuel successfully. Camera locations and capabilities are important to the control of the operator and the remote system. Jaw and end effector tool design is crucial for the effective acquisition and handling of fuel components.

Abbreviations and Acronyms

AES	Application Engineering Study
BNFL	British Nuclear Fuels Limited
CDR	Conceptual Design Review
CSB	Canister Storage Building
D&D	Decontamination and Decommissioning
DESH	Duke Engineering Services Hanford
DOE	Department of Energy
ETL	Equipment Testing Laboratory
FRS	Fuel Retrieval System
ID	Inside Diameter
IWTS	Integrated Water Treatment System
LATA	Los Alamos Technical Associates
MCO	Multi Canister Overpack
OD	Outside Diameter
PNNL	Pacific Northwest National Laboratory
ROSEE	Remotely Operated Sediment Extraction Equipment
SNF	Spent Nuclear Fuel
SRS	Schilling Robotic Systems
VCR	Video Cassette Recorder
WHC	Westinghouse Hanford Company
XXS	Double Extra Strong

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Introduction

Fuel handling development testing was performed in support of the Fuel Retrieval System (FRS) Sub-Project at the Hanford Site in Richland, Washington. The Spent Nuclear Fuel Project will retrieve K Basin Spent Nuclear Fuel (SNF) from existing storage locations in the basins, clean and remove the fuel from canisters, repackage the fuel into baskets, and load the fuel into a multi canister overpack (MCO) for hot and cold vacuum drying and eventual interim dry storage at the Canister Storage Building (CSB). The FRS is required to retrieve basin fuel canisters, clean the fuel elements sufficiently of uranium corrosion products (or sludge) and remove them from the canisters, sort debris and scrap from whole elements, and repackage the fuel in baskets in preparation for MCO loading.

Westinghouse Hanford Company (WHC) and Duke Engineering Services Hanford (DESH) were contracted to provide a retrieval system for safe repackaging of spent nuclear fuel in the K basins in FY 1996 and FY1997, respectively. British Nuclear Fuels Limited, Ltd (BNFL) was contracted by WHC/DESH to provide design performance specifications for use in procurement of systems and equipment. As part of the design process, developmental testing was required to provide design information where experience and calculations could not provide the design basis.

Pacific Northwest National Laboratory (PNNL) was requested to lead the test and computer simulation needs for the development of the fuel handling retrieval system. BNFL supplied the test specifications (Appendix A) indicating the specific design needs. The Equipment Testing Laboratory (Hanford 305 Building) was used for facility space, equipment design and fabrication, test engineering, and technician support. Schilling Robotics Systems (SRS) performed fuel basket loading tests in accordance with test specifications provided by BNFL

The purpose of fuel handling development testing was to provide proof of concept and criteria, optimization of equipment layouts, initial process definition, identification of special needs/tools, and identification of required design changes in support of performance specification development.

The scope of fuel handling testing included the tipping station for tipping the fuel from the wash basket; sorting/handling of fuel, scrap (fuel less than 3 inches long), and debris (all non-fuel components) on the process table; fuel disassembly with the aid of the manipulator; handling of fuel, scrap and debris as required to load MCO baskets, scrap baskets, and debris bins; and the handling of debris, sludge, fuel assemblies, elements, pieces, and tooling as required to clean the process table and prepare the work area for further processing.

This report describes fuel handling development testing performed through October 1996 using a Schilling HV manipulator. In October, Schilling provided an unsolicited proposal to use a specially designed Conan (Konan) manipulator. The Fuel Retrieval System (FRS) sub-Project decided to procure the Konan system, and testing was terminated to obtain a Konan manipulator before continuing the development testing.

To test the fuel handling process, a test bed that represented the process table was fabricated at the Hanford Site 305 Building Equipment Testing Laboratory (ETL). Design input has been provided by the design agent, BNFL, to establish a test bed that meets the test objectives.

The test bed included a Schilling HV series manipulator that was prototypic of the Schilling Hydra manipulator, at one time considered for use by BNFL. The manipulator was mounted from an overhead mast. The arm configuration and base-mounting configurations were varied to identify the optimal configuration. The overhead mast was supported in various combinations from being fixed in position, providing azimuth rotation and vertical elevation, to being translated by an overhead trolley with three degrees of freedom.

The test bed also included the process table that was fabricated out of plywood board, allowing the flexibility to modify the table configuration in a very short period of time. The table was designed to hold the wash basket for tipping of fuel onto the table. A variable slope ramp allowed the fuel to roll or fall onto the process table. Side rails were temporarily mounted alongside the ramp and table, to vary the table configuration quickly. Barriers along the length of the table were easily moved to represent various process zones. The table was modularly designed so that special handling needs could be considered. The mock process table could also slide into various positions to represent the manipulator moving along the monorail.

To simulate remote conditions, the manipulator was managed with a master controller isolated from the table by a curtain, while the table was monitored with video cameras and lighting. The overhead trolley and mast controls were located next to the manipulator controls.

To support the design activities, the process of repackaging spent nuclear fuel in the K-basin storage facility was simulated using the Deneb IGRIP® 3-D modeling program. An IGRIP® model was prepared to analyze process table layouts and manipulator configurations. The model was based on the Conceptual Design Review (CDR) and the 50% detail design table layout.

The CDR model was prepared to form a baseline for performance comparisons with other design concepts. The CDR process simulation included two 4-degree-of-freedom Schilling Hydra manipulators mounted to a 4-degree-of-freedom overhead bridge/trolley assembly. The second layout, based on the 50% detail design, was modeled with a shorter table than the CDR layout. Two simulations were performed with this table layout. The first included two 4-degree-of-freedom Schilling Hydra manipulators each mounted to a 4-degree-of-freedom overhead bridge/trolley assembly. The second simulation included two 6-degree-of-freedom Schilling Titan II manipulators, each mounted to a 4-degree-of-freedom overhead bridge/trolley assembly.

The simulation of the fuel handling process included the initial acquisition (picking) of the fuel assemblies after they were dumped from the wash basket onto the table, placing the fuel assemblies in the disassembly station, placing each separated element in the inspection station, loading damaged fuel elements into the scrap Multi-Canister Overpack (MCO) basket (only for the 50% detail design table layout), and loading acceptable fuel elements into the MCO basket.

Test Description

In general, the results of fuel handling testing were used to provide design information, support the optimization of fuel handling by reducing the number of pick and place operations, develop time and motion data, and provide a process area layout. Test specifications were developed by BNFL and are provided in Appendix A. The overall objectives of fuel handling developmental testing include:

- Validating time lines projected by BNFL from an individual operation basis
- Evaluating and recommending process table configurations
- Evaluating the effects of fuel orientation, i.e., perpendicular vs. parallel to the process path
- Optimizing fuel loading workflow for maximum throughput
- Developing techniques to load defective fuel (bits, partials, corroded, etc.), and sorting out material classified as non-fuel
- Optimizing manipulator arm placement including contingency for irregularities
- Optimizing the type and quantity of end effectors
- Identifying other tooling and fixtures required for optimal handling.

A series of tests were conducted in the 305 Building ETL and at the Schilling Robotic Systems (SRS) facility in Davis, California to assist in the development of underwater, remotely operated hardware for retrieving SNF at K Basin. No radiological materials were used in these tests. This interim test report deals with only a portion of the total development testing to be done. Testing was performed to evaluate wash basket tipping of fuel onto the process table and different configurations of the Schilling HV manipulator arm and its gripper fingers, for picking up and handling inner and outer fuel elements. This limited scope of testing also addressed the placement of video cameras to optimize performance of tasks by remote operation. All testing was performed in air using simulated fuel elements.

Testing was performed on a wood mockup of the process table layout defined by BNFL. A Schilling HV manipulator was used to represent the Schilling Hydra manipulator. The Schilling HV is a lower operating pressure (2000 psig) prototype of the Hydra. Geometrically and functionally, the two manipulator systems are identical. The maximum reach of the Hydra is 36 inches. The manipulator was suspended from an overhead mast to represent the in-basin configuration.

Phase 1 Testing

Phase 1 testing was performed to evaluate key table layout features, such as the tipping station and basket loading station, to develop an initial feel for the articulation limitations of the HV manipulator, and to evaluate specific end effectors and arm configurations.

A tipping station was identified by BNFL as a table location for dumping fuel from the canister and the wash basket. Tests were performed to evaluate the tipping angle required to dump fuel from the basket and the effect of various ramp slopes, and to understand how fuel reacts (both full length and scrap) when dumped from the wash basket and down the table ramp.

The Schilling HV manipulator was tested to evaluate the ease of articulation and the range of motion of the arm. The arm was operated to determine the best base location, orientation and height above the process table for picking and loading fuel into an MCO basket. The need for azimuth base rotation and elevation of the arm was also evaluated.

The standard SRS jaws were tested for their ability to pick and place fuel elements and scrap. A custom set of jaws was also evaluated. Two types of end effector tools were evaluated for their ability to acquire and load fuel into the fuel basket.

Schilling Robotic Systems Testing

SRS was contracted to develop an optimum fuel-handling configuration for a remote manipulator and associated tooling to handle spent fuel. The primary goal for SRS was to provide a manipulator configuration that could process fuel from the process table and into an MCO fuel basket within a specified time. The use of the manipulator was required to be intuitive, i.e., it should be easy to train operators, and easy for them to operate for long periods of time. SRS provided recommendations for end effectors and for practical ranges of motion to suit the process envelope of the fuel-handling table.

Phase 2 Testing

The second phase of tests was designed to quantitatively and qualitatively evaluate the capabilities of different configurations and deployment modes of the Schilling HV manipulator to pick up and handle simulated inner and outer fuel elements.

Tests performed in the first phase indicated that the basic Schilling arm, with only azimuth mast rotation, was unable to perform certain necessary fuel handling tasks without the addition of vertical translation capabilities. The proposed Phase 2 tests were a continuation of Phase 1 tests. For these new tests, the arm was mounted on a carriage that added vertical translation capabilities to the existing mast azimuth rotation.

Phase 3 Testing

This phase of testing was performed using the Schilling HV arm attached to an overhead trolley, which added X-Y translation in a horizontal plane above the process table to the earlier motions. These tests also included evaluation of various special tools used to assist the arm in the performance of its fuel handling tasks. At this point in the testing, a decision to use the Schilling Konan manipulator was made by the FRS sub-project. Therefore, testing was terminated until a Schilling konan manipulator could be obtained for testing.

Computer Modeling

To aid in the understanding of the process table layout and the range of motion of the Schilling Hydra manipulator, a simulation approach was taken using the Deneb IGRIP® computer software. The computer model geometry included the manipulators, process table (single line CDR layout), table equipment, and simulated fuel-handling tools. The physical dimensions of the objects were based on SRS vendor drawings and BNFL concept sketches. A baseline process description was established based on process flowcharts and design layouts provided by BNFL.

The computer simulation was then based on this process description that defined the motion sequences and tasks to be accomplished by the manipulators, including fuel tipping from the wash basket through fuel loading into the MCO basket. Other motion devices were also modeled, e.g., disassembly station, inspection station, secondary cleaning, scrap basket loading, etc.

Important parameters for the design evaluation included the table layout and equipment configurations, the number of manipulator cycles required to handle fuel (manipulator reliability), and the overall process time needed to load an MCO basket. Input from the BNFL time-motion estimates, 305 Building ETL testing, and SRS vendor data were incorporated into the time-motion evaluations.

An alternative manipulator, specifically, the Schilling Titan II was also simulated. A comparative analysis of manipulator capabilities was made on the baseline CDR process.

Man-Machine Interactions and Training

To evaluate man-machine relationships, training records and operator experiences with the Remotely Operated Sediment Extraction Equipment (ROSEE) at N Reactor were collected. ROSEE was an underwater remotely controlled tracked vehicle that used a Schilling HV manipulator. These records and experiences were used to provide insight into the use of the Schilling Hydra manipulator in basin operations, and to understand the training requirements.

Test Method and Equipment

Testing of the fuel handling system began with a set of conditions to allow the design agent to evaluate the baseline design performance. The starting parameters were varied, based on results of the initial tests, until acceptable performance was achieved, or the cause of poor performance was identified.

Phase 1 - Preliminary process table mockups were fabricated to evaluate the effects of layout on the fuel handling process. New end effectors and tools were evaluated for picking, moving and deploying fuel. Wash basket tipping and fuel basket loading was also evaluated with various arm configurations.

Schilling Tests - Based on concerns that emerged during Phase 1 testing, Schilling Robotics Systems (SRS) was contracted to perform basket loading tests in Davis, California. Appendix B is a copy of a test specification developed by BNFL and Appendix C is a copy of the test report provided by SRS.

Phase 2 - A process line was set up in the 305 Building using existing facilities, tables and equipment (CCTV, pan & tilts, monitors, fixed lighting, etc.). Unique items, such as jigs and fixtures, were fabricated as required. A handling process was established for fuel loading, debris sorting, and inspection based on the proposed BNFL design. Placement of equipment, manipulators, and holding fixtures for fuel baskets was evaluated.

Phase 3 - The process line was revised to incorporate recommendations from Phase 2 testing, and then tested. New fixtures and/or equipment were added to the process line and tested to evaluate potential production rate improvements. At this point, it was decided to abandon the Schilling Hydra manipulator. SRS had presented an offer for the use of the Konan manipulator and the FRS sub-project accepted it.

Computer Modeling - Geometric modeling and kinematic animation of the fuel handling system was performed to evaluate the process table layout and manipulator range of motion.

Each of these testing phases is described in detail in the following sections.

Phase 1 - Wash Basket Tipping

Simulated fuel assemblies, scrap and debris were dumped from the wash basket onto the process table (Figure 1). The wood mockup was only representative of the process table tipping station. The wash basket was made from ¼-inch rolled steel plate 50% perforated with ¼-inch holes. How the fuel rolled or tumbled on a ramp slanted at 10 and 25 degrees was evaluated. Bits and scrap were also dumped form the wash basket onto the ramp to determine the basket rotation required to dump the fuel and to evaluate the effect of bits/scrap on the fuel rolling down the ramp.

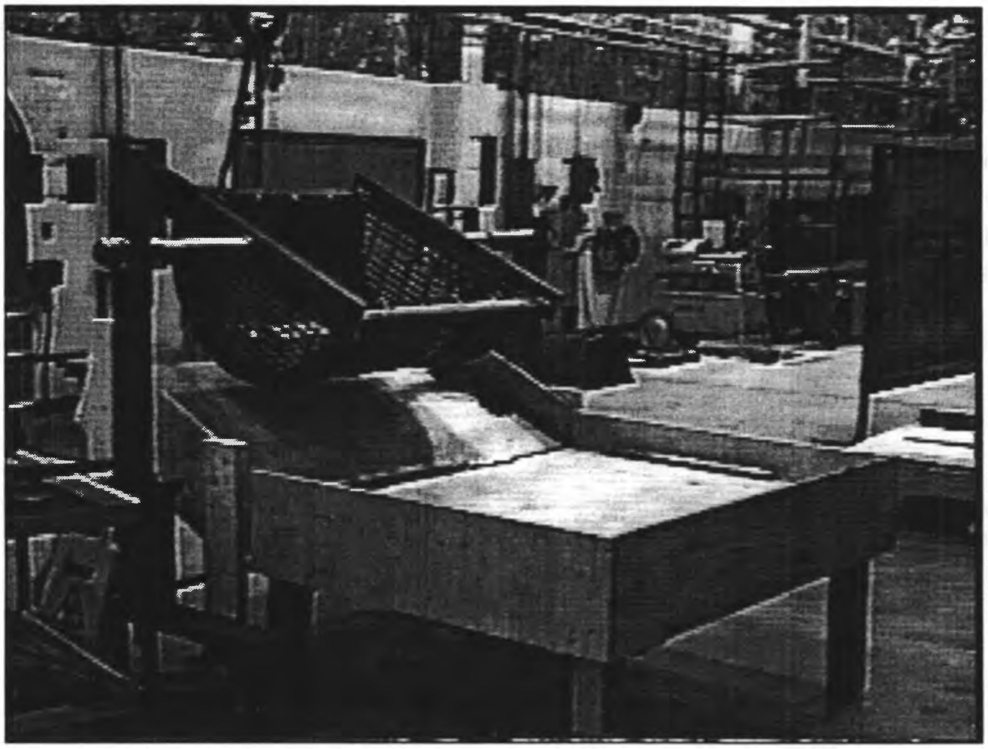

Figure 1. Tipping Station Mockup with Wash Basket Full of Dummy Fuel

Simulated fuel included lead assemblies that represented the weight and outer dimensions of a typical fuel assembly. Steel inner and outer elements were also used to represent the actual geometry of the fuel elements. Steel outer element were cut 26 inches long out of 2-inch Schedule 160 pipe. Steel inner elements were also cut 26 inches long from 1-inch Double Extra Strong (XXS) pipe. All dimensions of the inner and outer elements were representative of actual fuel, except that the inner element inner bore was 0.65-inch compared to approximately 0.45-inch for real fuel. The slight difference was not considered significant from a handling perspective. Some of the steel inner and outer elements were welded together to represent an intact assembly. Other assemblies had shoes (Figure 2) welded to the inner elements to maintain the inner and outer element axes, but were allowed to slide relative to each other. Some assemblies had no shoes at all.

Simulated scrap consisted of 3- to 4-inch sections of steel pipe previously described. Some pipe was cut with an irregular end and/or crushed. Simulated debris consisted of steel plate, bar stock, rubber and leather gloves, buggy springs, wire filament, nuts, bolts, etc.

Phase 1 - End Effector Tools

Two expanding collets, identical to the equipment used by SNF Characterization Sub-Project for retrieving and inspecting fuel in canisters (Figure 3), were modified to be remotely operated with a pneumatic valve (Figure 4). Pneumatic actuation of the collets was chosen for ease of testing. The

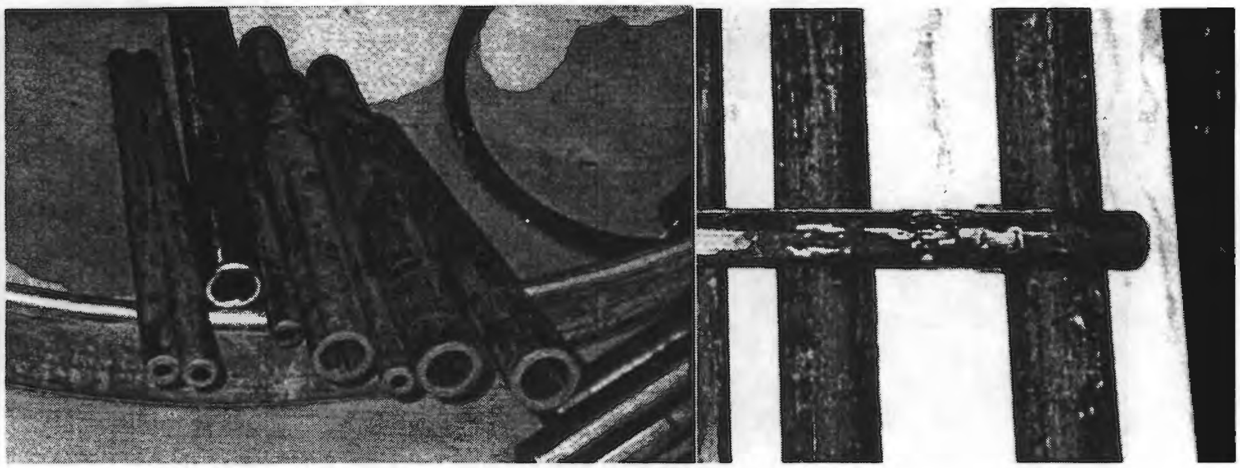

Figure 2. Inner and Outer Dummy Fuel Elements on the Left, Close-Up of Inner Element Shoes on the Right

Figure 3. Fuel Canister Full of Lead Fuel Dummies

modified collets were first suspended from an overhead crane and used to lift fuel elements from a fuel canister and lower them into a MCO fuel basket (Figure 5). A second test was performed by picking and placing the fuel elements manually (to eliminate the overhead crane boom swing) from and to a fuel canister. The ease of handling and the time required to acquire and deploy steel dummy fuel was evaluated.

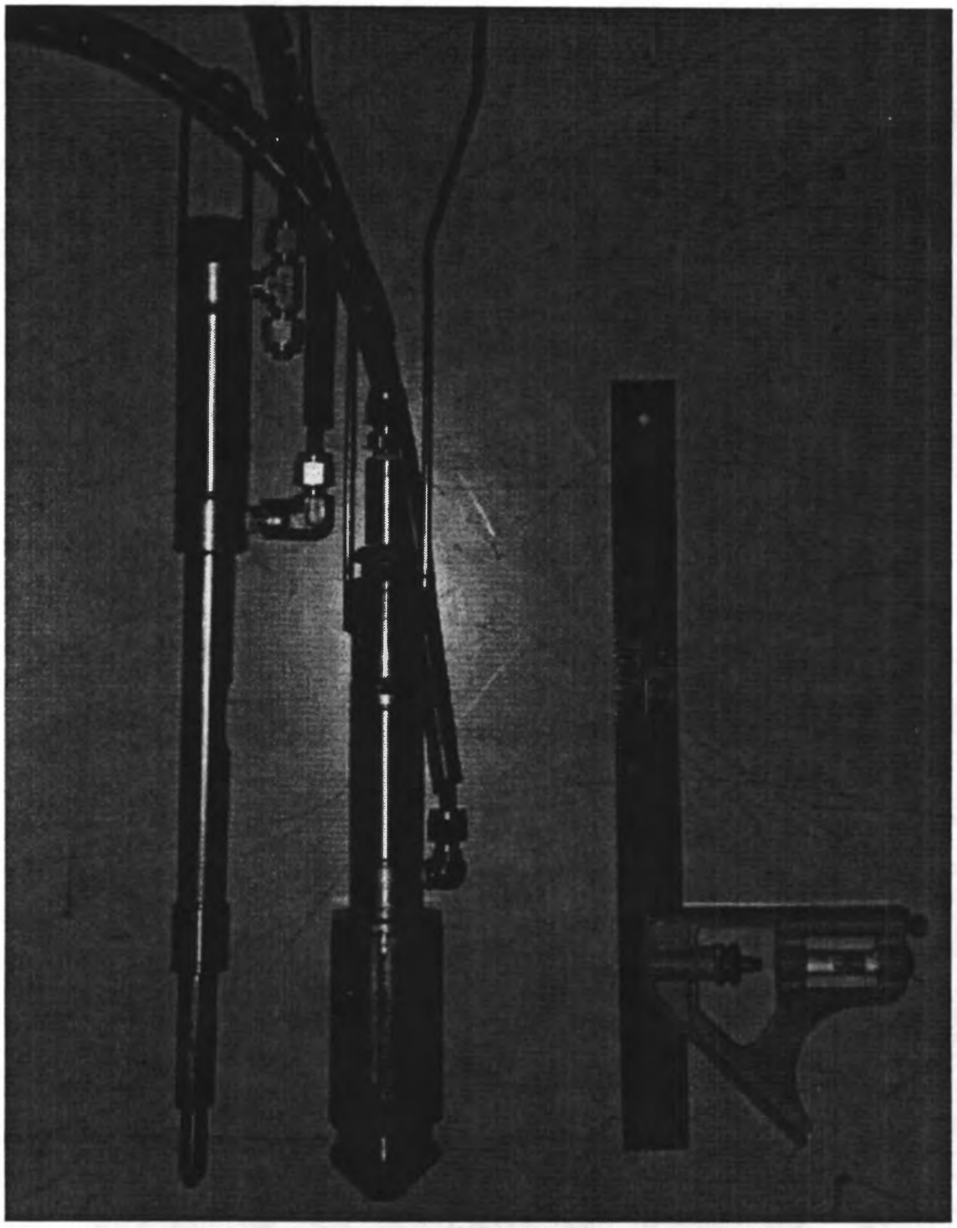

Figure 4. Modified Remote Fuel Handling Collets

A custom set of manipulator arm jaws was also fabricated, installed, and tested. Modifications consisted of adding curved outer surfaces and curved cutouts on the finger faces (Figure 6). These modifications allow the cutouts on the finger faces to grip the outside of the fuel elements. The curved outer surfaces allow the fingers to be placed inside the fuel element and expanded to grip the fuel internally. Basket loading was evaluated with the new configuration.

The standard manipulator jaws were tested for their ability to acquire fuel horizontally from the table and place it in another location. Three variations of the standard jaw were also fabricated and tested (Figure 7 - Left). The first variation included a standard parallel jaw, but 3-inches wide instead of

Figure 5. Crane Hook Supporting Collet Tool Above MCO Fuel Basket on the Left, Manual Loading of Fuel into MCO Fuel Basket on the Right

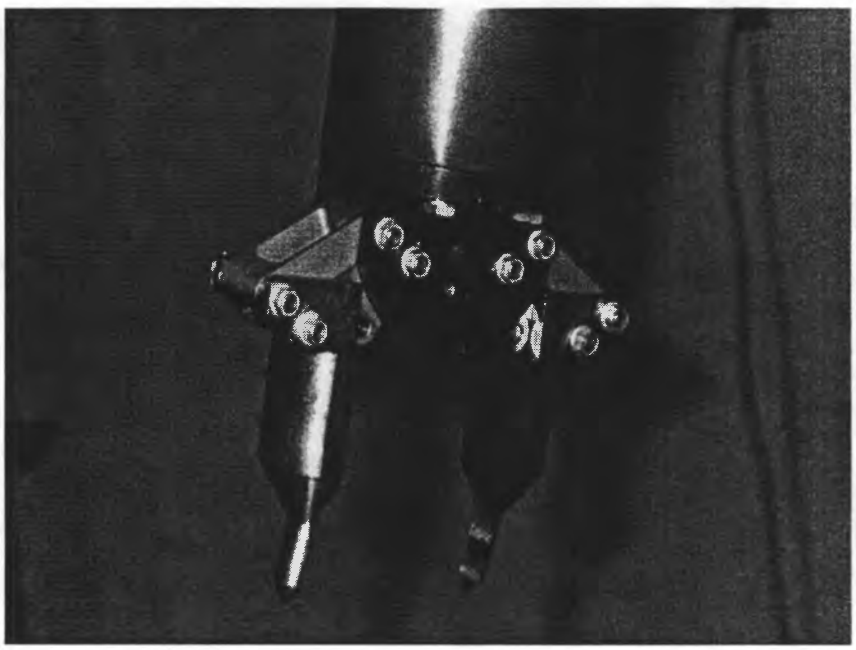

Figure 6. Custom Jaws for Handling Fuel Ends

the tapered design. The second variation was similar to the first except that it had a V-block style closure in place of the parallel jaw. The third variation was identical to the second, except that it had a deeper V-block depth (1/4-inch on each jaw as compared to 1/8-inch). These variations were based on testing results and were not planned from the outset of testing.

Tool interfaces were also evaluated (Figure 7–Right). Three variations (only one shown) of a cross pattern design were fabricated and tested for ease and speed of tool engagement. The standard SRS Tee bar (1/2-inch round) style tool interface was also fabricated and tested.

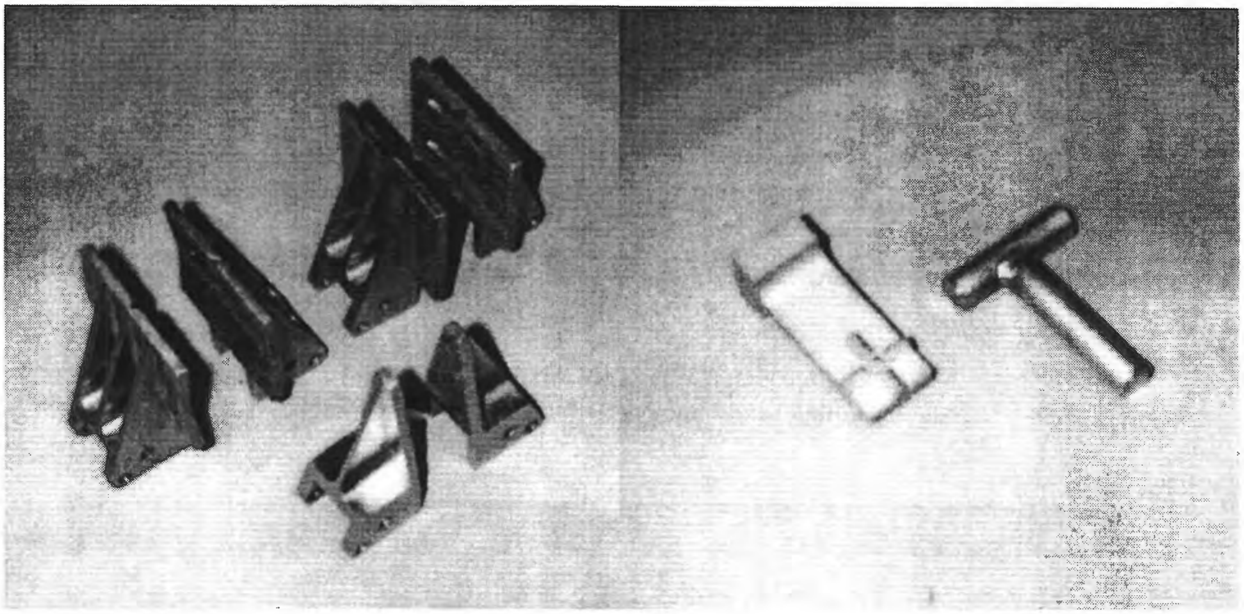

Figure 7. Left – Standard SRS Hydra Jaws at Lower Right, 3-inch Wide Parallel Jaws at Upper Right, and V-block Style Jaws at Left
Right – Tool Interfaces: Beveled Cross Design at Left, Standard SRS Tee Bar at Right

Phase 1 - Fuel Basket Loading

The Standard Schilling HV manipulator (Figure 8 - Left) was used to lift fuel from the table and load it into a fuel basket. No vertical or azimuth rotation was provided. Different base mount orientations were evaluated. They included horizontal, vertical and 20-degree above horizontal. Standard SRS parallel end effectors were used. Special tools to load the fuel were also evaluated.

A rotating mast was added to the base of the Schilling HV manipulator (Figure 8 - Right). The manipulator arm was modified to allow all pitch joints to be in line. The arm was oriented with its base perpendicular to the mast.

Fuel elements were loaded into an MCO basket with the standard jaws and with the modified jaws. A swivel joint tool was also tested to load fuel oriented vertically into the fuel basket (Figure 9).

Basket loading tests also led to special camera needs to improve operator efficiency. Both localized and end effector cameras were evaluated during basket loading. A special end effector camera and mount that followed the motion of the jaws is shown in Figure 10.

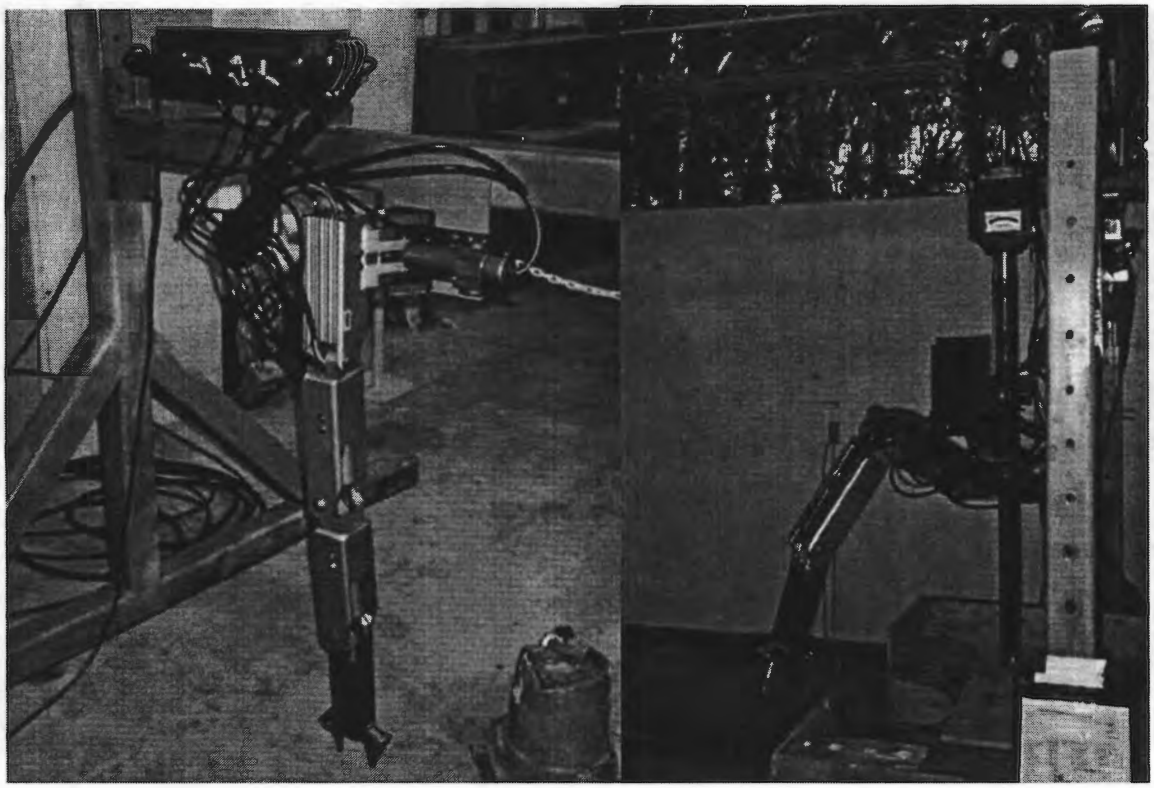

Figure 8. Standard Schilling HV Mounted on Test Frame at 305 Building ETL on the Left Modified All Pitch Joint Schilling HV with Base Rotation on the Right

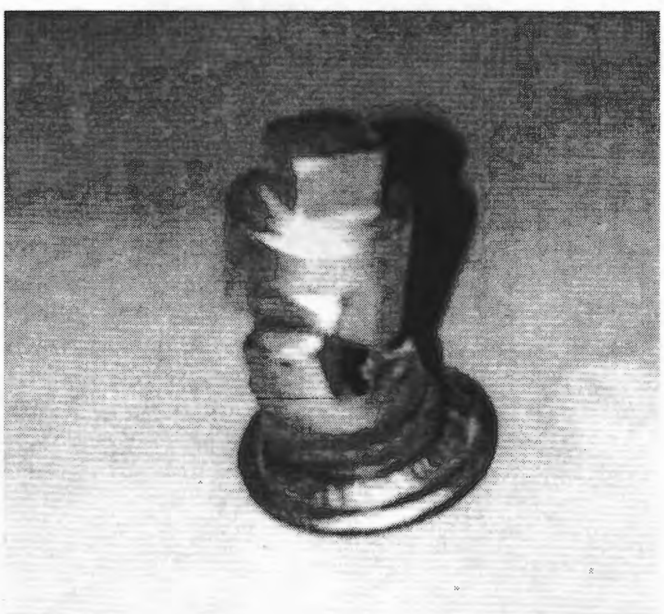

Figure 9. Swivel Joint Tool Was Welded to the Steel Dummy Fuel and Lifted at the Top by the Manipulator Jaws

Figure 10. Wrist Mounted End Effector Camera on the Left End Effector Camera View on the Right

Schilling Robotic Systems Tests

Requirements for the SRS tests were developed by BNFL and are provided in Appendix B.

SRS prepared a test bed at their home site of Davis, California (Figure 11 - Left). A WHC owned Schilling HV manipulator, MCO fuel basket, and steel pipe dummy fuel were provided to SRS to perform the test. The test bed consisted of an overhead beam used to mount the manipulator, a wood table ramp barrier used to acquire dummy fuel, and a special end effector tool used to pick up and deploy fuel into a MCO fuel basket (Figure 12). A control center was established next to the test bed (Figure 11 - Right). Two cameras, monitors, and halogen lights were established in strategic locations to provide the operator a practical view of the manipulator, table, and basket.

Figure 11. Test Bed at Schilling Robotic Systems Facility on the Left Control Center for Manipulator on the Right

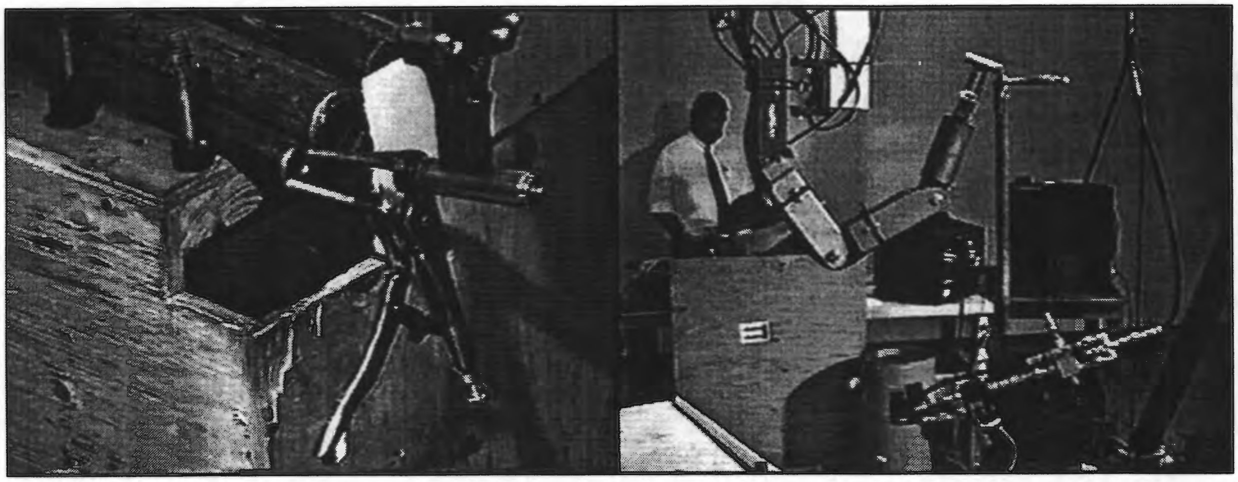

Figure 12. Close-up of SRS Compliant Fuel Handling Tool on the Left, Manipulator with Tool Holding Dummy Inner Element on the Right

The special compliant end effector tool consisted of a small diameter rod attached to one jaw of a vise grip and a clamping plate attached to the other jaw. The vise grip was used as a locking mechanism for demonstration purposes only. The small diameter (approximately 0.25-inch) rod engaged the hollow end of a dummy fuel element. Once the rod (approximately 3-inches long) engaged, the vise grip was manually closed and locked. A real tool of this nature could be hydraulically or mechanically activated with the manipulator jaws as the actuator.

The second part of the end effector consists of a spring-loaded cable attached to the vise grip tool described above. The spring is housed in a 1-inch diameter tube and holds the vise grip firmly perpendicular to the spring-and-tube assembly (Figure 12–Left). Once a fuel element is acquired, its weight extends the spring and the spring releases the cable (approximately 1/8-inch diameter) to provide a spherical type joint (Figure 12–Right). Thus, gravity keeps the element vertical once it is acquired.

The demonstrated arm configuration was with all three pitch joints in-line, as had been attempted in the 305 Building, except that here the base was mounted vertically and the arm was curled up (like an elephant lifting a log from underneath; in the 305 Building the base was horizontal). The base of the slave arm was mounted on a vertical 4-inch square aluminum tube that was supported by an overhead I- beam. The azimuth rotation was mocked by the standard base rotation provided with a Schilling Hydra manipulator (which is limited to a range of 90 degrees rotation).

The tele-operator master controller represented all the joint motions of the slave except that it had one extra, unused link, and the link lengths were not identical to the slave. It did include the azimuth rotation (which had been lacking in the 305 Building mockup). Two video displays and two halogen lights were provided at the control center. One display showed the overall manipulator and allowed a manual zoom of the end effector. The second display provided a view of the basket bottom, from above, for fuel loading.

Phase 2 Testing

Testing was conducted in accordance with the test procedure provided in Appendix D of this document. The basic test setup is shown in Figure 13. In general, testing consisted of subjecting various configurations of the arm and grippers to certain basic fuel handling maneuvers expected to be executed by the arm in actual operation. Three video cameras were placed at strategic locations specified in the procedure, and VCRs were used to record all tests. Camera A was a Panasonic Model WV-CL704 color camera with a Comicar 6 to 1 zoom lens and a Pelco pan and tilt unit. Camera B was a Hitachi Model VK-C150 CMOS color camera with a Computar 6.5 mm right angle fixed focus lens. Camera C was a Panasonic CCD color camera with a 4-mm fixed focus lens.

An opaque curtain was placed between the operator and the fuel handling area, forcing the operator to rely only on the video images to perform each task. The time to complete the maneuver was recorded and the degree of difficulty in completing the task was observed. A unique test number was assigned to each series of maneuvers performed with each hardware configuration. This unique test number is displayed on the video recordings at the start of each segment pertaining to a respective arm configuration. For an overall perspective, a hand-held video camera was also used to record some of the tests.

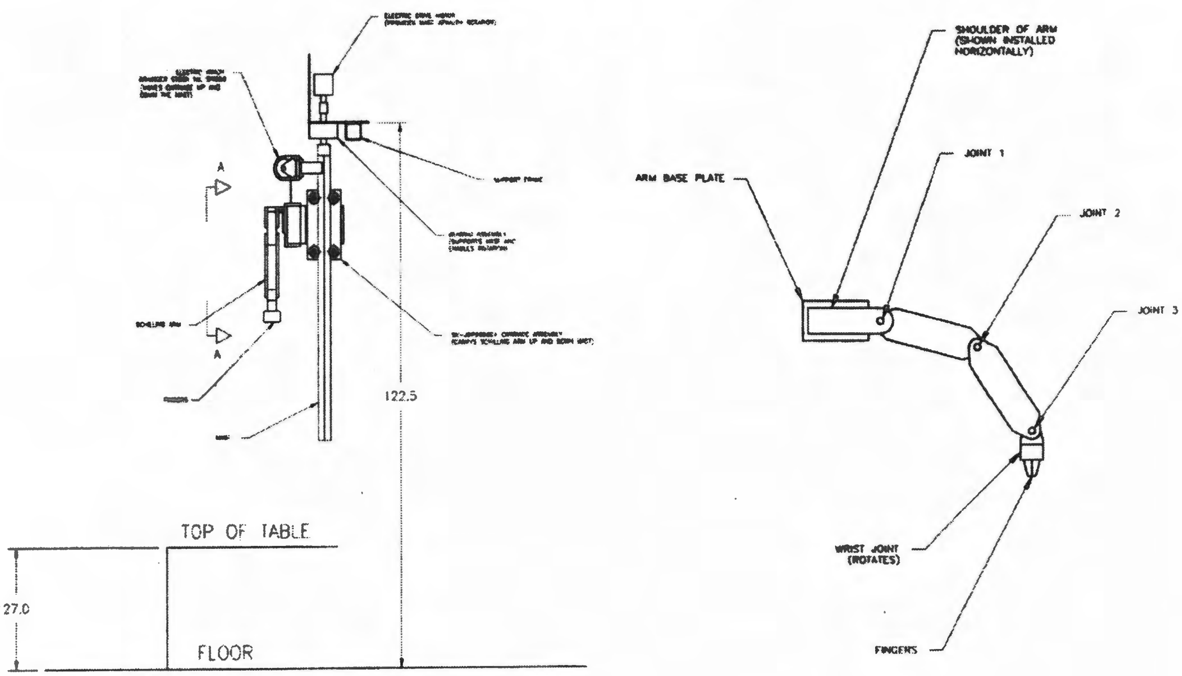

Figure 13. Left - Phase 2 Manipulator Setup, Right - View A-A

The hardware configurations tested per the following parameters, as specified on the respective data sheets in accordance with the test procedure:

- Orientation of Base of Arm (Figure 13 - Right):

  A. Arm base horizontal

  B. Arm base vertical

- Arm Joint Configuration (Figure 13 - Right):

  A. Base joint yaw; two end joints pitch (this is basic configuration as provided from Schilling)

  B. All three joints pitch up

  C. Upper joint pitches up, other two joints pitch down

- Mast Configuration:

  A. No vertical translation, azimuth rotation by Schilling yaw only

  B. Azimuth rotation (by mast or Schilling) and vertical translation

  C. Vertical translation only (no azimuth rotation)

  D. No vertical translation; no azimuth rotation

  E. No vertical translation; azimuth rotation by mast only

  F. Vertical translation; azimuth rotation by mast only

  G. Base joint rolled out, azimuth rotation by mast only, vertical translation

  H. Base joint rolled in, azimuth rotation by mast only, vertical translation

  I. Base rolled in and out, azimuth by mast, vertical translation

- Configuration of Fingers:

  A. 3-inch wide parallel jaws

  B. 3-inch wide V-block jaws

- Special Tools

  A. No special tools

  B. Expanding Collet

  C. Rod/clamp style Gripper

Individual Phase 2 test parameters are listed in Table 1. Test parameters were chosen based on equipment availability and test results.

Table 1. Phase 2 Test Parameters

Test #	Base Orientation		Configuration														Special Tools		
			Joint			Mast									Fingers				
	A	B	A	B	C	A	B	C	D	E	F	G	H	I	A	B	A	B	C
1		x		x		x									x		x		
2		x		x			x								x		x		
3		x			X		x								x		x		
4	x				X		x									x	x		
5		x			X					x						x	x		
6		x			X						x					x	x		
7		x			X		x									x	x		
8		x	x				x									x	x		
9		x	x							x						x	x		
10	x		x									x				x	x		
11	x		x											x	x		x		
12	x		x										x			x	x		
13	x		x				x									x	x		
14	x		x									x				x	x		
Note – Headers A, B, C, ... are defined above.																			

Phase 3 Testing

Phase 3 tests are conducted with the arm base vertical and with the arm configuration having all joints pitch down. Time did not allow testing of all possible combinations, but the goal was to demonstrate fuel-handling feasibility and identify areas for improvement.

Phase 3 testing was conducted using the following test parameters:

- Arm Base Orientation
  - Vertical
- Arm Joint Configuration
  - Pitch down
- Mast Configuration
  - Trolley with azimuth rotation and vertical translation
- End Effectors

  A. Wide V groove grippers

  B. Compliant spring mandrel
- Starting Fuel Location

  A. Tipped from basket onto the process table

  B. Vertical in canister

  C. MCO Fuel Basket loading staging ramp
- Scrap/Debris Tools
  - Wide V-groove grippers
- Dummy Fuel Type

  A. (6) 26-inch long assemblies with loose inner elements and outer elements and without shoes, (6) 26-inch long elements with loose inners and outers and with shoes, (2) 26-inch long elements with inners locked in outers.

  B. Barrel one: (1) 24-inch long assembly with loose inner element and outer element and with shoes, (1) 24-inch long assembly with inner element locked in outer element. Barrel two: Same as barrel one but with 21-inch long assemblies.

  C. Barrel one: (1) 14-inch long assembly with loose inner elements and outer elements and without shoes, (1) 14-inch long assembly with inner element locked in outer element. Weight will be added to elements to represent actual fuel.

Barrel two: (2) 26-inch long assemblies with loose inner elements and outer elements and without shoes, (1) assembly made up of approximately 3-inch segments of inner and outer elements, (3) 26-inch long assemblies with loose inner elements and outer elements and with shoes, (1) 26-inch long assembly with inner element locked in outer element. Also included are five "buggy springs," one latex glove, two one-inch nuts, and a 12-inch piece of wire bent into about a two-inch ball.

- Manipulator Function

  A. Move all fuel from tipped basket to fuel disassembly/inspection area. Move scrap to the scrap basket.

  B. Acquire tool.

  C. Move fuel from sorting area to MCO basket fuel staging ramp.

  D. Move fuel from the staging area to the MCO fuel basket.

  E. Move all fuel from the canister to fuel staging area.

Phase 3 testing included transportation of stuck dummy fuel from a tipped basket/canister to the disassembly area. Full-length fuel that was loose was separated by rotating the elements and sliding the inner element from the outer element, if required, and placed directly into the inspection area. When barrel two of dummy fuel C was used, non-fuel items were placed in the debris bin. Loose fuel materials, such as cladding or buggy springs, were swept into the scrap basket along with fuel segments less than 3 inches in length. When the fuel was located vertically in the canister (B) and the dummy fuel type was C, the canister was dumped onto the process table after the longer pieces were removed vertically. The remaining scrap and debris were then sorted on the table.

Phase 3 test parameters are listed in Table 2. Test parameters were chosen based on equipment availability and test results.

Table 2. Phase 3 Test Parameters

Test #	End Effectors		Starting Fuel Location			Dummy Fuel Type			Manipulator Function				
	A	B	A	B	C	A	B	C	A	B	C	D	E
15	x		x			x			x				
16	x		x					x	x				
17	x	x	x					x	x				
18		x								x			
19	x		x			x					x		
20	x				x	x						x	
21		x		x		x							x
Note – Headers A, B, C, ... are defined above.													

Computer Modeling

The process of repackaging spent nuclear fuel in the K-basin storage facility has been simulated using the IGRIP® 3-D modeling computer program. An IGRIP® model was prepared, in support of the BNFL design efforts, to analyze process table layouts and manipulator configurations. The model is based on the CDR option B table layout and the shorter 50% detail design table layout. The differences associated with the use of a Schilling Titan II manipulator on the shorter table design were also evaluated. The fuel handling process was simulated from the point at which the wash basket dumps fuel onto the process table to the point at which the elements are loaded into the MCO basket. Before basket loading, the elements are sorted, disassembled and inspected.

The simulations concentrated on the manipulator mounted to a bridge/trolley assembly. End effector trajectories and manipulator response during the simulated process were studied to gather information about joint motion. Cycle time calculations were performed to determine the throughput for repackaging the fuel assemblies.

The baseline process simulation is predicated on the table design and system process developed for the CDR. The steps in the process are: picking up fuel assemblies after they are dumped from the washing system, disassembling and separating the fuel assemblies into separate elements, inspecting both the outer and inner elements, and loading the elements into the final MCO. The detailed operational sequences for the fuel handling process are outlined as follows:

1. Acquire Fuel

    1.1 Pick up complete fuel assembly and move to disassembly fixture

2. Disassemble Fuel Elements

    2.1 Push inner element through outer element

        2.1.1 Hold outer element in V-block fixture

        2.1.2 Push inner element through outer element

        2.1.3 Inner element moves to V-block fixture

    2.2 Pick up outer element and move to outer element inspection fixture

    2.3 Pick up inner element and move to inner element inspection fixture

3. Inspect Fuel Elements

3.1 Inspect inner fuel elements (Fixture and cameras are optimized for inner elements.)

3.1.1 Inspect interior walls for cleanliness

3.1.2 Inspect exterior walls for cleanliness

3.2 Inspect outer fuel elements

3.2.1 Inspect interior walls for cleanliness

3.2.2 Inspect exterior walls for cleanliness

4. Load Scrap Elements in MCO Fuel Basket

4.1 Load Single Elements

4.1.1 Pick up outer fuel element

4.1.2 Place outer element into scrap basket in vertical position

4.1.3 Pick up inner fuel element

4.1.4 Place inner element into outer element in vertical position

The above tasks are performed by the first manipulator. The second manipulator performs only the MCO basket loading. While actual MCO basket loading can occur concurrently with fuel element inspection, the simulation is simplified to illustrate loading only after inspection of all elements is completed.

5. Load MCO Fuel Basket

5.1 Load Complete Elements

5.1.1 Pick up outer fuel element

5.1.2 Place outer element into basket in vertical position

5.1.3 Pick up inner fuel element

5.1.4 Place inner element into outer element in vertical position

Assumptions

Several assumptions were made in preparing the IGRIP® model and performing the simulations. These assumptions included:

- Motion of the overhead bridge/trolley assembly was minimized in fuel handling, with the exception of the mast rotation; i.e., the manipulator was required to perform as much of the motion as possible to accomplish the required tasks
- The simulations were guided by, but not restricted to the range of motion of the off-the-shelf Schilling Hydra manipulator
- Manipulator cycle time calculations did not include the potential for reduced performance due to water resistance
- Time durations for discrete activities were provided by BNFL and used for the simulation
- Fuel was dumped from the wash basket for sorting
- Secondary cleaning was not modeled
- For fuel acquiring operations and sorting, the manipulator end effector grabbed the fuel elements/assemblies on the outside middle surface, and not at the ends
- For MCO basket loading operations, the manipulator end effector grabbed the fuel elements/assemblies at the ends to insert the fuel in the MCO basket
- Gripping operations for acquiring fuel at the middle of the element were performed from overhead, with the end effector vertical; fuel ends were acquired with the end effector horizontal
- All manipulator and bridge/trolley assembly motions were simulated to occur simultaneously
- Motion of the trolley across the width of the table was limited to +/- 19 inches (per BNFL).

Test Results and Discussion

Phase 1 Tests

The following sections discuss results of the Phase I testing of fuel handling operations, the Phase 2 testing of various configurations and deployment modes of the Schilling HV manipulator, the Phase 3 testing of alternate manipulator configurations and special tools, and the simulation studies of table layouts and manipulator configurations.

Phase I tests at PNNL were designed to evaluate key features of the table layout, including the wash basket loading and tipping stations; and to study manipulator articulation, arm configurations, and specific and effectors.

Wash Basket Tipping

Wash basket tipping tests were performed in air with a wood mockup of the tipping station associated with the process table (Figure 1). The mockup allowed the ramp slope to vary. Four tests were performed to determine the appropriate ramp slope to direct fuel to the sorting area of the table.

In the first test, 3 solid lead simulated fuel assemblies were placed in the wash basket and tipped onto the ramp which was set at a 25-degree incline. As the basket was rotated at approximately ~0.5 rpm from the horizontal, the assemblies rotated along the contour of the basket and fell onto the ramp at a 90-degree tip angle. Fuel assemblies rolled down the ramp at a speed of more than a foot a second. The fuel rolled uniformly, at almost full speed, until it hit the table stop at 4 feet from the basket.

In the second test, 8 solid lead simulated fuel assemblies started in the wash basket at a horizontal position. The basket was tipped onto the ramp which was set at a 25-degree incline, at approximately 0.5-rpm. The assemblies slid along the inner surface of the basket as the basket was rotated. Fuel assemblies started to fall at a 90-degree basket-tipping angle. The first assembly fell from the basket, bounced off the ramp once, and landed on the flat sorting area below. The assemblies again moved faster than a foot a second as they exited the basket. Again, the assemblies hit the table stop, approximately 4 feet from the basket, at almost full speed.

In the third tipping test, 8 solid lead simulated fuel assemblies were placed in the wash basket and tipped onto the ramp that was set at a 10-degree incline. The assemblies slid on the inner surface of the basket as the basket rotated at approximately 0.5 rpm. Fuel assemblies started to fall from the basket at approximately a 90-degree basket-tipping angle. All assemblies fell out at approximately a 100-degree basket-tipping angle. Down the 10-degree ramp, the velocity of the assemblies was less than half the previous velocity down the 25-degree ramp incline. The fuel assemblies were moving slowly, almost stopped, as they approached the sorting area table stop approximately 4 feet away.

The last test included 8 solid lead simulated fuel assemblies and 2 steel simulated inner elements mixed with 8 approximately 4-inch long sections of scrap pipe and 3 approximately ¼-inch thick pieces of plate stock. These materials were placed in the wash basket and tipped onto the ramp which was again set at a 10-degree incline. The fuel assemblies slid along the inner surface of the basket as the basket rotated at ~0.5 rpm. Fuel assemblies started to fall at approximately a 90-degree wash basket-tipping angle. All assemblies fell out at approximately a 100-degree tipping angle. One piece of crushed pipe did not come out of the basket even at a 100-degree tipping angle. Fuel assemblies stayed relatively aligned and perpendicular to the width of the ramp as they fell out of the wash basket. Four lead assemblies and 2 steel inner elements were held up on the ramp by a piece of plate stock (Figure 14).

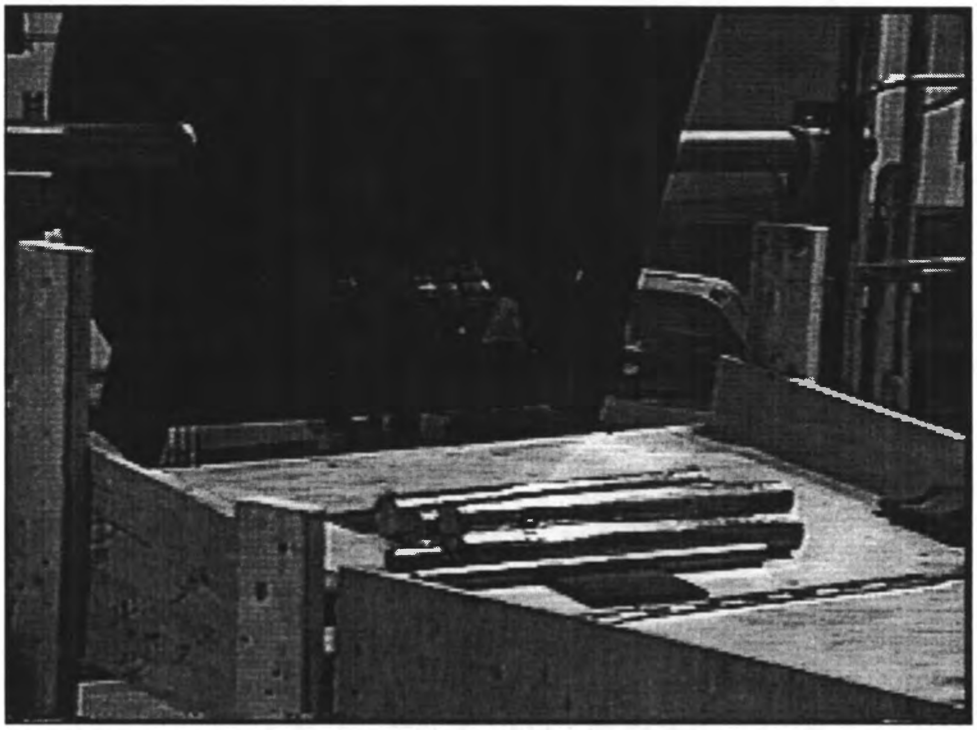

Figure 14. Simulated Fuel Assemblies/Elements Held up on a 10-degree Ramp by a Piece of Plate Stock

In general, the 10-degree ramp incline provides an adequate amount of fuel control. The fuel and scrap are sufficiently directed to the sorting area without too much energy absorbed at the barrier to stop the fuel. The 25-degree incline provides too much velocity to the fuel. Wash basket tipping rotation of greater than 90 degrees is required to empty the basket of fuel. Most fuel and scrap is removed after the basket rotates 100 degrees.

End Effector Tools

Two expanding collets, typical of those used for retrieving fuel by the Characterization Sub-project (Figure 15), were modified to be remotely operated. The modifications consisted of 1) adding a pneumatically operated cylinder to the tapered mandrel which expands the collet and 2) adding a lift bail. The modified collet was then suspended from the overhead crane hook and used to pick and place fuel in

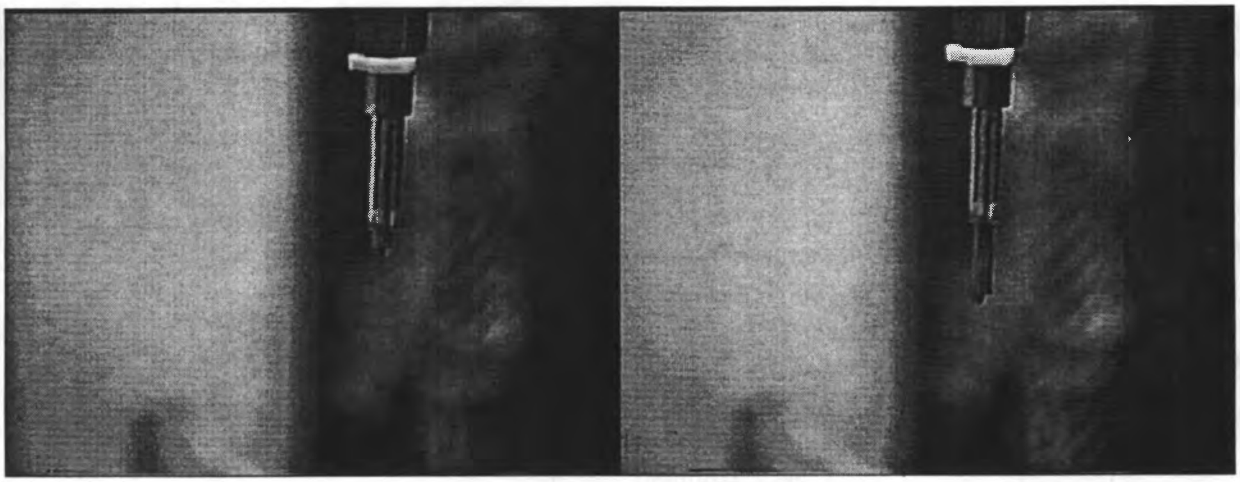

Figure 15. Modified Characterization Collet Tool for End Lifting Inner Element Fuel. Left view shows the collet engaged to lift the ID of a fuel element. Right view shows the collet disengaged for acquisition and release of fuel. Figure 4 shows the complete tool.

a vertical orientation. The crane was used to remotely acquire an inner and outer element for MCO basket loading (socket. design). In a timed test, seven outer elements were retrieved from a fuel canister barrel and transferred vertically to an MCO basket in 9 min. 48 sec. This is an average transfer time of 1 min 24 sec per element. This time could be greatly decreased by using equipment that was better designed for this specific task. Problems included: 1) inadequate slow motion controls on the overhead crane, 2) swaying of the tackle block and hook, and 3) too tight a tolerance between the collet and the fuel element cavity.

In a second test where the collet was managed by hand, an element could be acquired in a canister, moved to/deployed in a MCO fuel basket, and the tool moved back to the canister for the next acquire in less than 10 seconds. Assuming good fuel condition, the tool was efficient, but requires proper deployment.

To gather the inner and outer elements, the standard Schilling HV manipulator was mounted in the inverted position and its jaws were replaced with the tool shown in Figure 6. With the element starting in the vertical position, an inner and an outer could be acquired almost immediately. Observations included 1) a greater dimensional tolerance between the tool and the fuel ID could be accomodated for the collet design, 2) the thin inner prong portion of the tool was easily damaged, and 3) the tool was of limited use for other operations, although it was good at handling debris.

Four tool interface designs were tested for ease of acquisition and control of a tool. The first three designs were similar in nature and evolved through trial and error. The designs consisted of a simple raised cross pattern that fit into a matching slot pattern in the jaws. The first design was flat, the second design beveled, and the third design provided a combination of the flat and bevel that raised the bevel for better alignment. All three designs were poor in their ability to align easily with the jaw slots. The third design, with a larger beveled cross, may have succeeded, but all three designs were discarded in favor of the standard SRS Tee bar design. The 0.5-inch round tee bar easily slipped into and aligned with the jaw whether a circular or V slot was used in the jaw.

The end effector camera provided a view of the jaw during handling. The camera was useful for acquiring small items such as found in debris. The camera had limitations in the field of view and alignment with the jaws, however, since it didn't rotate with the jaws. A zoom and/or wide angle lens might have improved its usefulness.

Basket Loading

The standard Schilling HV manipulator (as supplied by Schilling) was used to lift fuel from the table and load it into a fuel basket. No vertical or azimuth rotation was provided. It was difficult to lift fuel with the standard parallel jaws provided with the Schilling HV. A swivel joint tool (Figure 9) that grabbed the end of the fuel was used to load the socketed bottom MCO basket design. Once the tool was engaged, it was relatively easy to load the basket. It had been very difficult to load the basket with the jaw in direct control of the fuel. The tool allowed the fuel to hang vertically no matter what the arm configuration was. This eliminated the need to articulate the arm into a specific configuration.

The operation of the manipulator was evaluated with the base mounted horizontally, vertically, and at 20-degrees above the horizontal. Special links that changed the manipulator base angle from yaw to pitch were also evaluated with various base configurations. Each configuration had strengths and weaknesses depending on the task required. In general, it appeared that the four-degree of freedom system was simply not enough to perform all required tasks from fuel sorting to basket loading. Mast rotation and vertical elevation were identified as necessary capabilities to perform many of the simple acquisition and deploying tasks.

To enhance the range of motion of the Schilling Hydra manipulator, a rotating mast was added to the base of the manipulator arm. The manipulator arm was also modified to allow all pitch joints to be in line. The arm was oriented with the base perpendicular to the mast. Basket loading was evaluated with the new configuration and found to be extremely difficult. The articulation of the arm traversed the fuel element through an arc. This was satisfactory for picking up elements and moving them, but did not accommodate the motion required for basket loading. In addition, rotating the fuel from horizontal to vertical would have been much easier if the manipulator could have been moved in a vertical plane (e.g., with an elevating mast). The fuel element had to be raised above the table surface prior to rotating it from horizontal to vertical. Although this could be accomplished with multiple movements of the arm joints, it would be much simpler if the arm could be raised to the point where a simple wrist rotation would allow the fuel to be upright. The mast rotation provided a large improvement in arm mobility. The arm could access a much larger portion of the sorting table. The noticeable drawbacks to mast rotation appear to be added mechanical complexity and the fact that greater control is required of the operator.

Placing the fingers or a tool into the inner diameter of the fuel element was also difficult, since the arm does not have a direct translating capability. The end effector is difficult to align with the longitudinal axis of the fuel, and the fuel tends to move while the fingers are being inserted.

Schilling Tests

SRS performed an Application Engineering Study (AES) on Friday July 26, 1996 in accordance with the specification of Appendix B. Jeff Prince and Dave Bennett of SRS presented the demonstration. In general, SRS met the requirements that BNFL had requested, specifically, that a batch of dummy fuel assemblies be acquired from a mock staging area and loaded into an MCO basket in less than 2.5 minutes per element (average). A final SRS report of the study and demonstration is provided in Appendix C.

SRS was able to show that a basket could be loaded within the specified time, though some difficulty in operator coordination was evident. The end effector tool designed by SRS (Figure 10) substantially aided the acquisition of the fuel. Vertical translation would have decreased the time necessary to load the basket.

End Effector Tool

The end effector tool used to acquire and load inner and outer elements was quite different than anything used to date at Hanford. It was similar to the tool developed by 305 Building ETL staff in that it was a modification of the swivel joint approach. It was enhanced with a rod/clamp mechanism to acquire and hold the fuel.

The acquisition piece of the end effector was novel and simple in its approach, and allowed use of a single tool for both inner and outer elements. SRS indicated that it was a simple matter, and of insignificant cost, to make this end effector operate off the hydraulics of the manipulator, and that they could attach it to the side of the last joint, thus leaving the standard jaws available for other needs. Schilling indicated that the tool would be oriented perpendicular to the line of closure of the jaws.

Some advantages of the SRS developed tool, over the collet style tool used by the Characterization Sub-Project, were that it made acquisition of a dummy element simpler because the center rod did not have to fit so closely to the ID of the element, thus limiting the possibility of sticking when the tool is released. The tool does not have to be perfectly aligned with the axis of the element, either. It also eliminates the need for a second tool to handle a different element size.

A second end effector of similar nature was also demonstrated, which grabbed the OD of the outer element using a clamp mechanism. It was intended to demonstrate the handling of a complete assembly by a vise grip. It had the same advantage of being robust for grabbing element ODs of various sizes, possibly including swollen element ends.

Discussion

Schilling indicated that before the demonstration their best time to date was 11 minutes for four full steel assemblies. This translated to an average of 1.38 minutes per element, well under the specified limit of 2.5 minutes per element.

The demonstration manipulator operator was a SRS technician. He loaded four full assemblies in approximately 15 minutes (1.9 minutes/element). This time was affected by interruptions resulting from questions and delays due to the manual gripping of the end effector. The operator did not look at the fuel or manipulator, and used only the camera views. Other factors that Schilling claims affect performance include the limited ability of the operator to see the basket bottom, the slave link lengths not being optimum for the application, the limited azimuth rotation, the inability to translate vertically, and the master-slave relation. The basket bottom was dark, making it difficult for the operator to see that the fuel had engaged the basket socket. Lighting from below may facilitate the fuel placement. Link lengths limited the reach distance and affected the articulation required to acquire, lift and deploy the fuel. Longer lengths are required. Limited azimuth rotation forced the arm to articulate in non-standard configurations at certain points, to perform the required operations. The master-slave relationship also affected the performance, since the master and slave continually required realignment. Final deployment of the fuel, once it was over the basket, would have been greatly enhanced if vertical motion were available. Some time was lost trying to articulate the fuel straight down into the sockets. All of these effects may only amount to seconds, but more importantly, they relate to the man-machine relationship and operator intuition.

Steve Shaw, of LATA, next loaded two assemblies. He performed the effort in 13.5 minutes, or 3.4 elements per minute. He looked directly at the fuel and manipulator and used the cameras only when necessary.

Gary Ketner, of PNNL, ran the manipulator and loaded an assembly. He performed it in 3.5 minutes, or 1.75 elements per minute, while looking directly at the equipment. Constant realignment of the master and slave were required. The extra link in the slave also caused some confusion. The end effector was easier to use and simpler to engage into a fuel end than anything used at the 305 Building tests. It was difficult and more time-consuming to load an inner element vertically into an outer element.

Although the Schilling master controller is the most intuitive on the market, there is still a lack of one-to-one correlation with the slave that limits controllability. One case in point is that when an attempt was made to insert the tool rod into a horizontal fuel dummy, the tool would hang up--usually because the approach angle of the tool did not allow the rod to fully engage into the hole. Rather, it engaged until the tip of the tool rod hit the element ID and then proceeded to push the fuel element.

Jeff Prince performed a fourth test. He loaded 3 assemblies in 16 minutes, or 2.7 elements per minute. He used the cameras to view the manipulator and the fuel. A zoom camera was needed during tool engagement. Another camera over the MCO fuel basket would also have been helpful.

Further work on the AES study and demonstration results is reported in Appendix C.

Phase 2 Testing

The results of this testing are best described in four separate sections: 1) the configuration of the Schilling arm; 2) the configuration of the mast; 3) the type of gripper fingers used; and 4) adequacy of the video cameras. Data sheets with results are included in Appendix E.

Schilling Hydra Arm Configuration

The Schilling arm configurations tested include arm joint variations, as well as variations of the position in which the arm base was attached to the carriage. For these tests, the main objective was for the operator to position the gripper on the fuel element, grasp it, and manipulate it to another position. In general, the fuel was picked up from a flat table, then rotated to a vertical position. Another objective was to pick up fuel which had been pre-positioned vertically in a rack, then rotate it to a horizontal position. Both outer and inner fuel elements were used. The elapsed time to achieve each operation was measured, as required by the procedure. It did not seem a practical use of testing time to perform all tests three times, for each possible hardware configuration combination, as that would result in nearly 300 individual tests. Instead, only enough testing was performed on each configuration to determine any apparent advantages or disadvantages associated with that respective configuration.

The elapsed times measured (Appendix E) to accomplish each individual operation may be misleading as to how they quantitatively relate to the parameter of arm configuration. Other factors affecting the elapsed time may include something as minor as the operator accidentally bumping the gripper against the fuel element, causing it to roll to an area beyond his grasp (this happened on several occasions); viewing difficulties; or the degrees of freedom permitted the carriage to which the arm was attached, etc. Therefore, elapsed times aside, the merit of each arm configuration tested is actually more a qualitative judgement call than a quantitative measure.

In general, it was shown that any of the arm configurations can be made to work reasonably well, provided that sufficient degrees of freedom are available at the arm carriage, and video viewing is adequate. Likewise, any of the arm configurations became more difficult to operate as the degrees of freedom at the arm carriage were reduced (i.e., joints were locked out). Other factors aside, some arm configurations were observed to be better at certain tasks than others. With the base vertical and the arm configuration having all three pitch joints up, the manipulator is in a better arrangement for engaging fuel that is vertical. With the base horizontal and the arm configuration having the base joint pitch up and the outer joints pitch down, the manipulator is best at engaging fuel that is horizontal. Surprisingly, the arm configuration with base joint yaw and the two end joints pitch (the configuration provided by Schilling) was not superior to the other configurations for many tasks.

Mast Configuration

As shown in Figure 13, the arm was attached to a carriage that could translate up and down a mast for approximately 5 feet. The mast was designed to provide 360° azimuth rotation capabilities to the carriage. The carriage translation and mast rotation were each individually controlled by the operator.

For those tests in which the mast rotation and carriage vertical translation were locked out, the arm had great difficulty in performing most fuel handling tasks, regardless of the arm configuration used (thereby confirming past test results). Unless care was given to pre-position the fuel within a relatively narrow access zone, the gripper could not orient itself perpendicular to the fuel as necessary to achieve satisfactory engagement. Even after engagement was attained, the arm often could not manipulate the fuel to another position because the long length of the fuel caused its ends to trace a path not compatible with the top of the table or other nearby obstacles.

The addition of vertical translation resolved many of these handling problems. The zone within which the grippers could be engaged was significantly increased, and after engagement the fuel could be translated away from the table top before attempting to manipulate it. Similarly, but to a lesser degree, mast azimuth rotation tended to eliminate similar problems in a vertical plane.

Jaw Configuration

To save testing time, it was decided to first subject each gripper finger configuration to an attempt to pick up a "heavy" dummy fuel element of the same size and weight as an intact outer and inner fuel assembly. The gripper providing the best results was then used for the remaining portions of the arm test, in which pieces of steel pipe simulating outer and inner fuel elements were used. These simulated elements were of the same approximate size as actual fuel elements, but lighter in weight.

The 3-inch wide parallel flat jaws could not grip the "heavy" cylindrical simulated fuel sufficiently well to allow it to be held horizontally without dropping it, even though the jaws had serrations. Engaging and picking up the fuel when vertical could be achieved, but the grippers could not hold on when the fuel was rotated to the horizontal. Perhaps this gripper could be made to work with hydraulic pressures greater than were available for these tests (the Schilling HV was limited to 2000 psig operating pressure; the Schilling Hydra is designed for 3000 psig).

The 3-inch wide parallel V-block jaws were much more effective at picking up the cylindrical fuel assembly than were the flat jaws, but still left much room for improvement. Horizontal fuel lying on a flat surface often did not set fully within the V-groove, but instead was held more towards the end of the fingers, sometimes resulting in the fuel being dropped. This difficulty in fully engaging the fuel in the V-groove was even more apparent when handling the inner fuel elements, because of their smaller diameter. However, once the fuel was fully seated within the V-groove it could be rotated horizontally or vertically without dropping it. It is recommended that the V-groove be made more pronounced, to see if that reduces the tendency for the fuel to be gripped by the ends of the fingers.

A test was made to determine if a complete fuel element (outer fuel with inner fuel inside it) could be successfully picked up from a horizontal position and rotated sufficiently until the inner fuel element slid out. This was successfully accomplished with the V-block jaws. However, the vertical translation height did not allow rotation far enough above the surface of the work table, resulting in the inner fuel element sliding out and hitting the table before its upper end could clear the outer element. With some mast rotation the inner fuel eventually dropped free of the outer element. A little more vertical translation would have made this test easy. The angle at which the inner fuel element slid out was not measured, but was close to 45 degrees.

Video Cameras

Three video cameras were used to assist the operator in performance of the tasks. These cameras were designated as A, B, and C (Figure 16). Camera A was mounted on a tripod slightly above the work surface to provide an elevation view. Camera B was located approximately 10 feet above the work table to provide a plan view. Camera C was mounted on the wrist of the Schilling arm to provide a close view of the gripper fingers (Figure 10). All three cameras were color, but only Camera B had pan, tilt, and zoom capabilities controllable by the operator.

Figure 16. Camera B on the Left, Camera A on the Right

It soon became apparent that the operator could not efficiently determine how to position the arm joints for a task when he could not simultaneously view the positions of all moveable elements (i.e. the gripper, each arm joint, carriage azimuthal orientation, and carriage elevation).

Initially, Camera B was mounted very close to the mast, about 10 feet above the work table. At this location the cables, hoses, and even the Schilling arm itself, often obstructed viewing of the gripper. Camera B was moved to a location about 5 feet to one side of the mast, still at about 10 feet above the work table. However, because of insufficient wide angle capabilities, Camera B still could not fully see the position of all moveable elements of the arm system without having to change pan/tilt. Camera B was again relocated to get it far enough away such that all portions of the arm system could be seen (this time to a structure about 12 feet from the mast and about 8 feet above the work table).

Camera C, mounted on the wrist of the arm, was not the right camera for the job. Because of its large size and narrow field of view, Camera C had to be mounted so that it protruded out too far from the wrist. This resulted in the camera often being an obstacle to performing a task without bumping it against portions of the table, or against the fuel element itself. Although mounted on the wrist, the camera did not rotate in azimuth with the wrist. Except for showing how the fingers were closing around the fuel (not an insignificant feature), this camera contributed little to positioning the arm. Much work needs to be done to select the right camera and location arrangement for wrist mounting (especially if the gripper must enter into a fuel canister).

The lack of pan, tilt and zoom for Camera A made operations more difficult. The best viewing location for Camera A was found to depend upon the arm configuration and azimuth rotation.

Phase 3 Testing

These tests were follow-ons to Phase 2 tests using what was considered the optimal arm/base configuration. The focus of Phase 3 testing was on the use of end effectors. Refer to Table 2 for test parameters.

In Test 15, a full canister of 26-inch long steel dummy fuel was moved from the sorting area to the disassembly area, using wide V-block jaws. The HV arm was configured with all joints pitched down and the base mounted vertically. Picking and moving fuel was accomplished with relative ease. 14 fuel assemblies were moved from the sorting area to the disassembly station in 23 minutes. The shoulder, elbow, and yaw joints were frozen for the duration of handling of fuel. Only the x, y, z motion of the trolley was used to acquire and move fuel with the manipulator jaw. Assemblies were picked from the ramp side of the sorting area.

The ¼-inch deep V-block style jaws worked very well for acquiring and moving fuel in the horizontal position. Fuel could be handled at the middle or ends and still remain horizontal. The camera positions and types were adequate for these tests. An end effector camera view was not required to perform this activity.

In Test 16, a full canister of 26-inch long steel dummy fuel and assorted debris was moved from the sorting area to the disassembly area, using wide V-block jaws. The HV arm was configured with all joints pitched down and the base mounted vertically. Picking and moving fuel was accomplished with relative ease. Results were identical to Test 15. Dummy steel inner elements with shoes were found to slide out of the outer elements when the fuel assembly was rotated more than 45 degrees from the horizontal. The nine items of trash took nearly as long to move to the appropriate containers as the rest of the fuel. Picking and placing of each item of trash or broken fuel with a gripper type end effector is not very practical. The arm was able to acquire materials from a tipped wash basket, but a broom and dustpan would be useful for this task. Time to complete all tasks was 1 hour and 25 minutes. Camera angles and types were poorly suited to this operation. Smaller items were hard to see with the cameras used. A good end effector camera with wide angle or zoom would have helped debris handling significantly.

Test 17 was the same as Test 16, except that a compliant collet tool was used to pick the ends of the dummy fuel. Loose inner elements were extremely difficult to pick up, since the collet tended to push the inner element inside the outer element and away from the reach of the tool. This was partly due to the tight fit of the collet design and partly due to the inability to align the axis of the tool with the axis of the fuel element. Even after an inner element was acquired, it was difficult to move the arm in a straight path to withdraw the inner element from the outer element. Debris was put in appropriate containers in 46 minutes with V-block jaws.

Test 18 was performed to acquire and stow a tool with jaws, using a tee handle interface. This test was repeated three times and the average time to complete the task was a little over one minute. Arm articulation was not difficult and the tee handle was relatively easy to acquire and deploy. A good end effector camera, with wide angle and zoom capability, would have helped tool acquisition.

In Test 19, a full canister of 26-inch long steel dummy fuel was moved from the sorting area to the fuel staging area ramp for MCO fuel basket loading. The HV arm was configured with all joints pitched down and the base mounted vertically. Picking and moving fuel was accomplished with relative ease. Fuel was acquired using wide V-block jaws and moved horizontally. If elements were placed perpendicular to the slope of the ramp, the fuel rolled smoothly to the bottom of the ramp. If the fuel was placed with a slight angle, it would hang up on the side walls. A nudge of the manipulator typically straightened the fuel and allowed it to roll freely. The dummy elements were steel, and therefore did not have the extra weight that may have helped the actual fuel to self-align and roll down the ramp. Inner elements with shoes were not tested. Inner and outer elements were moved from the staging area to the ramp in 44 minutes. In general, the staging was not difficult.

Test 20 used the same arm configuration as previous tests to load an MCO fuel basket. V-block jaws were used to acquire and load the fuel. It took 45 minutes to load two outer and one inner element into the basket. Once a few assemblies were placed into the basket, there was limited space for the jaw to lower the outer elements into the basket sockets. It was not very practical to load a fuel basket with this configuration. Camera type and position were poor due to the inability to zoom into the basket to see the sockets while loading fuel. An overhead camera directly above the basket would have improved loading times.

In Test 21, fuel was moved from a vertical canister in the sorting area to the MCO basket loading staging area ramp using a compliant collet tool to grab fuel ends. It was not practical to move fuel from a vertical orientation to a horizontal orientation using the compliant tool. Rotating the fuel element using the tool required substantial arm articulation that was very difficult to master. The camera was unable to see into the canister.

It was quickly apparent that there was a high reliance on the overhead trolley. Because two hands were required to articulate the arm with all joints free to move, the operators found that it was easier to perform tasks with only the last joint free using the trolley to position it. Arm articulation with all joints free required significant operator skill.

A problem in acquiring fuel lying against a barrier or wall was discovered early. It was found that the manipulator jaws could not easily get into a position to separate the fuel form the barrier or wall. Picking fuel from the middle of a pile was also difficult, since the surrounding fuel wedged it together. To work around this difficulty, the operators placed a ¾-inch piece of square bar stock alongside all vertical surfaces. This kept the fuel from touching the wall, allowing the manipulator fingers to get between the fuel and the vertical surface. Another possible solution to this difficulty would be to make the sidewalls with a 30-degree slope from vertical.

Again, the end effector camera interfered with many of the operations and was bumped against the table walls many times. In one case it got caught on the outside of the table wall and was almost ripped off. The end effector camera was not used for most operations since an overview of the work zone sufficed. The end effector camera was needed only when a small object had to be handled or a tool had to be acquired. It may have helped in basket loading and fuel withdrawal from the canister, since the operators could not see into the baskets or canisters. The camera mounted during these tests did not have zoom capability and was not oriented to see beyond the ends of the manipulator jaws.

During the review of the videotapes, it appeared that the fuel handling operations went relatively smoothly. During actual testing, however, the operators struggled with which camera to use and with control of the manipulator when more than one joint was articulated. Neither the master controller nor the trolley controller were efficiently placed for operator ease and operation become difficult over long periods. Three different sizes of monitors were used. One was black and white and the others were color. None were placed for ergonomic reasons, but rather for convenient installation. This caused some stress to the operators, since they would tend to focus their attention on the easiest system to view. The easiest monitor to watch was not necessarily the one that made it easiest to control the manipulator.

Lighting was found to be very important. Shadows of objects during close-up work helped in determining depth and avoiding obstacles. Shadows were invaluable in lieu of tactile feedback.

Computer Modeling and Simulation

The spent nuclear fuel repackaging process was simulated to support the project design activities. The baseline simulation model was derived from the Conceptual Design Review (CDR) and the 50% detail design of the table layout. The study evaluated and compared alternate table layouts and manipulator configurations.

Modified Schilling Hydra Manipulator Simulation on the CDR Table Design

Initial testing of the off-the-shelf Schilling Hydra manipulator indicated that a different configuration was necessary to acquire and handle fuel for the process table. An IGRIP® model of a Schilling Hydra manipulator was constructed, with an all pitch-up joint configuration. The inverse kinematic equations were developed based on standard link lengths of 12 inches.

The manipulator was modeled as vertically mounted to a mast attached to a bridge/trolley assembly. The bridge/trolley assembly was modeled with linear motion in the X-Y frame of reference. The mast between the bridge/trolley assembly and the manipulator was modeled to include one vertical and one azimuthal rotation degree of freedom. The Schilling Hydra was modeled as mounted to the base plate on the mast, which hung vertically from the overhead bridge/trolley assembly.

The all-joint pitch-up Schilling Hydra manipulator configuration would not acquire and place spent fuel within the manufacturer's specified range of motion. The manipulator arm and bridge/trolley assembly motion required to perform fuel sorting, disassembly, inspection, and basket loading exceeded the manufacturer's specified joint limits. The IGRIP® simulation showed that, to perform the required handling tasks, the wrist joint should be pitch-down and all remaining joints pitch-up. The basket tipping of fuel was also modeled as a uniform and orderly activity. It is expected that this will not be the case during actual process operations, and that greater dexterity and/or articulation will be required than was modeled. This will be further evaluated during hardware tests in 305 Building.

Figure 17 shows the simulated joint orientations for the Schilling Hydra to acquire, lift and place fuel elements.

The station modeled in this simulation will disassemble, inspect and place a single fuel assembly in about 6.7 minutes. An additional 2.5 minutes is required to load the assembly in the MCO basket. Processing a single assembly requires two assembly picks (30 seconds each), two element puts (10 seconds each), two inspection actions (120 seconds each), and a single press (assembly disassembly)

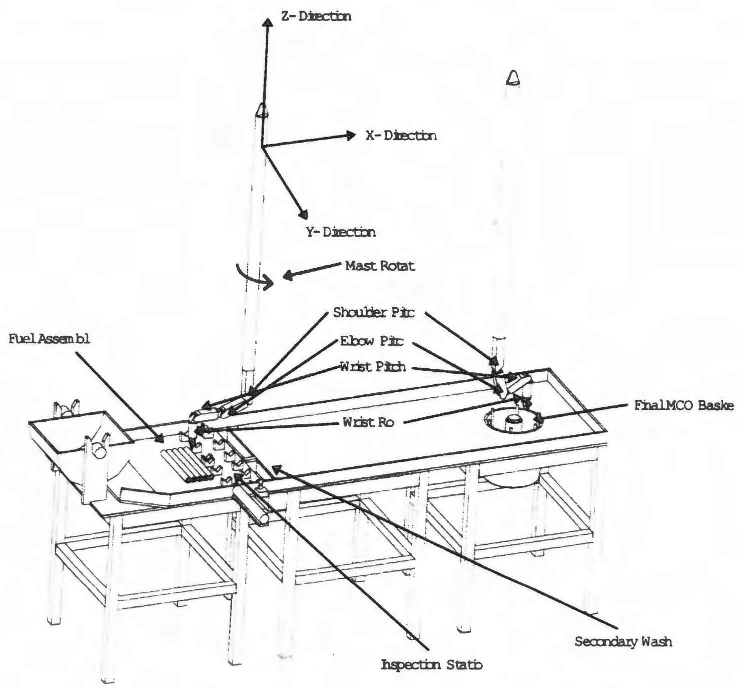

Figure 17. CDR Fuel Handling Station with the Schilling Hydra Manipulator

operation (45 seconds). Thus, out of the 6.7-minutes process time, the manipulator is idle for 365 seconds (6.1 minutes). This is reflected in the manipulator joint angle figures (Figures 18 through 21), where manipulator idle periods are obvious. An important consideration in improving process throughput is to enhance the efficiency of the individual process stations.

The basic Schilling Hydra manipulator mounted on a bridge/trolley assembly should provide a very flexible and capable tool for manipulating objects. If this manipulator system is correctly designed, it should be capable of implementing the desired process even in the presence of rather substantial changes to the table layout or to the process itself. Since a manipulator system that will not do the job will cost just as much as one that will, it is important to ensure that the manipulator system design is correct. In this context, the process cycle time is relatively insensitive to the details of the table layout and design.

The process simulated with the CDR table included only fuel elements that were found acceptable during inspection. No modeling was performed for the handling of unacceptable elements, broken bits, or scrap.

Figure 18 illustrates the joint angles of the Schilling Hydra as an assembly is acquired, disassembled, inspected, and staged for MCO basket loading. Figure 19 shows the trolley/bridge assembly joint displacements for the same activity.

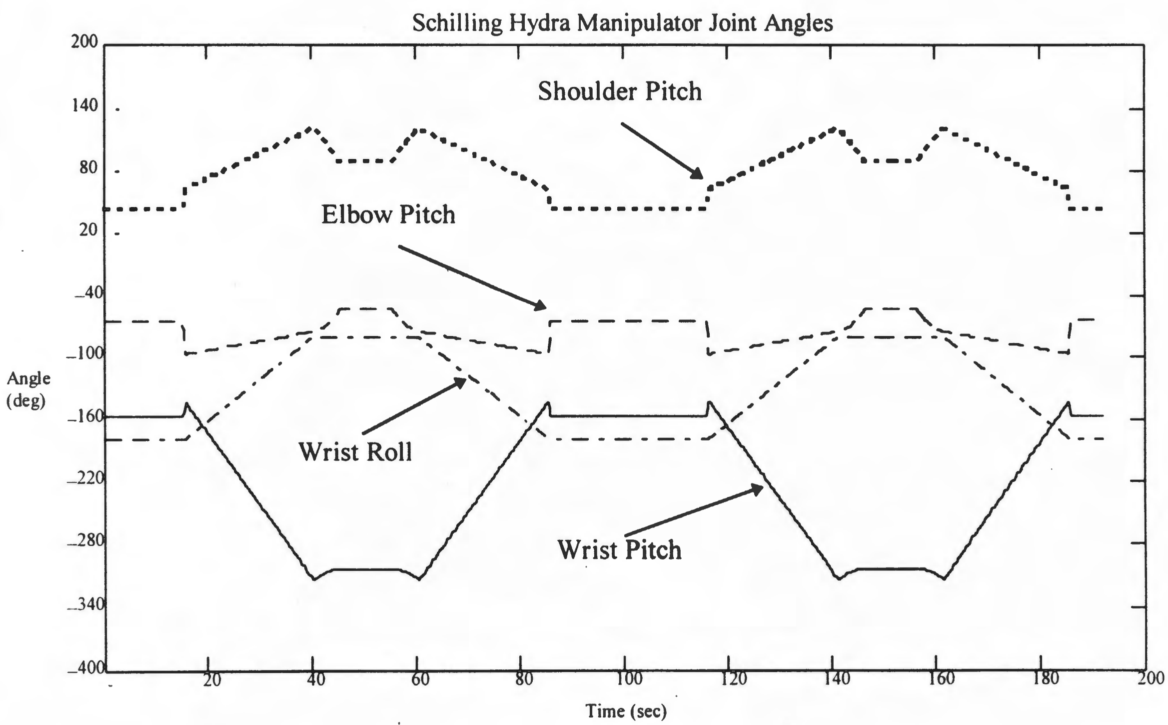

Figure 18. Schilling Hydra Joint Rotations for Sequences 1 Through 4

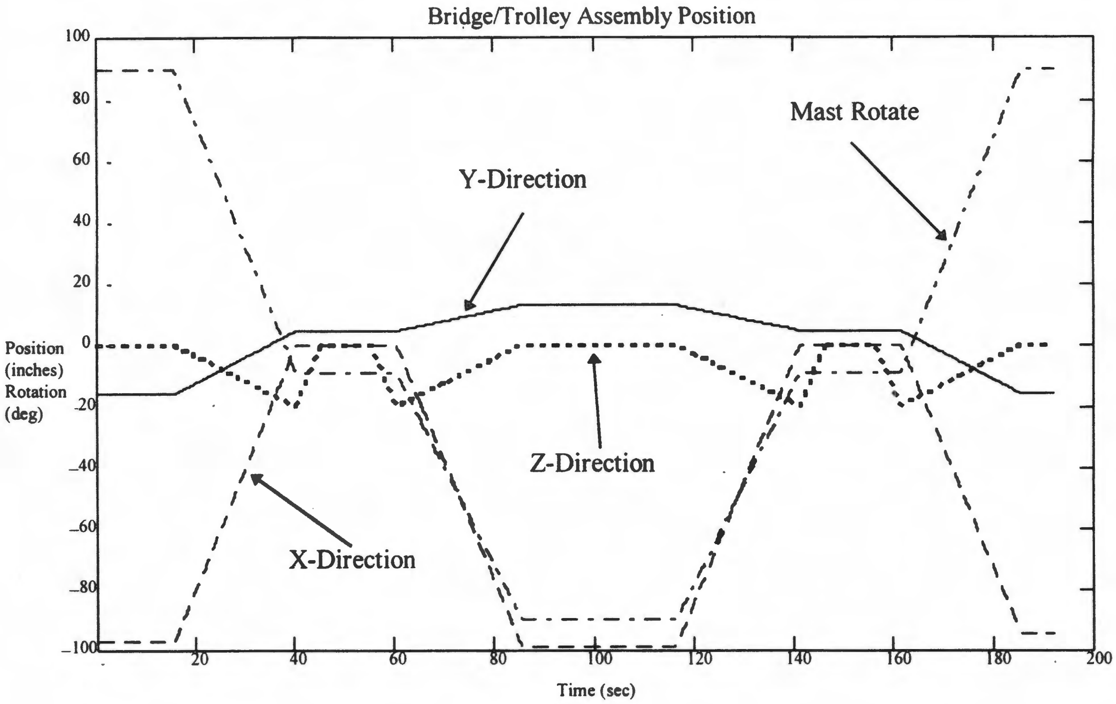

Figure 19. Bridge/Trolley Assembly Displacements for Sequences 1 Through 4

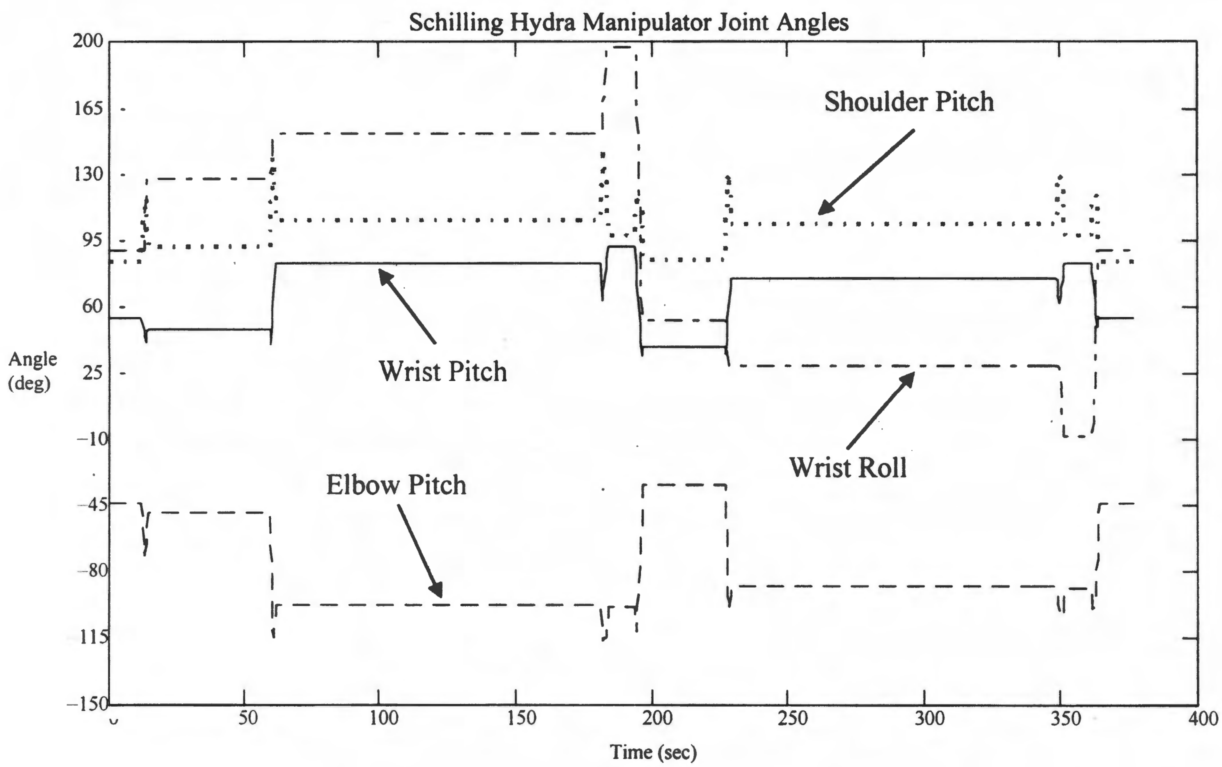

Figure 20. Schilling Hydra Joint Rotations for Sequence 5

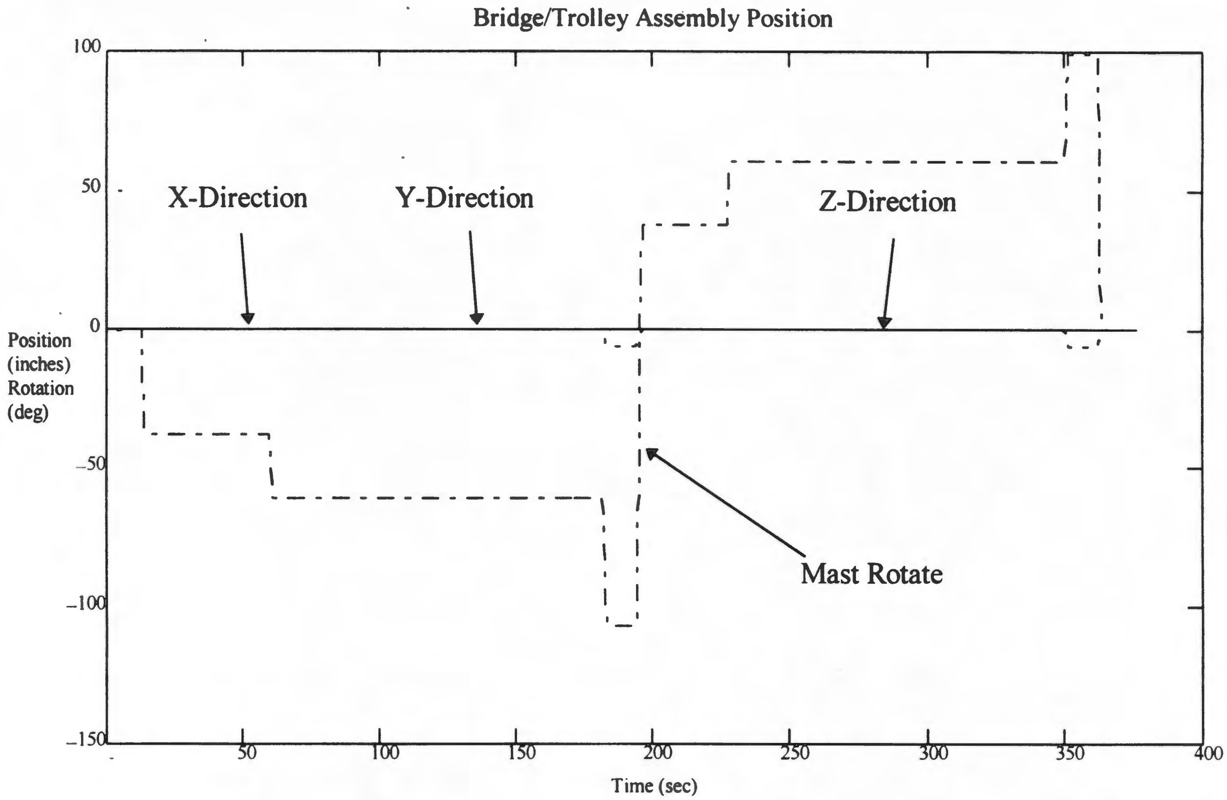

Figure 21. Bridge/Trolley Assembly Displacements for Sequence 5

Each of these figures can be characterized as having long periods of idle time followed by brief periods of motion. It should be noted that this simulation has the bridge/trolley assembly moving at a linear rate of 4 inches per second for each of the linear joints. This is quite slow for this type of equipment; a rate of 12 to 18 inches per second is readily achievable.

Figure 20 shows the joint angles of the Hydra as an assembly is loaded into the MCO basket (Sequence 5). This basket-loading step is not optimized to drive the manipulator efficiently. Figure 21 shows the joint displacements of the bridge/trolley assembly for the MCO basket loading task.

The same model of the Schilling Hydra manipulator and the bridge/trolley assembly from the CDR simulation were used in this simulation. Several variations of the final table layout were investigated. Changes to the table layout were made to circumvent manipulator constraints as well as process constraints. Changes included the removal of the secondary wash and the addition of the scrap bit basket. Final layout of the table and the process is shown in Figure 22. Figure 22 also shows the simulated joint orientations for the all joint pitch-up Schilling Hydra for acquiring, lifting, and placing fuel.

IGRIP® was used to determine manipulator reach envelopes for off-table loading of fuel elements and bits/scrap. It was determined that the modified Schilling Hydra manipulator would perform off-table loading operations within a reach envelope of 53 inches from the table center, given a +/- 19-inch table

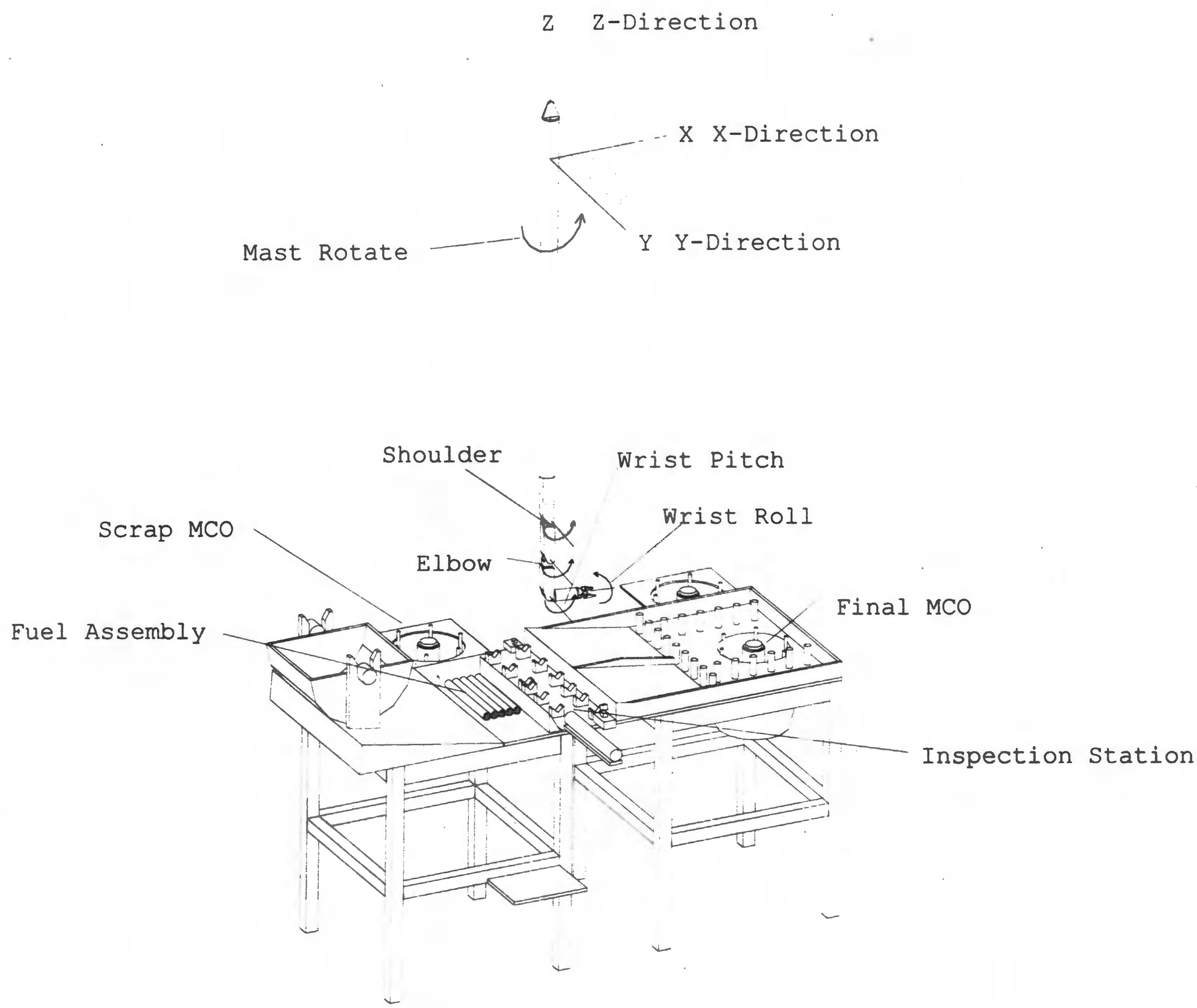

Figure 22. 50% Design Fuel Handling Station with the Schilling Hydra Manipulator

width translation of the trolley. Without the trolley, the manipulator is limited to a 34-inch radius of effective fuel handling. With the wrist joint in the vertical orientation, this radial range reduces to 20 inches.

Modified Schilling Hydra Manipulator Simulation on the Latest Table Design

The joint rotations executed in the IGRIP® simulation of the modified Schilling Hydra manipulator and bridge/trolley assembly were recorded throughout the simulations. The resulting motions for the modified Schilling Hydra manipulator are shown in Figures 23 through 28. Figures 23 and 24 show the results for the modified Schilling Hydra manipulator and the bridge/trolley assembly performing Sequences 1 through 3 on one fuel assembly, as described in the process sequence above. Figure 23 also shows the time required to process one fuel assembly. The total time to perform Sequences 1 through 3 on one fuel assembly was ~400 seconds or 6.7 minutes. In all figures, the time axis starts near the beginning of the described process and ends near the end of the described process. These times were the result of calculations made using process times provided by BNFL for discrete activities, and manipulator motion velocities provided by Schilling for articulating the arm into position for the next discrete activity. The Schilling Hydra manipulator and overhead bridge/trolley were operated at 75% of the manufacturer-specified maximum velocity in an air environment. The velocity of the manipulator could be significantly less in water due to resistance created by water viscosity.

Figure 23 shows the manipulator action with integrated joint motion to achieve minimum duration. To maximize throughput for each operation, the manipulator must move all the joints simultaneously. The present method of controlling/operating the manipulator slave arm is with a kinematically similar master arm. This master controller allows integrated joint movements of the manipulator, with the use of two hands by the operator. Ergonomic studies (References 1 through 5) have shown that over time an operator's efficiency is reduced, due to the repetitive nature of the process.

To reduce fatigue, the optimum method of operating the manipulator is to use pre-programmed tasks (semi-automation), after the assembly or element has been acquired and lifted.

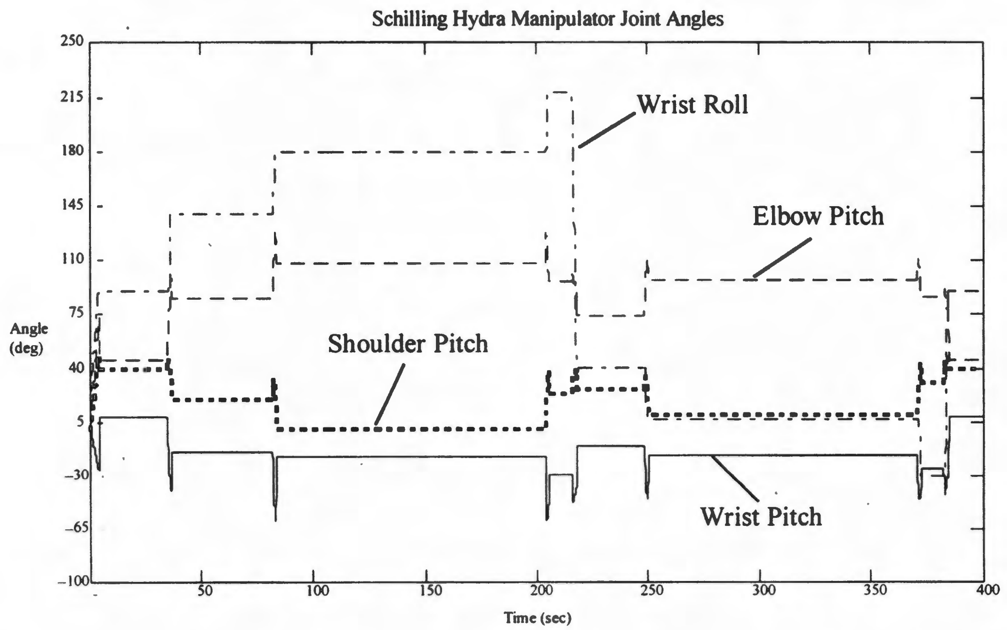

Figure 23. Modified Schilling Hydra Joint Rotations for Sequences 1 Through 3

Figure 24 shows the joint motion for the bridge/trolley assembly covering Sequences 1 through 3. The only required motion of the bridge/trolley assembly was to rotate the mast to orient the manipulator properly for acquire and place operations.

Figures 25 and 26 show the manipulator joint positions when the modified Schilling Hydra was used to load three complete assemblies into the scrap MCO basket located by the inspection station. Figure 25

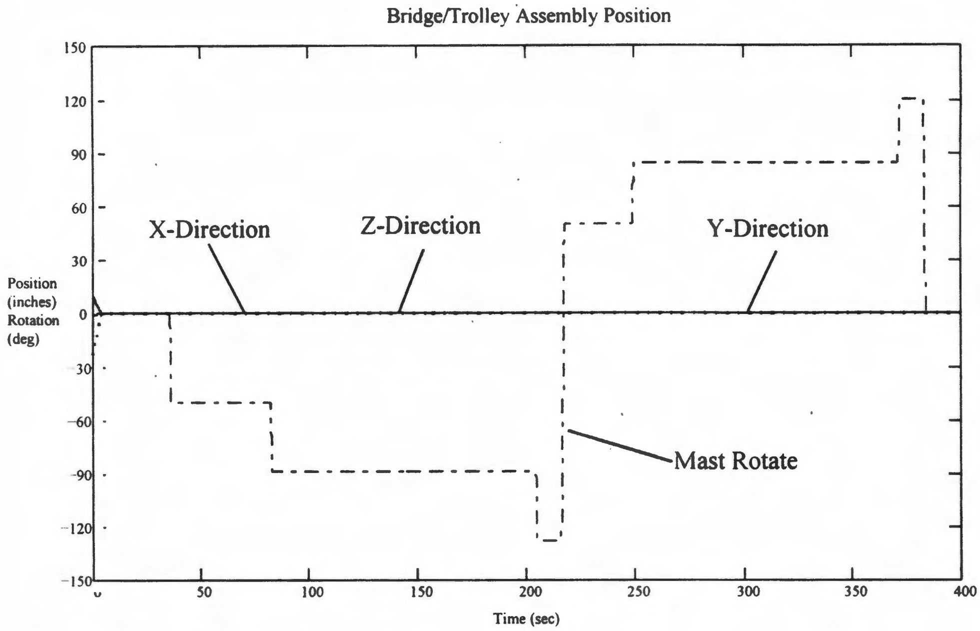

Figure 24. Bridge/Trolley Assembly Displacements for Sequences 1 Through 3

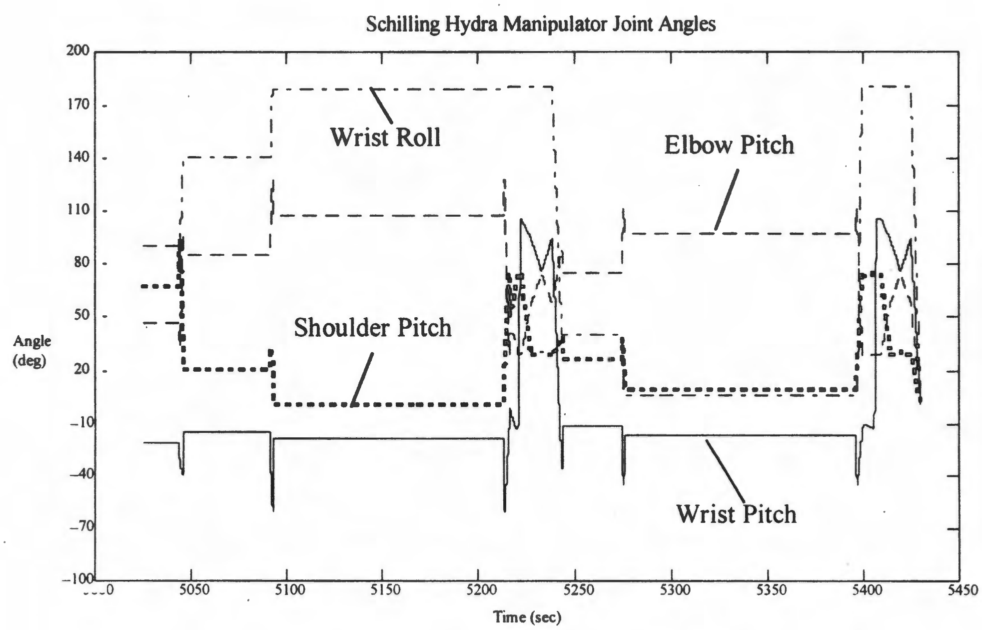

Figure 25. Modified Schilling Hydra Joint Rotations for Sequences 1 Through 4

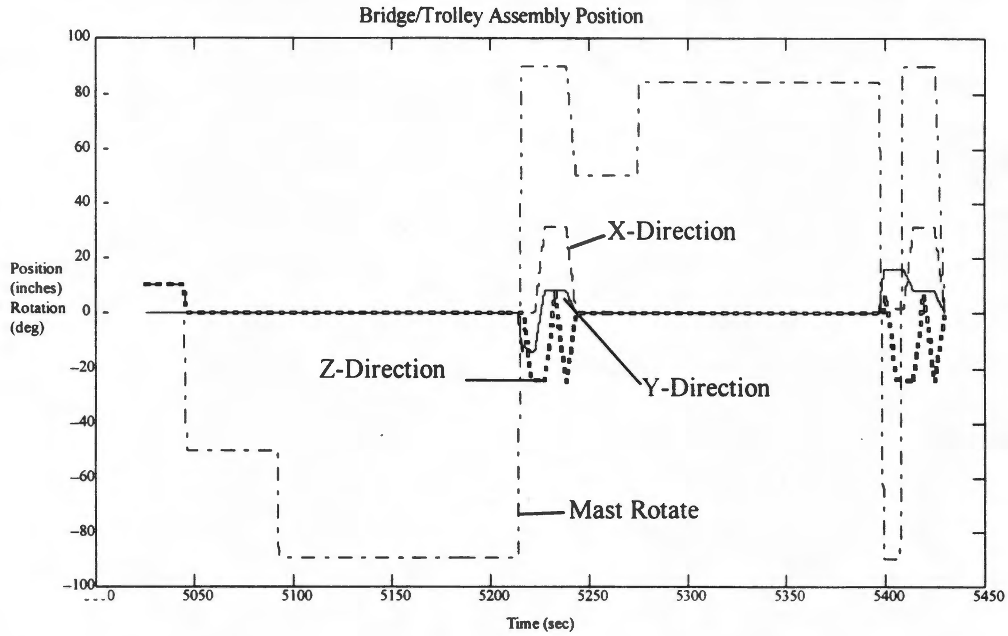

Figure 26. Bridge/Trolley Assembly Displacements for Sequences 1 Through 4

shows the joint positions for the modified Schilling Hydra manipulator. Figure 26 shows the translations/rotations for the bridge/trolley assembly. The overall motion required to move the fuel elements into the scrap MCO basket was much greater than the motion used to inspect the assemblies.

As mentioned previously, Sequences 1 through 3 were simulated with integrated motion of the manipulator joints. Sequences 3 and 4 were simulated with additional integrated motion of the manipulator and the trolley assembly. Even though the ranges of motion are larger for loading the scrap MCO basket, they still fall within the limits for the modified Schilling Hydra manipulator and the bridge/trolley assembly. To optimize performance, integrated path planning was used for all degrees of freedom of the system, i.e., all the joints and the bridge/trolley assembly were moved at the same time. If the degrees of freedom were not integrated, then these motions would have been made in a stepped, or one at a time, approach. A stepped approach would reduce the throughput rate and require more operator involvement. Integrated path planning for routine repetitive activities, such as moving the fuel from the disassembly station to the inspection station, would again reduce the demand on the operator and increase the throughput rate.

Figure 26 shows the motion of the bridge/trolley assembly to load unacceptable fuel assemblies into the scrap MCO basket. The bridge/trolley assembly motion in the y-direction hits a limit when the fuel assembly is loaded into the scrap MCO at the farthest location from the center line of the table.

Figures 27 and 28 show the manipulator and bridge/trolley assembly motion required to acquire fuel elements from the staging ramp and load them into the final MCO basket (Sequence 5). Loading the fuel assemblies into the final MCO required the full capabilities of several joints on the modified Schilling

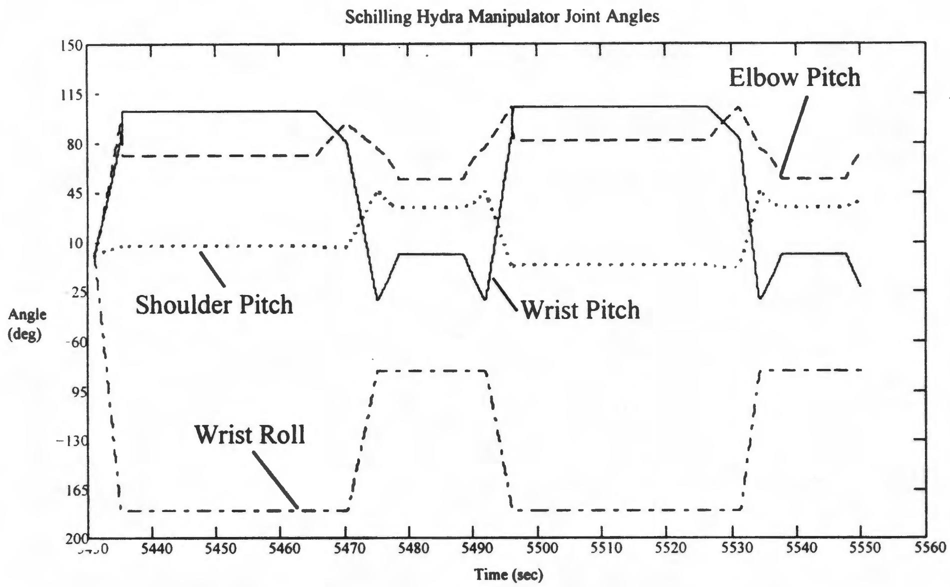

Figure 27. Modified Schilling Hydra Joint Rotations for Sequence 5

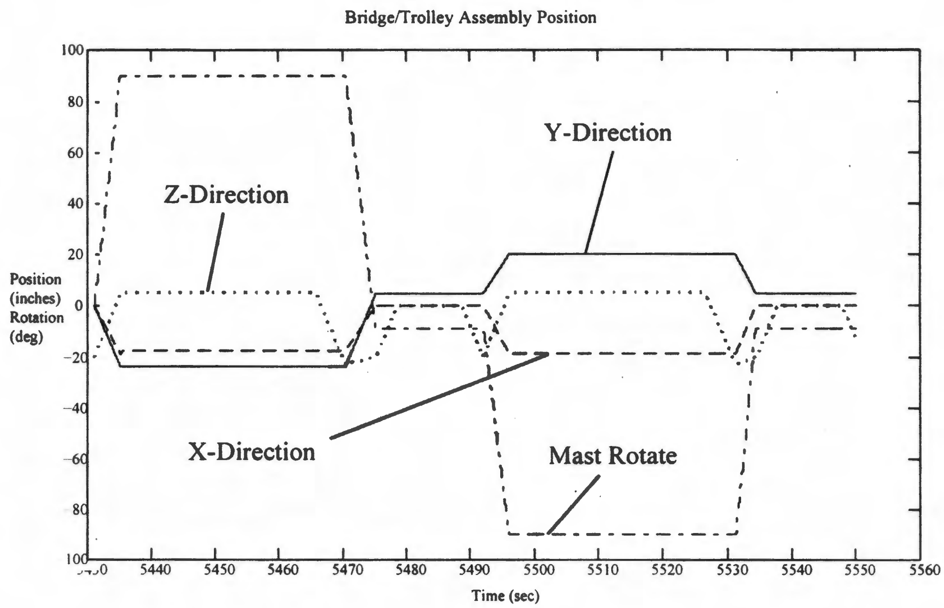

Figure 28. Bridge/Trolley Assembly Displacements for Sequence 5

Hydra manipulator with significant trolley travel using all four degrees of freedom. This sequence, when compared to the previous two sequences, requires less frequent overall integrated joint motion, but requires the manipulator's joints to rotate through much larger angles.

Figure 27 shows the joint motion required by the Schilling Hydra manipulator to acquire two inner and one outer fuel element and load them into an MCO basket. Figure 27 indicates that the time required to complete the processing of one fuel assembly is ~110 seconds or 1.85 minutes.

Figure 28 shows the motion required of the bridge/trolley assembly, to allow the modified Schilling Hydra manipulator to perform the activity of Sequence 5. Integrated motion of the bridge/trolley assembly and the Schilling Hydra manipulator was simulated.

When operation of the bridge/trolley assembly was separated from, and managed in series with, the manipulator motion, the process times increased by approximately 1.0 minute for a clean, acceptable fuel element, and by approximately 1.3 minutes for a damaged, unacceptable fuel element that had to be disposed of in the scrap basket.

The total number of joint rotations, defined as movement through an arc without reversing direction, for the Schilling Hydra manipulator to process one full assembly (clean and acceptable) on the 50% design process table was 74, and 34 of these were associated with basket loading. For an unacceptably damaged assembly processed to the scrap basket, the total number of joint rotations was 96. Since there are 3 joints per manipulator, the normal process averages to 13 rotations per joint per assembly for Sequences 1 through 4. Assuming that there are approximately 3500 canisters per basin, with 14 assemblies per canister, this results in a lifetime total of 546,000 rotations per manipulator joint.

Schilling Titan II Manipulator Simulation on the Latest Table Design

An IGRIP® model of a Schilling Titan II manipulator was constructed for a comparative analysis with the modified Schilling Hydra manipulator. The manipulator was mounted on a mast attached to a bridge/trolley assembly. The bridge/trolley assembly provides linear motion in the X, Y, and Z frame of reference. The mast also includes an azimuthal rotational degree-of-freedom. The Schilling Titan II was mounted to the base plate on the mast, hanging vertically from the overhead bridge/trolley assembly. One key difference between the Titan and the Hydra is that the Titan is mounted like a system placed on a table (base joint rotates above the horizontal); for the Hydra, the base is inverted (base joint rotates below the horizontal). Final layout of the short table design using the Schilling Titan II manipulators is shown in Figure 29.

The joint rotations from the IGRIP® model of the Schilling Titan II manipulator and trolley were recorded throughout the simulation. The results for the Schilling Titan II manipulator are shown in Figures 30 through 35. Figures 30 and 31 are the results of the Schilling Titan II manipulator and the bridge/trolley assembly performing Sequences 1 through 3. Figures 30 and 31 show the results of processing one fuel assembly.

Figure 31 shows the motion of the bridge/trolley assembly for Sequences 1 through 3. The only required bridge/trolley assembly motion was the rotation of the mast to orient the manipulator properly for acquisition and placement operations.

Figures 32 and 33 show the joint rotations when the Schilling Titan II was commanded to load one complete assembly into the scrap MCO basket. Figure 32 shows the joint rotation for the Schilling Titan II manipulator. Figure 33 shows the positions of the bridge/trolley assembly. The motion required to move the assembly elements to place them into the scarp MCO basket was much larger than the motion used to inspect the assemblies.

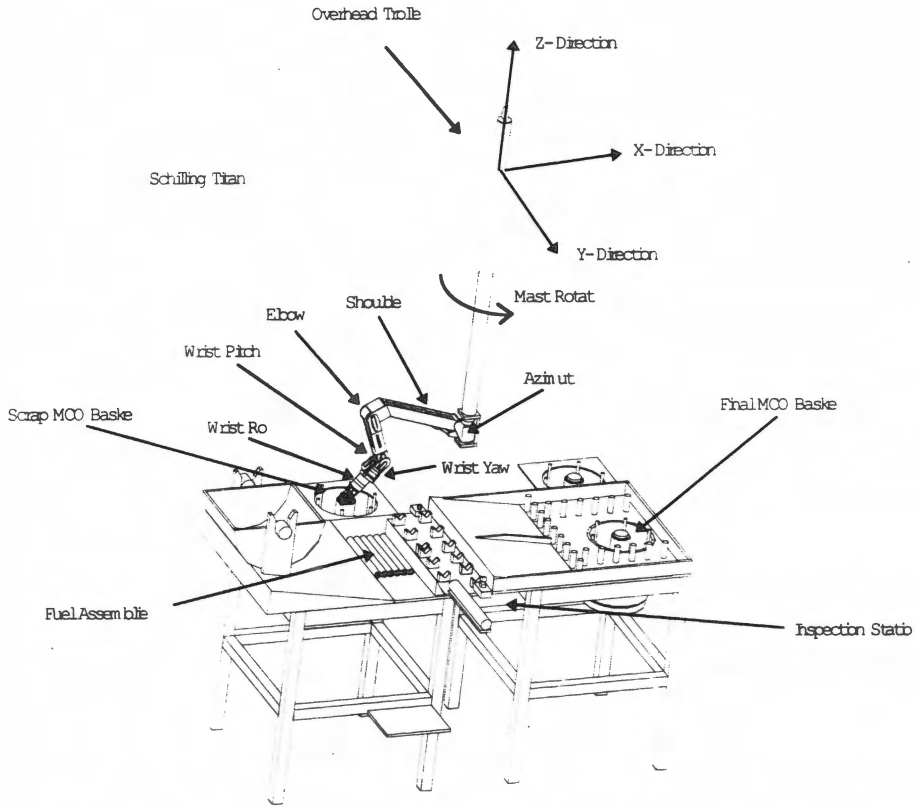

Figure 29. K-Basin Fuel Handling Station with the Schilling Titan II Manipulator

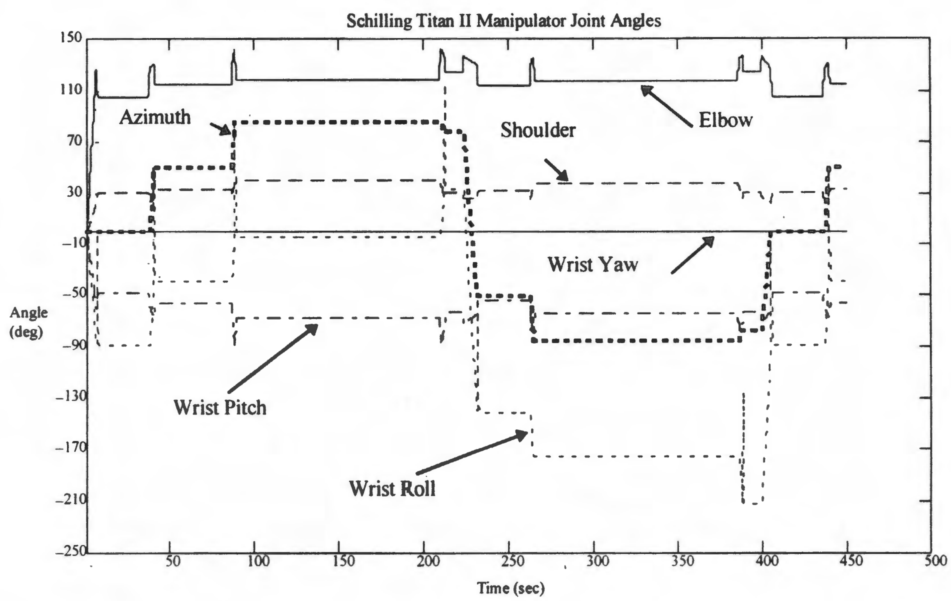

Figure 30. Schilling Titan II Joint Rotations for Sequences 1 Through 3

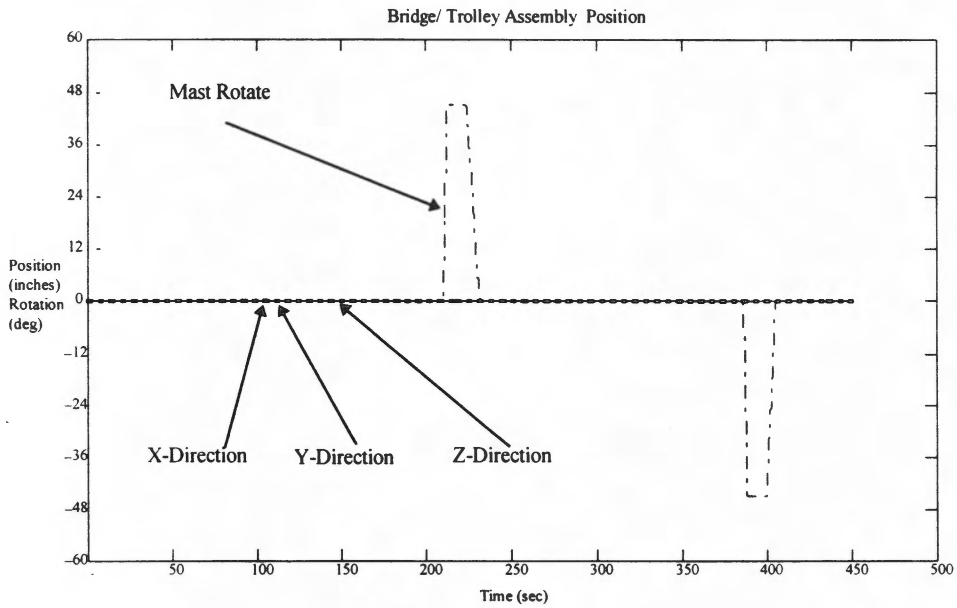

Figure 31. Bridge/Trolley Assembly Displacements for Sequences 1 Through 3

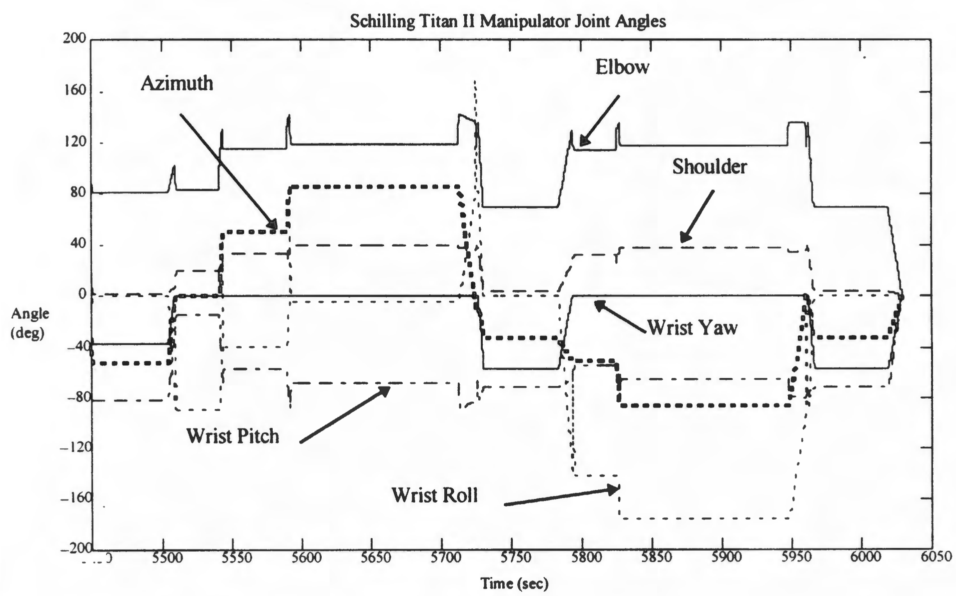

Figure 32. Schilling Titan II Joint Rotations for Sequences 1 Through 4

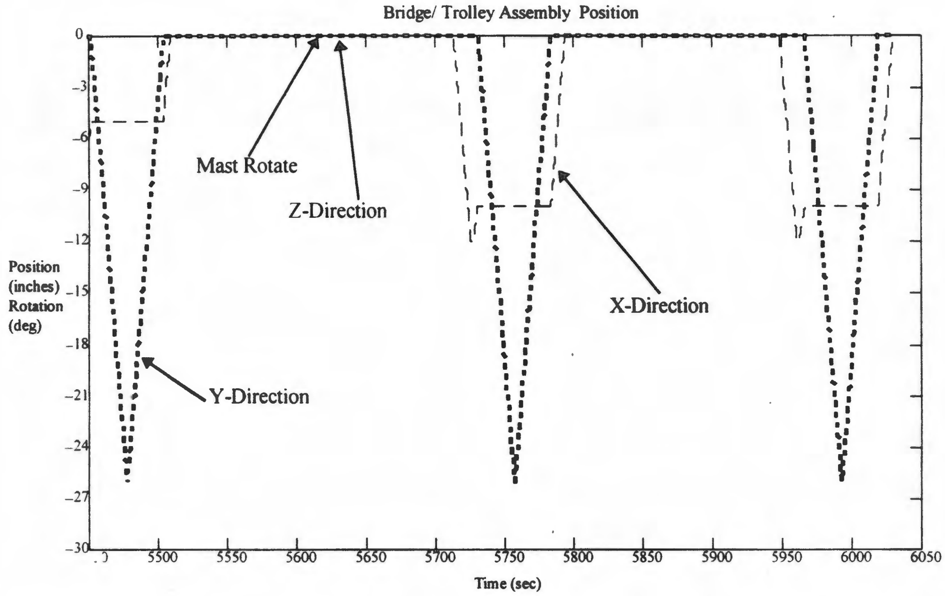

Figure 33. Bridge/Trolley Assembly Displacements for Sequences 1 Through 4

As mentioned previously, Sequences 1 through 3 are simulated with integrated motion. To maximize throughput, Sequences 3 and 4 require additional integrated motion of the manipulator and the trolley assembly resulting in larger joint rotations. Even though the motions to load the scrap MCO basket are larger, they still fall within the range limits for the Schilling Titan II manipulator and the bridge/trolley assembly. To optimize performance, integrated path planning was used for all degrees of freedom of the system.

Figure 33 shows the motion of the bridge/trolley assembly to load unacceptable fuel assemblies into the scrap MCO basket. The vertical motion hits a limit as the fuel assembly is loaded into the scrap MCO basket at the point farthest from the process table centerline.

Figures 34 and 35 show the manipulator and bridge/trolley assembly motions required to acquire fuel elements from the ramp and load them into the final MCO basket per Sequence 5. Loading the fuel assemblies into the final MCO basket required the full capabilities of several joints on the Schilling Titan II manipulator. Significant bridge/trolley assembly travel was also required, but with only two degrees of freedom.

Sequence 5 was simulated with integrated path planning between the manipulator and the bridge/trolley assembly. Figure 34 shows the joint motion of the Schilling Titan II manipulator for acquisition of one inner and one outer fuel element and loading them into the MCO fuel basket.

Figure 35 shows the motion required for the bridge/trolley assembly to support the Schilling Titan II manipulator in the performance of Sequence 5. Integrated motion of the Schilling Titan II manipulator and the bridge/trolley assembly was simulated.

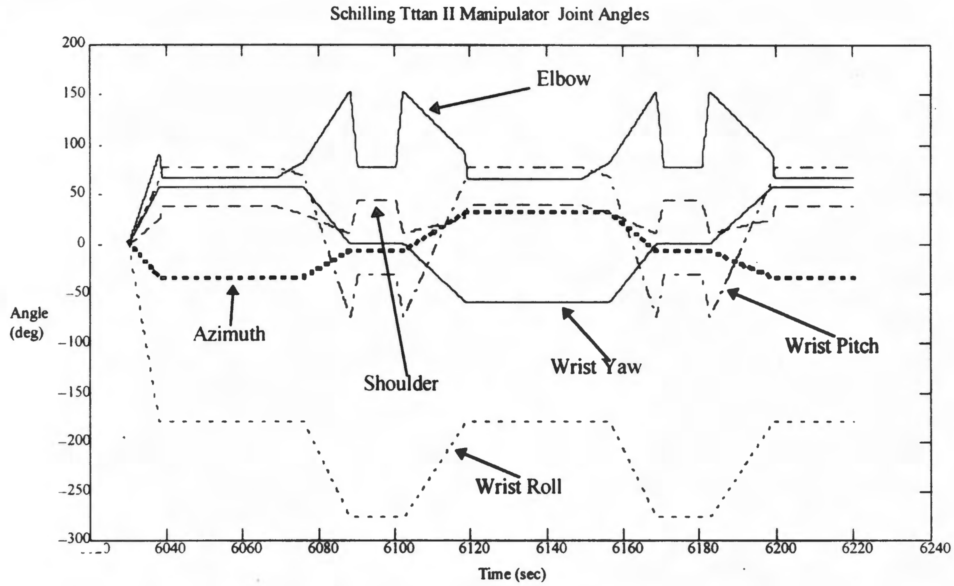

Figure 34. Schilling Titan II Joint Rotations for Sequence 5

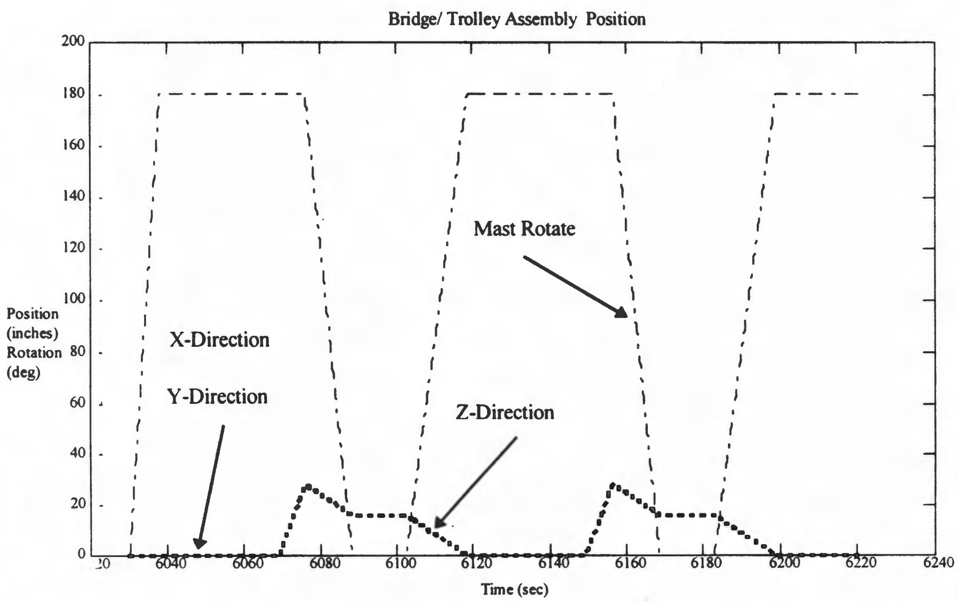

Figure 35. Bridge/Trolley Assembly Displacements for Sequence 5

Manipulator Comparisons

The differences between the modified Schilling Hydra manipulator and the Schilling Titan II manipulator are the number of degrees of freedom (DOF), the ranges of motion (ROM), the length of each link, and the configuration of each joint. Table 3 compares the modified Schilling Hydra manipulator and the Schilling Titan II manipulator.

Table 3. Comparison of Manipulator Types

	Modified Hydra				Titan II			
Joint	DOF	ROM	Link Length (in)	Slew Rates (deg/sec)	DOF	ROM	Link Length (in)	Slew Rates (deg/sec)
1	Pitch	+90, -30	12.0	300	Yaw	+135, -135	4.77	64
2	Pitch	+90, -30	12.0	300	Pitch	+78.19, -41.41	33.19	64
3	Pitch	+90, -30	12.0	400	Pitch	+90, -180	19.0	112
4	Roll	270, continuous	N/A	600	Pitch	+90, -90	5.25	240
5	N/A	N/A	N/A	N/A	Yaw	+90, -90	3.95	240
6	N/A	N/A	N/A	N/A	Roll	360, continuous	9.4	360

Several differences are readily apparent from Table 3. First, the modified Schilling Hydra manipulator has only 4 degrees of freedom, consisting of three pitch joints and one roll joint. The Schilling Titan II has 6 degrees of freedom consisting of two yaw, three pitch, and one roll joints. Second, the link lengths give an overall length of 36 inches for the modified Schilling Hydra and 75.6 inches for the Schilling Titan II. The Schilling Titan II has larger ranges of motion for all joints, where as the Schilling Hydra joints are limited due to the use of linear actuators.

The full extension capacity for the Schilling Hydra manipulator is 60 pounds; the Schilling Titan II has a payload capacity of 240 pounds. The other significant differences between the Schilling Titan II and the Hydra are the slew rates for each joint. The Titan II is slower than the Hydra by a factor of about 4. When the human interface is considered along with the master-slave configuration and the fact that the system will be operating under water, these speed differences become less significant than they presently appear. Considering the importance of the cycle time in processing the fuel assemblies; any speed difference could become an important factor. The simulation shows a slight speed difference between the Titan II and the Hydra, but the cycle time is still dominated by the non-manipulator processes occurring on the table.

Man-Machine Interactions and Training

In the fall of 1994, Bechtel Hanford contracted with Columbia Energies of Richland, Washington to develop a program to train Decontamination and Decommissioning (D&D) workers in the operation of the Remotely Operated Sediment Extraction Equipment (ROSEE). ROSEE is a tractor-mounted Schilling Hydra manipulator in use at the 100-N basin. The purpose of this system is to remotely pick up small items, such as buggy springs and fuel clips; and to hold a vacuum head to remove sludge from the from the floor of the 100-N basin.

The Columbia Energies training program consisted of roughly 15 hours in the classroom and 15 hours of practical manipulator operation. Following the 30 hours of training, the D&D workers were given a written test and a hands-on practical test. The written portion (module seven) of the training is attached to this report as Appendix F.

Eight of the 100-N Bechtel D&D workers received training by this method. In early 1995, union issues stopped the training. It is the belief of the union that if the crafts are required to take a written test to operate the system, they warrant a special craft classification. Bechtel did not want to have a special classification for trained ROSEE operators, so the Columbia Energies training and testing program was terminated.

The present method of 100-N operator training is 16 hours of on-the-job training by a certified operator in a one-on-one mode. After the 16 hours or when the trainee is comfortable with the operation of the manipulator, the trainee is required to perform eight predetermined actions. These actions include safe start up of the hydraulic power unit, pickup of a designated object, and safe shut down of the manipulator. The on-the-job evaluation sheet (Course Number 105020) is provided in Appendix F.

Overall manipulator competence varies widely from operator to operator. About 20% of the personnel possess the necessary hand-eye coordination to operate the equipment in a proficient manner. Many of the operators were unable to perform even the simplest task with the manipulator. Performing repetitive tasks with the manipulator in a 2-D mode (using a regular camera) greatly decreases the capability of the operator, regardless of training.

The ergonomics of the workstation were found to be highly influential in the productivity of the operator. The positions of the manipulator master, camera pan/tilt control, monitors and tractor joystick were all found to be very important. The maximum time an operator could be expected to run the ROSEE system at one sitting is about two hours, with productivity falling off drastically in the second hour.

Conclusions

Testing Results

The test results clearly indicate that the Schilling Hydra arm cannot effectively perform the fuel handling tasks required of it unless it is attached to some device that can impart vertical translation, azimuth rotation, and X-Y translation like a gantry robot. These additional degrees of freedom are needed because each joint of the arm is restricted to travel in a radial path about a pivot point. Without any translation capabilities (in X, Y, or Z), this does not work well for handling long objects that are close to obstructions. If the project had opted for the Schilling Hydra, additional testing would have been recommended to evaluate the performance of different configurations of the Schilling arm when attached to a device which can provide these additional degrees of freedom.

Recognizing that the Schilling Konan arm tests will include Z translating abilities (with azimuth rotation) by means of a trolley device, it is recommended that color video cameras and lights be placed at opposite ends of the traveling bridge. Each camera should be equipped to pan, tilt and zoom. The zoom at wide angle must be able to provide simultaneous viewing of all moving elements and joints of the arm, its gripper, and the arm base; and at telephoto must provide close-up views of the gripper, at the operator's discretion. The wrist-mounted camera should not protrude in such a manner that it interferes with the fuel being handled by the gripper. The wrist-mounted camera should be enclosed in a housing that will protect it from damage when bumped against an obstacle.

The control system of such a carriage-mounted arm needs to be greatly improved to achieve reasonable process throughput rates without operator "burn out". In the arm tests addressed in this report, the operator had to carefully plan how to individually position each joint of the arm, as well as the amount of vertical translation and mast rotation. This is like having to stop and think about how to position and move each joint in your fingers, wrist, arm, and shoulder in order to reach out and pick up a pencil. The control system of the site equipment should allow the operator to concentrate on the task to be performed, without having to think about how to move each movable element of the system; those functions need to be automatically performed by the control system. It is recognized that the advertised philosophy of the Schilling control system seems to address this need, but frequent "re-calibration" of the control system to the actual joint positions was found to be inefficient, inaccurate and annoying.

Although the V-block gripper worked better than the flat gripper, further studies should be made to make it easier to fully engage with outer and inner fuel elements. The current V-block gripper design often gripped fuel with the tips of its fingers instead of grasping the fuel firmly within its V-block.

Computer Simulation Results

Results of the simulations have shown that the handling of fuel elements/assemblies can be performed using the modified Schilling Hydra manipulator in coordination with the bridge/trolley assembly. Both the modified Schilling Hydra manipulator (with the wrist joint pitch-down) and the bridge/trolley assembly require their full available range of motion to perform all the activities on the process table.

The simulations have indicated that arm configuration is a significant factor in fuel handling. Neither the off-the-shelf or the all joint pitch-up Schilling Hydra manipulator configuration would allow successful fuel acquisition and placement, within the bounds of the assumptions used in this study, unless the manipulator remained in the vertical position and was deployed vertically with the mast. It was determined from the IGRIP® simulation that the wrist joint needs to be configured pitch-down (with the off-the-shelf range of rotation), with all other joints being pitch-up, to achieve any vertical fuel handling with the manipulator alone.

Simulations determined that the modified Schilling Hydra manipulator and the bridge/trolley assembly can perform loading operations within the envelope of +/- 53 inches from table center, assuming a trolley range of motion of +/- 19 inches. This articulation envelope reduces as a function of width of the trolley and/or trolley range of motion. Excluding the trolley motion, the manipulator has a radial reach envelope of 34 inches from the mast centerline, but an effective radial reach of only 20 inches with the wrist in the vertical orientation. This reach also requires special tooling to handle fuel over the full range of motion.

For optimum performance and to minimize cycle time for each operation, the manipulator and bridge/trolley assembly were simulated with all degrees of freedom moving at the same time. The complete fuel handling process time for clean, undamaged (or acceptably damaged) elements was 9.2 minutes per assembly for the CDR system, and 8.6 minutes per assembly for the final layout system. The process time included initial acquisition (picking) of the fuel assemblies after they were dumped from the wash basket onto the table, placing the fuel assemblies in the disassembly station, placing each separated element in the inspection station, and loading acceptable fuel elements into the MCO basket. Manipulator process times appear to be somewhat insensitive to process table layout.

When operation of the bridge/trolley assembly was separated from, and managed in series with the manipulator, the fuel assembly process times increased by approximately 1.0 minute per assembly. This duration will increase as bridge, trolley, and mast movements are further separated serially. The non-manipulator portions of the disassembly and inspection tasks dominated the process cycle time. This time could be optimized for manipulator sorting or for other activities, but at the expense of increased travel for the bridge/trolley assembly. The basket loading manipulator was idle for approximately two-thirds of the total process time. Elimination of the disassembly and inspection steps by means of process validation would be significant to the overall process time. If these steps were removed, the time to process fuel from the canister to the MCO basket is approximately 1.7 minutes per assembly.

The present method of operating the Schilling manipulator slave arm is to use a kinematically similar master arm. Ergonomic studies (References 1 through 5) have shown that over time an operator's efficiency is reduced, due to fatigue factors associated with a repetitive process. The most efficient method of operating the manipulator is to use pre-programmed tasks (semi-automation), after the assembly or element has been acquired. Integrated path planning for the manipulator, bridge, and trolley would reduce the demand on an operator and allow an increased throughput rate.

Seventy-four joint rotations, defined as movement through an arc without reversing direction, were required to process one full assembly through the full process on the 50% design process table with the modified Schilling Hydra manipulator. This equates to 546,000 joint rotations (for each joint) for the lifetime of one manipulator in the basin. Process validation could reduce this number significantly. On the other hand, this value is for ideal conditions and does not account for off-normal activities and additional work needed to process bits and scrap. This number is viewed as substantially non-conservative, and should be specified for design purposes at one million rotations per joint.

The simulation using the Schilling Titan II manipulator shows that the arm can perform more efficiently with a larger range of motion. Bridge/trolley assembly motion was not required, once a working position was established, except for loading unacceptable fuel into the scrap basket. Few tasks could be performed easily by parking the bridge/trolley assembly and operating the Schilling Hydra manipulator alone. Fixing the bridge/trolley assembly requires the Schilling Hydra manipulator to span from one extreme of its range of motion to the other. The cycle times using the Schilling Titan II manipulator were approximately equal to the cycle times using the Schilling Hydra manipulator.

The IGRIP® computer modeling and simulations have demonstrated the feasibility of using manipulators to repackage fuel, in concert with the proposed process tables. Simulations have demonstrated that BNFL design basis time requirements are achievable within the bounds used in this study.

Training

Overall manipulator competence varies widely from operator to operator. About 20% of the personnel possess the necessary hand-eye coordination to operate the equipment in a proficient manner. Performing repetitive tasks with the manipulator in a 2-D mode (using a regular camera) greatly decreases the capability of the operator, regardless of training.

The ergonomics of the workstation were found to be highly influential in the productivity of the operator. The positions of the manipulator master, camera pan/tilt control, monitors and tractor joystick were all found to be very important.

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Appendix A

Fuel Handling Test Specification

Westinghouse Hanford Company **Internal Memo**

From: Fuel Retrieval Systems
Phone: 373-0832 R3-85
Date: August 2, 1996
Subject: TEST SPECIFICATIONS

To:

K. D. Bazzell	S7-55	
B. S. Carlisle	R3-85	
G. L. Ketner	K5-22	
W. C. Mills	R3-85	
E. J. Shen	R3-86	
T. L. Yount	R3-85	
cc:	FRS Working File	R3-85
	SNF Project File	R3-11
	TLY/LB File	R3-85

The attached letter "Test Specifications" is for your information. If you have any questions please call me on 373-0832.

TLYount

T. L. Yount

ddr

Hanford Operations and Engineering Contractor for the US Department of Energy

BNFL Inc.
1835 Terminal Drive, Suite 220
Richland, WA 99352
Tel: (509) 946-4006
Fax: (509) 946-4852

SNF-PM-96-066
File# 110200.O (ltr)
170500.S

July 22, 1996

Mr. Thomas L. Yount
Westinghouse Hanford Company
P.O. Box 1970, MSIN R3-85
Richland, WA 99352

Subject: Test Specifications

Reference: WHC-SD-SNF-SOW-004, Rev. 1

Dear Mr. Yount:

We are pleased to submit the following design end item as required by the Statement of Work for the Design of the SNF Fuel Retrieval Sub-Project:

SNF-FRS-SPC-02, Rev. 0, *"Fuel Handling Test Specification"*

All comments resulted from the review of the draft submitted to you have been resolved.

If you have any questions, please feel free to call me at 946-4006.

Sincerely,

pp. Stewart M. Mackay
Project Manager

le

cc: Bruce Carlisle, WHC
Jim Knight, WHC
Dana Wolfe, WHC
Dean Tulberg, FW
Berry Lieberman, BNFL
Project Files

No. SNF-FRS-SPC-002
SNF Fuel Retrieval Sub-Project Rev. 0

TITLE: Fuel Handling Test Specification

Transfer Cranes

Client: Westinghouse Hanford Company

Safety Class: Non-safety related

Prepared by:

/ July 22, 1996

Name, Discipline: Al Zindel, Mechanical Date

Checked by:

/ July 22, 1996

Name, Discipline: Ian McCourty

Approved by:

/ July 22, 1996

Name, Position: Ian McCourty, Engineering Manager Date

RECORD OF REVISION		Document No.: SNF-FRS-SPC-002		Page 1
Title: Fuel Handling Test Specification				
Rev.	**Description of Change:** Replace, add, and delete pages	**Authorized for Release**		
		LDE	**Date**	**Proj. Mgr. Date**

TABLE OF CONTENTS

1.0 PURPOSE/SCOPE

1.1 PURPOSE

This test specification establishes objectives and requirements for functional demonstration tests. This information will provide proof of concept and criteria, optimize equipment layouts, integrate equipment, and identify required design changes in support of performance specification development as early as possible in the definitive design process. This testing is proposed to be performed on mockups in a cold test facility.

1.2 SCOPE

This specification applies to Westinghouse Hanford Company (WHC) test engineers involved in preparation and performance of procedures, documents, and tests to support K Basin Fuel Retrieval Sub-Project's design concept validation. This test specification pertains to fuel handling activities and focuses on the following specific workstations/tasks:

- The tipping station and function for tipping washbaskets
- The main process table function/configuration
- The handling of fuel assemblies, elements, and pieces on the table surface as required to accomplish transfer between the process table work zones.
- The handling of fuel assemblies, elements, and pieces and tooling as required to load MCO baskets, bits or scrap baskets and other containers as specified.
- The handling of debris, sludge, fuel assemblies, elements, and pieces and tooling as required to clean the table and prepare the work area for further processing.

2.0 TEST REQUIREMENTS

2.1 GENERAL DESCRIPTION

The test requirements are provided in the following sections which have been grouped into four broad categories. The categories, in order of priority, are:

- Loading (MCO baskets)
- Tipping
- Transfer within the process table work zones
- Work area preparation

The following categories have been deferred per the testing review meeting of 5/31/96.

- Inspection
- Secondary cleaning
- Disassembling
- Sorting

In general, objectives of the testing will be to:

- Achieve or exceed the baseline throughput values established by the CDR WITNESS model (Specifically meet or exceed loading times in CDR WITNESS model on an individual operation basis)
- Establish a process table configuration
- Test jig and tool performance
- Test and validate full and broken element loading process
- Identifying tooling and fixtures required after testing
- Establish the required basket orientation
- Test options for fuel orientation on the table
- Establish manipulator reach, motion pathways, interferences, and equipment placement
- Test viewing placement options
- Test defined minimized fuel handling paths
- Test scrap and debris handling process.

2.2 LOADING

2.2.1 Objective

The primary objective of the performance of basket loading testing is to establish the ability to load all types of baskets (including bits or scrap baskets) efficiently with full length and partial length assemblies/elements for all types of fuel.

2.2.2 Tests

The basket loading orientation

- Vertical orientation is the base case. Additional cases are, 45 deg., and horizontal.
- Include a "Lazy Susan" mount with position lock.

Test Loading Jigs (see sketch)

- Base case is load with no jig..
- Test a combination jig.

Test techniques for loading full and partial length fuel elements.

- Load full outers and then insert partial inners.
- Load longest partial outer-9" minimum, load full inner, then complete with partial outers.

Test techniques for loading fuel elements (basket array)

- Zig-zag pattern
- Fortress wall-whole and half pattern
- Load from inside out
- Load by quadrant

Fuel Dummies to be used for testing

- Lead, steel pipe, damaged ends.

2.3 TIPPING

2.3.1 Objective

The primary objectives of the tipping testing are to prove the concept of rotating and tipping a wash basket using an overhead hoist, test the ability of the manipulator to reach into the basket, determine requirements for table profiles, and, establish limits of basket/tipper motion.

2.3.2 Tests

- Using a mock up" wash basket " and "fuel assemblies" including "bits and scrap" rotate washbasket with monorail hoist or long handled tool. Use/adjust motion limiters as required to facilitate unloading without flipping the basket over pulling the basket off the stand or trapping fuel.

- Test manipulator reach and ability to pull assemblies from basket using existing end effector.

- Verify that no bits and debris remain in basket.

- Perform a series of trials in which slope elevations and fuel guides are repositioned.

- Alter the unload slope from the wash basket to test fuel transfer and to support separation and sorting. Incline basis is 5°, with additional tests at 10° and 25°.
- Add and remove/relocate v block guides to adjust roll of assemblies down incline.
- Alter the tipper range of motion to establish the optimum travel for unloading the basket. 90° is base case, invert the basket is second case.
- Projected Horizontal length of slope is 3 Ft.
- Landing zone is to be tested, flat, crowned, troughed and tilted.

2.4 TRANSFER WITHIN THE PROCESS TABLE WORK ZONES

2.4.1 Objective

Develop means to facilitate fuel transfer between work zones in the process area.

2.4.2 Tests

- Test different orientations and fuel stacking to facilitate passing materials between work stations or re-picking materials. As found is the base case, also test parallel to table centerline and perpendicular to table centerline.
- Test expanding mandrive fixture with manual engagement
- Test curved jaws

2.5 WORK AREA PREPARATION

2.5.1 Objective

To develop methods and tooling for clean up and preparation between canisters of fuel.

2.5.2 Tests

Small Tool Testing

- Test rakes and squeegee for sweeping off the table top. All tools have 6 inch width see sketch.

Table Configuration Testing

- Test grid and trough for debris collection

Debris Collection Testing

- Fabricate debris from nuts and bolts and simulated w/springs.
- Develop gross estimate of time required to clean up table with manipulator tools.

3.0 FACILITY CONDITIONS

No special conditions required.

4.0 SPECIAL EQUIPMENT

4.1 EQUIPMENT REQUIREMENTS

- Lighting
- Cameras
- Monorail hoist
- Manipulator
- Manual long reach tools
- Control console for cameras and lights as well as CRT display
- Mock fuel and scrap

4.2 TEST STAND ARRANGEMENT

The test stand should be arranged in accordance with the general arrangement drawing provided in Appendix A. All critical elements should be assembled as required to facilitate modifications during testing. The process table will be assembled from individual tables mounted on casters which can be arranged as required to facilitate testing. The operator should initially be shielded from any view of the test stand except via the CCTV equipment. Lighting should be arranged as required to eliminate glare or deep shadows which will affect the detail of the view on the CRT. The entire set up should be aligned to allow an overhead monorail to traverse the table lengthwise. An overhead platform is to be provided to allow some use of long reach tools.

4.3 FABRICATED STRUCTURES/COMPONENTS

- Test table fabricated as process table surface
- Variable pitch slope for use with tipping stand
- Tipping stand
- Washbasket
- Transfer/tipping jig for transporting washbaskets
- Fuel trays
- Fuel stands
- Grated surface
- Adjustable V blocks and guides
- Platform area above the process table to allow the use of long reach tools
- Various end effector configurations and long reach tool configurations.

4.4 LIGHTING AND CAMERA ARRANGEMENTS

See the general arrangement drawings in Appendix A for preliminary locations. Camera and lighting to be arranged throughout testing period.

5.0 ACCEPTANCE CRITERIA

5.1 ACCEPTANCE CRITERIA

The acceptance criteria below is developed from the test objectives and assumes completion of multiple test set ups with sufficient repetition to ensure the timing and repeatability of desired function. The acceptance of completion of testing will be verified on several levels, achievability, repeatability, ease of operation, and minimization of time to complete. The methods employed must be failsafe or provide a means of recovery with minimized operator involvement. This can be reported in a matrix format as provided in Section 6.0.

5.1.1 Loading Test Acceptance Criteria

The testing must successfully (within CDR WITNESS model time limits) load an MCO basket mockup using all proposed loading jigs and methods. The testing will be considered acceptable when all jigs have been tested, and the operation is successful with all classes of elements (full, partial length elements, inners and outers, swelled and bowed fuel.) Times must be established for three basket positions, vertical, 45°, and horizontal. Operator difficulties must be qualitatively assessed for each fuel loading pattern and assigned an order of difficulty relative to all others. This is to be reported in a matrix similar to Figure 2.

5.1.2 Tipping Testing Acceptance Criteria

Fuel Dumping Tests

This testing is to be performed as a series of steps and a qualitative review provided on Figure 1. Success is an empty wash basket. Failures to perform must be identified and a solution evolved and tested in the field.

Equipment Configuration Tests

This testing must be completed as a series of repeated tests and analyzed and reported in accordance with Figure 2. The fuel must be unloaded in a configuration which allows the manipulator to pick up individual elements/assemblies with a minimum amount of fuel rearrangement.

5.1.3 Transfer Within the Process Table Work ZonesTest Acceptance Criteria

This testing will use several options for staging material in preparation for transfer between zones. It will also determine the optimum positioning of fuel within zones in order to facilitate the follow on process step. The data will be recorded and rated using Figure 2. Successful test will be completion of all options and compliance with CDR WITNESS model time limits.

5.1.4 Work Area Preparation

This testing will be performed in conjunction with other ongoing tests and will be reported in the format provided by Figure 1. Successful test will be clean up of debris with the manipulator and tools.

6.0 DATA REQUIRED

6.1 WITNESS POINTS

The significant (TBD from test procedure) milestones in testing where data recording is required will be reported on the attached sample format test report (Figure 1). This information will be developed and reviewed preliminarily as the testing is performed. Based upon immediate conclusions the test procedure may then be redlined to review a different avenue of testing based upon lessons learned. Where comparative testing that requires a selection process is to be performed, the format provided by Figure 2 is to be used.

6.2 POST TEST CLOSURE AND DOCUMENTATION TRANSFER

This will be performed in accordance with WHC test procedure requirements.

Fig. 1. Example Format

Test Basis:
Test Objective:
Comments:
Witness (BNFL):

Ref #	Test Procedure step/reference # requiring data record. (Hold points are to be selected based upon a review of the Test Procedure)	Results Summary/data record or qualitative analysis.	Test Tech. Signature/ date	Resp Eng.	Comments/ Conclusions/ Recommendations	Design mod Reqd.	Close out Signature/Date BNFL/WHC
	This table is a sample format for the recording and transmitting of test data. The equivalent concept as provided in the Test Procedure will be reviewed and approved prior to initiation of testing.						

Fig. 2. Example Format

ACCEPTANCE CRITERIA SUMMARY MATRIX (SAMPLE)

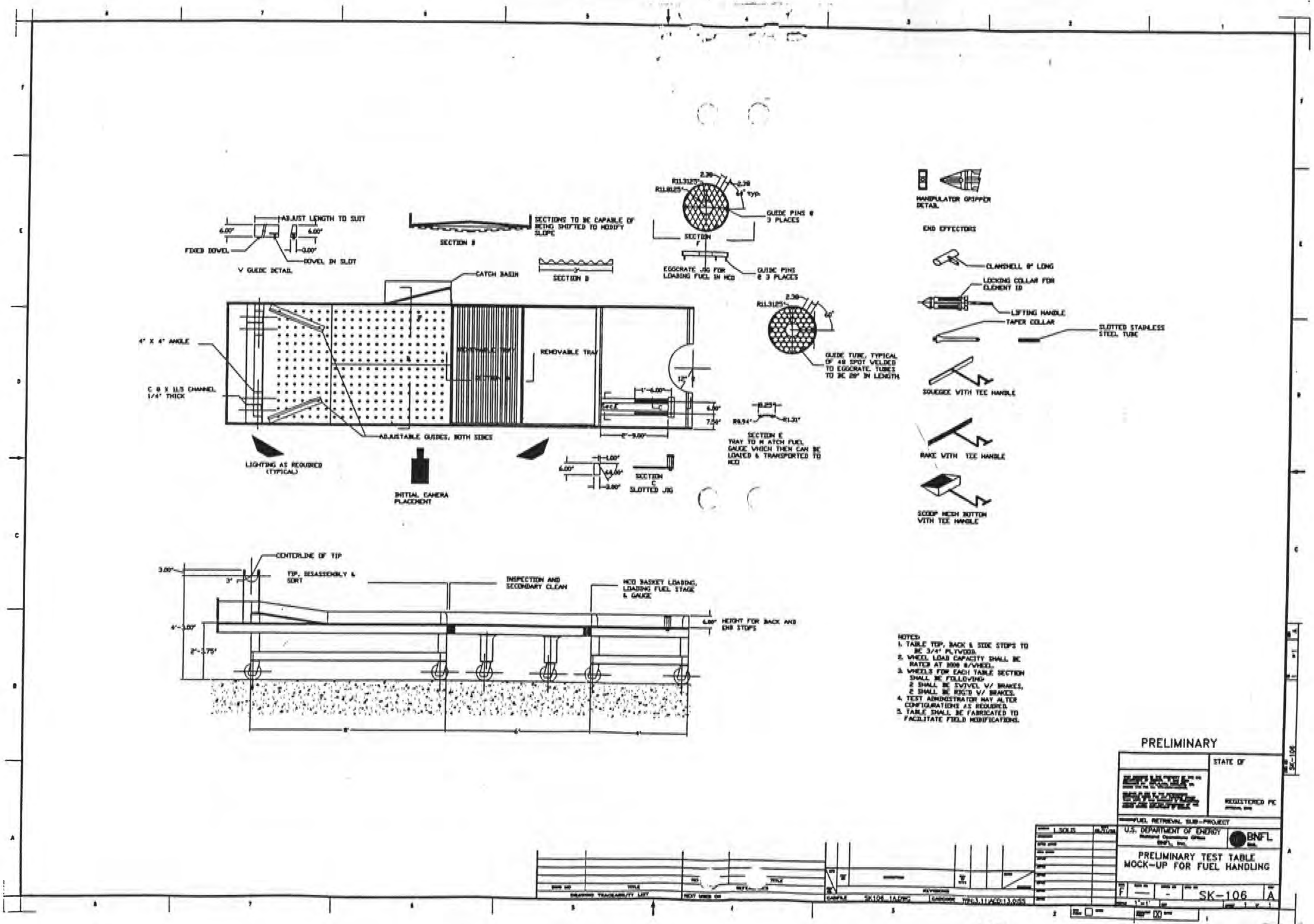
Test Method/ Arrangement	Achievability Rating	Repeatability Rating	Ease of Operation	Recoverability	Recorded Time to Complete	Comments/ Other Data	Selection Summary Score
A	M	L	L	H			
B	H	H	M	M			
C	L	M	H	L			

Note:

Use H, M, L for high, medium, and low or other numbered scoring technique.

APPENDIX A - SKETCHES

The following sketches are provided to support test stand fabrication.



ADJUST LENGTH TO SUIT
FIXED DOWEL
DOWEL IN SLOT
V GUIDE DETAIL
SECTIONS TO BE CAPABLE OF BEING SHIFTED TO MODIFY SLOPE
SECTION B
SECTION D
CATCH BASIN
GUIDE PINS @ 3 PLACES
SECTION F
EGGCRATE JIG FOR LOADING FUEL IN MCO
GUIDE PINS @ 3 PLACES
GUIDE TUBE, TYPICAL OF 48 SPOT WELDED TO EGGCRATE. TUBES TO BE 20" IN LENGTH.
4" X 4" ANGLE
C 8 X 11.5 CHANNEL, 1/4" THICK
REMOVABLE TRAY
ADJUSTABLE GUIDES, BOTH SIDES
LIGHTING AS REQUIRED (TYPICAL)
INITIAL CAMERA PLACEMENT
SECTION C SLOTTED JIG
SECTION E
TRAY TO MATCH FUEL GAUGE WHICH THEN CAN BE LOADED & TRANSPORTED TO MCO
MANIPULATOR GRIPPER DETAIL
END EFFECTORS
CLAMSHELL 8" LONG
LOCKING COLLAR FOR ELEMENT ID
LIFTING HANDLE
TAPER COLLAR
SLOTTED STAINLESS STEEL TUBE
SQUEEGEE WITH TEE HANDLE
RAKE WITH TEE HANDLE
SCOOP MESH BOTTOM WITH TEE HANDLE
CENTERLINE OF TIP
TIP, DISASSEMBLY & SORT
INSPECTION AND SECONDARY CLEAN
MCO BASKET LOADING, LOADING FUEL STAGE & GAUGE
6.00" HEIGHT FOR BACK AND END STOPS
NOTES:
1. TABLE TOP, BACK & SIDE STOPS TO BE 3/4" PLYWOOD.
2. WHEEL LOAD CAPACITY SHALL BE RATED AT 1000 #/WHEEL.
3. WHEELS FOR EACH TABLE SECTION SHALL BE FOLLOWING: 2 SHALL BE SWIVEL W/ BRAKES, 2 SHALL BE RIGID W/ BRAKES.
4. TEST ADMINISTRATOR MAY ALTER CONFIGURATIONS AS REQUIRED.
5. TABLE SHALL BE FABRICATED TO FACILITATE FIELD MODIFICATIONS.
PRELIMINARY
STATE OF
REGISTERED PE
FUEL RETRIEVAL SUB-PROJECT
U.S. DEPARTMENT OF ENERGY
BNFL
PRELIMINARY TEST TABLE MOCK-UP FOR FUEL HANDLING
SK-106
A

Appendix B

BNFL Test Specification for Schilling

APPENDIX B - CDR WITNESS Model

The attached summary time scale is provided for information as baseline test data.

APPLICATION ENGINEERING PROPOSAL FOR DETERMINING MANIPULATOR CONFIGURATION AND END EFFECTOR REQUIREMENTS IN SUPPORT OF HANFORD'S SPENT NUCLEAR FUEL RETRIEVAL SUB-PROJECT

INTRODUCTION:

Difficulty is being experienced at the Hanford Facility in getting the test manipulator to pick and place simulated N Reactor type fuel assemblies (a fuel assembly consists of an inner, and outer element as shown in figure 1) into an MCO Tier Basket. Schilling representatives have viewed the set-up and propose that a short Application Engineering Study be undertaken (approximately two weeks), to determine the optimum configuration of the machine and the most suitable end effectors.

This will be basic experimentation to confirm that an "off the shelf" machine, or a machine with "off the shelf options," can perform the fuel processing tasks at the required

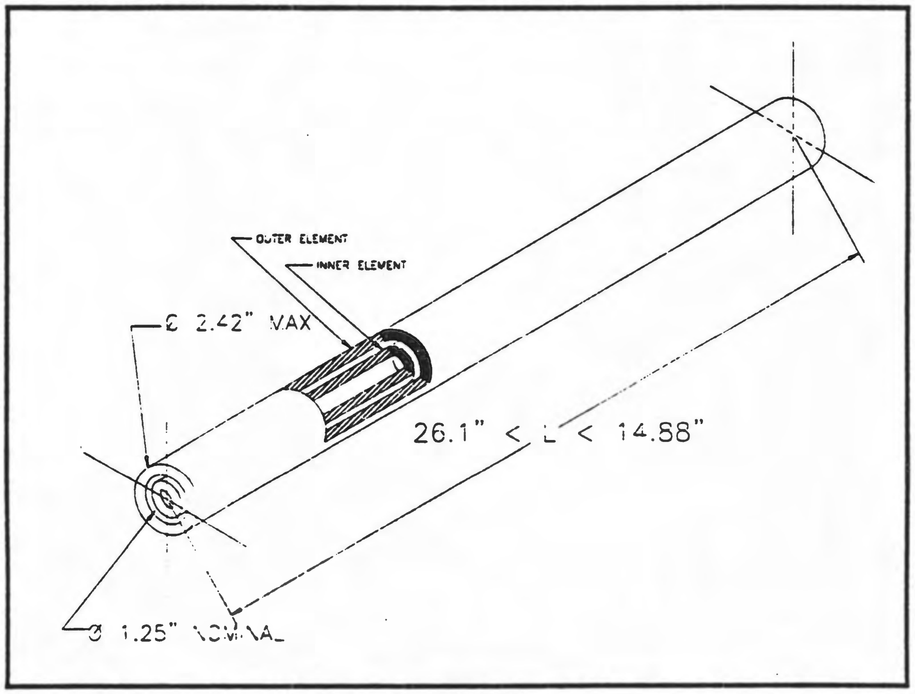


Figure 1 Typical N Reactor Fuel Assembly

performance levels. The primary requirement is to develop a successful manipulator configuration to load MCO Tier Baskets. The other information we are requesting should be supplemental to the main objective. The additional testing relative to vision and the process table would be useful if it can be obtained as a result of the MCO Tier basket loading testing.

REQUESTED PERFORMANCE:

Schilling shall perform application engineering, and the required testing to make recommendations to BNFL in the following areas:

MANIPULATOR CONFIGURATION

- The required manipulator configuration, including link orientation, range of motion, payload capacities to meet the functional and throughput requirements established for the manipulators.
- Manipulator mounting configuration and requirements with respect to allowable deflections, elevations, translation requirements and rates.
- End effector(s) configuration to facilitate fuel handling.
- Tooling required for use by the end effectors to meet functional and throughput requirements.
- Any special design provisions which should be provided to enhance reliability, or facilitate the maintenance and repair of failed units.

MAN/MACHINE INTERFACE

- Vision Requirements. This includes requirements for cameras, camera placement, camera type, and an assessment of the benefit of a stereo vision system.
- Control Configuration. This includes the types of controls (rate, position, etc), and their layout relative to the human operator.
- Manipulator Feedback Requirements. What benefit with respect to operating efficiency might be gained by the incorporation of force feedback controls? What would be the associated impact on the manipulator's reliability? Recommendations for this application.

PROCESS TABLE

- Process table configuration. Includes dimensions, work station orientation, visual cues, cross-section, etc.
- The preferred fuel orientation in the MCO Tier basket loading staging area.
- The required end effectors/tools/jigs and a preferred loading pattern to effectively load MCO Tier baskets.
- The optimum position of the MCO Tier basket relative to the manipulator to facilitate

fuel loading.

PROVIDED BY OTHERS:

Westinghouse Hanford Company shall provide to Schilling:

1. one simulated MCO Tier Basket,

2. 9 lead filled dummy fuel slugs which represent the OD, length, and weight of a complete fuel assembly,

3. and 4 sets of inner and outer elements which are geometrically similar to the SNF fuel assemblies, but lighter in weight.

FUNCTIONS AND REQUIREMENTS:

During normal operations, process table coverage will be accomplished via two manipulator assemblies running along the same set of bridge rails. Each manipulator position will be responsible for performing a predefined set of tasks. The first unit will pick up fuel from the sort table, and move the fuel through disassembly, inspection, and secondary cleaning as required. The fuel will be passed over a feature (wall, or hump) provided on the table, and the second manipulator position will be dedicated to MCO tier basket loading. More detailed discussion of the functions and requirements to accomplish these activities is included below. Flow diagrams of the fuel handling functions to be performed by each manipulator work station are provided in Figures 3 and 4 for information.

Each unit will be independently capable of providing coverage over the entire process table length with a minimum of effort. If a manipulator assembly fails, this will allow fuel processing to MCO tier baskets to continue at a diminished capacity until a failed manipulator assembly can be repaired or replaced.

- **Process Table Coverage**

The manipulators must be capable of handling fuel in any orientation along the entire width and length of the process table. Nominal process table dimensions will be 5 feet wide, and 30 feet long. The end effector will be required to work at elevations 26" above, and 13" below the process table working surface elevation.

- **Fuel Handling**

The manipulators will be required to pick fuel up from the process table below the tipping station, try to separate the inner and outer elements by orienting the outer element permitting the inner to slide from the outer. Once disassembled, the manipulator will then be used to translate the fuel elements and place them in their respective inspection, secondary clean station, and into a staging area for MCO tier basket loading.

- **Place Fuel in MCO Basket.**

Fuel categorized as clean will be loaded into MCO Tier baskets, with 54 assemblies per basket. The manipulator may have to work in conjunction with a jig to facilitate fuel loading. Fuel may be placed into the basket in the vertical orientation.

Typical fuel loading methodology will be to first place an outer fuel element in the MCO Tier basket, and then place an inner element into the outer. It will be necessary however, to adjust this scheme on a case by case basis, as a number of the fuel elements are expected to be broken. For example, it may be necessary to load half of an outer element into the basket, place a full length inner into the broken outer, and the slide the remaining portion of the outer fuel element over the inner. Broken elements less than 3 in. long will be loaded into "bits" baskets.

The manipulator will also be used to load fuel bits and complete elements into MCO bits baskets and stand them on end. There is no requirement for the orientation of the bits during basket loading.

- **Sorting**

The manipulators will be required to sort debris from fuel. Debris, which is defined to be anything which is not fuel, will be placed in debris baskets attached to the process table, for eventual transfer to debris removal. Debris may include small fasteners, and other items as small as 1/4" in diameter.

The manipulators will be required to sort fuel, separating whole, or partial whole elements greater than three inches in length, from bits, which are defined as being incomplete elements greater than 1/4" in any dimension, but sufficiently small, and/or damaged to prevent their being loaded into MCO Tier baskets.

- **Throughput Requirements**

The second manipulator work position must be capable of loading the equivalent of 270 complete fuel assemblies (inner and outer elements) into MCO Tier baskets in 36 hours, with targeted loading rate of placing the equivalent of a fuel element in the tier basket every 2.5 minutes, with several operators of various capabilities.

- **Manipulator Response**

The manipulators must respond in real time to operator control inputs. Manipulators controls must be sufficiently "intuitive" to allow operators of various backgrounds and skill levels to meet throughput requirements.

DELIVERABLES

As a minimum, Schilling shall provide BNFL with the following at the completion of the effort described by this proposal:

- Using a tele-operated Hydra manipulator or equivalent, demonstrate the ability of a remotely located operator using CCTV to load MCO Tier baskets at a rate which meets or exceeds throughput requirements identified below, to be witnessed by WHC and BNFL.

- Video of MCO Tier Basket Loading by Manipulator

- Dimensioned Sketches of End Effectors/Tools Used to Meet Functional Requirements.

- Dimensioned Sketches of final recommended manipulator configuration and mounting preference.

- Dimensioned sketches for the manipulator test configuration.

- Recommendations regarding any special maintenance provisions which should be incorporated into the manipulator installation's design.

- Recommended location of the MCO Tier baskets with respect to the manipulator during fuel loading.

- Recommended loading pattern for MCO Tier Baskets.

- Description, including sketches, of recommended control configuration.

- Description of recommended camera placement and operator vision requirements.

- Recommendations regarding the process table layout, and design features which may be incorporated to facilitate operators in meeting throughput requirements.

INTERFACE DEFINITION

A description of the items/systems that will interface with the manipulators is provided below.

FUEL: The maximum Outside Diameter (OD) of any "good" fuel assembly's outer element is 2.421 in. The maximum OD of any fuel assembly inner element is 3.25 cm (1.28 in). It is anticipated that there will be swollen fuel that may exceed these dimensions. Maximum weight in air of any fuel assembly (inner and outer elements combined) is 25.12 kg (55.38 lb). Detailed descriptions of the SNF is provided in Table 1.

MCO BASKET: Fuel will be rotated into the vertical orientation for loading into the basket. The base of the basket is provided with sockets in a hexagonal (close pack) array, with nominal dimensions as shown in Figure 2 (Reference SK-1-80208, attached). Maximum radial clearance between a pristine Mark IV outer fuel element and the MCO tier basket socket will be 0.08 in.

PROCESS AREA/MANIPULATOR DEPLOYMENT: A sketch showing the approximate location of the process table, MCO Tier basket location, and conceptual manipulator mounting methodology is provided as drawing DW-320.

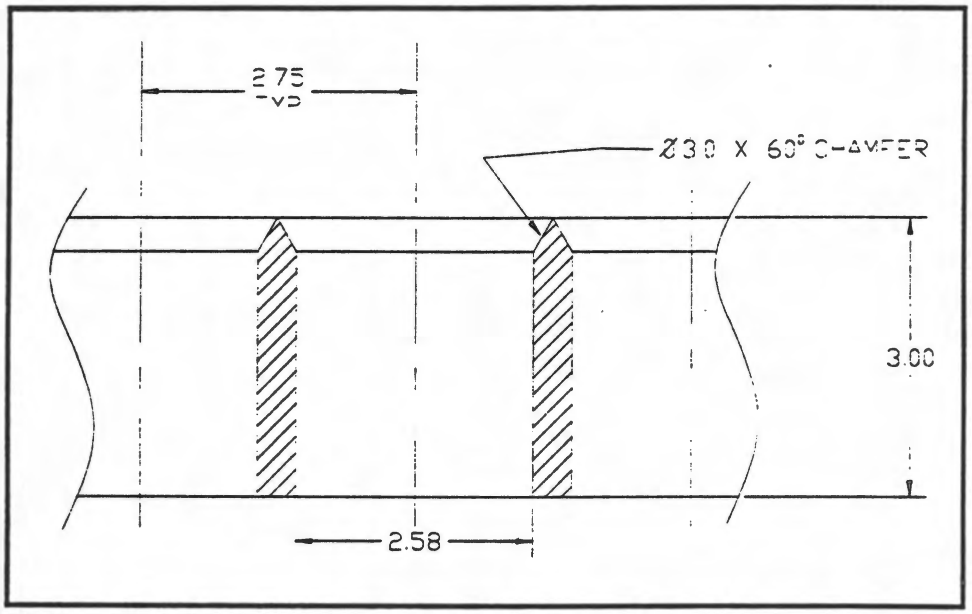


Figure 2 MCO Tier Basket Fuel "Socket" Detail

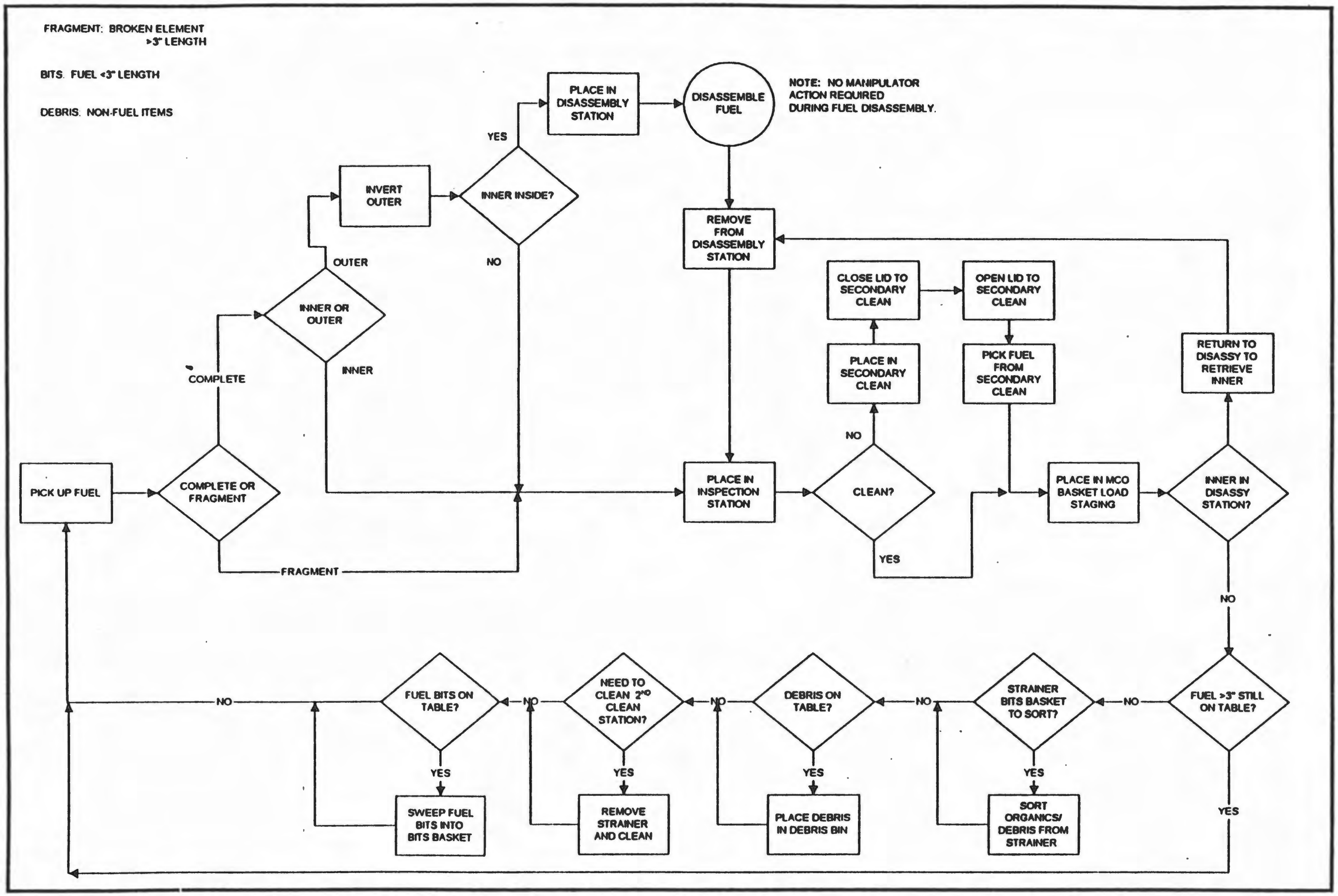


Figure 3 First Manipulator Position Work Flow Diagram

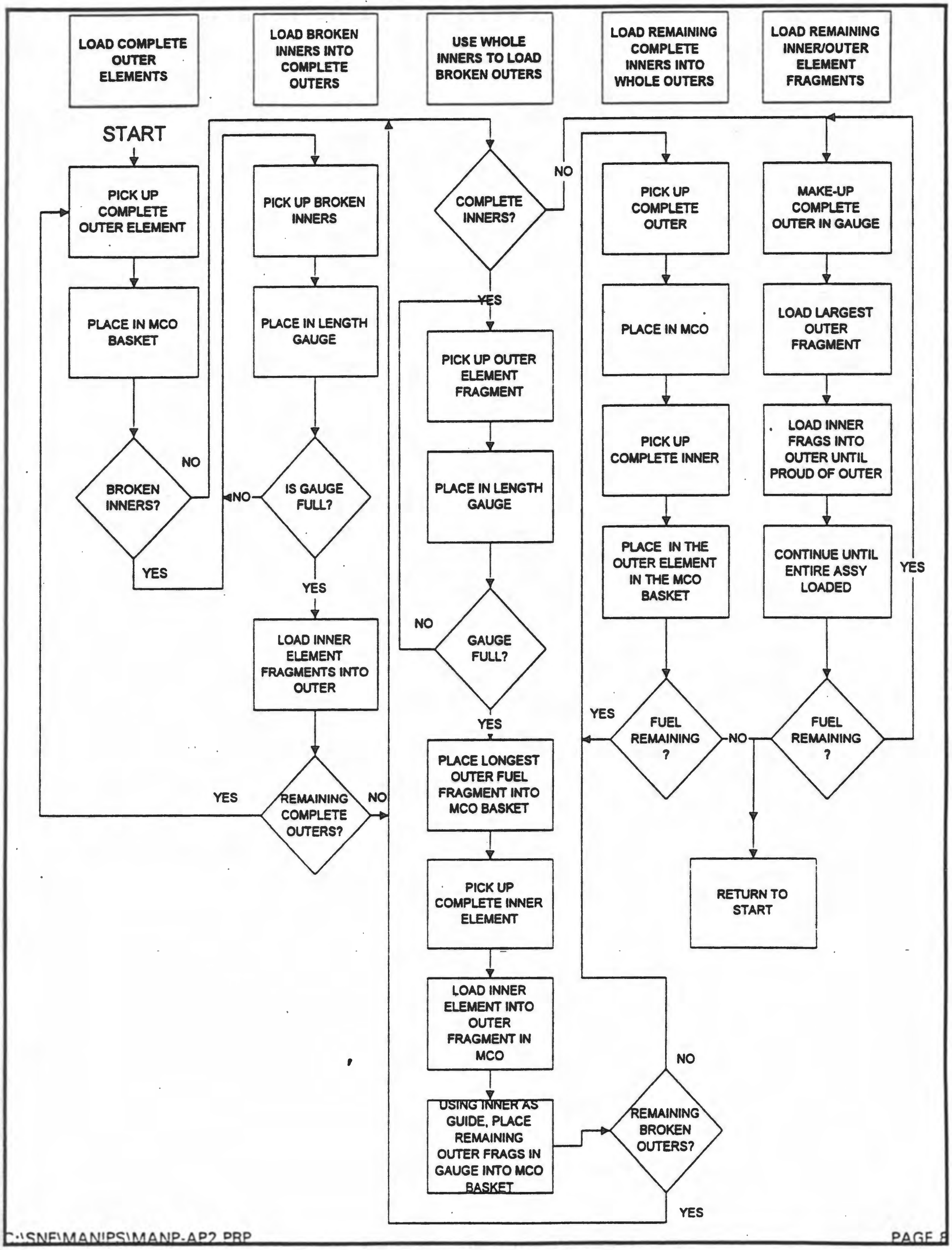


Figure 4 Second Manipulator Position Work Requirements

TABLE 1
PHYSICAL PROPERTIES OF SPENT NUCLEAR FUELS

	MARK IV				MARK IA		
Pre-irradiation enrichment of ^{235}U	0.947% Enriched				1.25-0.947% Enriched		
Type-Length Code[1]	E	S	A	C	M	T	F
Length (cm)	66.3	62.5	58.9	44.2	53.1	49.8	37.8
Element Diameter (cm)							
Outer of Outer	6.15				6.10		
Inner of Outer	4.32				4.50		
Outer of Inner	3.25				3.18		
Inner of Inner	1.22				1.11		
Cladding Mass (Kg)							
Outer Element	1.09	1.04	0.99	0.79	0.88	0.83	0.66
Inner Element	0.55	0.52	0.50	0.40	0.54	0.51	0.40
Mass of Uranium in Outer (Kg)							
0.947% ^{235}U	16.0	15.0	14.1	10.5			
1.25% ^{235}U					11.1	10.4	7.85
Mass of uranium in inner (kg) 0.947% ^{235}U	7.48	7.03	6.62	4.94	5.49	5.12	3.90
Weighted average of uranium in element (Kg)	22.7				16.3		
% of total elements	63				37		
% of length type of each fuel	78	10	7	5	87	10	3

1. Letter code differentiates the different lengths of the Mark IV or Mark IA fuel elements, i.e. a type "E" element is 66.3 centimeters long.

Appendix C

Schilling Test Report

GEC ALSTHOM
SCHILLING ROBOTIC SYSTEMS

August 5, 1996

BNFL Inc.
Attn: Ian McCourty
1835 Terminal
Richland, WA 99352

SUBJECT: Report and Video - Spent Nuclear Fuel Loading Demonstration

REFERENCE: BNFL PO 96-136

Dear Ian,

Please find attached three (3) copies of the subject report and one (1) VHS videotape of the demonstration which took place at Schilling Robotic Systems on Friday, July 26, 1996. Mr. Gary Ketner of PNL and Mr. Steve Shaw of LATA, both representing BNFL, attended the demonstration.

The demonstration showed that a Schilling Hydra manipulator could load spent fuel elements into the MCO tier basket in well under the 2 and 1/2 minutes per element allowed.

If you have any questions, please feel free to call me.

Sincerely,

Roger Bedard

Roger Bedard
VP of Programs

Engineering Systems Group
GEC ALSTHOM SCHILLING ROBOTIC SYSTEMS, INC. 1632 DaVinci Court, Davis, California 95616, USA
Tel: (916) 753-6718 - Fax: (916) 753-8092

Tele-operated Spent Fuel Loading Demonstration Using a Modified Hydra Manipulator

July 31, 1996

by: Jeffrey T. Prince
Schilling Robotic Systems

1.0 Introduction and Summary

Schilling Robotic Systems (SRS) performed a short-term application engineering study to determine the manipulator configuration and end effector requirements to support the Hanford Spent Nuclear Fuel Retrieval Sub-Project.[i] The main objectives for this study were to develop a suitable off-the-self manipulator or a manipulator that uses off-the-shelf options that can perform the required loading of spent fuel into the MCO tier basket, and to demonstrate that this manipulator configuration can perform the loading task within the allotted time. While not a requirement of this study, it is further understood that this manipulator configuration must be rugged enough to perform during spent-fuel loading with an availability of 98%; a quality that SRS is in a unique position to provide. A successful demonstration of loading mock-up fuel elements into an MCO tier basket using a Hydra manipulator was performed.

Other facets of this study were to determine end effector configuration and any special tooling that would be required to load the MCO tier basket, and determine the optimum placement of the manipulator for loading. In addition, we were asked to recommend the human-interface control configuration and the type and placement of cameras within the process area to support the loading process.

Although the main objective for this study concerned the MCO basket loading process, we did not limit our study to this area alone The process table, as well as the tipping and sorting process, were also considered. While the processing of spent nuclear fuel requires that the systems be able to efficiently perform with undamaged fuel elements, some of the fuel elements will be damaged and in pieces. This will introduce considerable uncertainty in the process environment. To this end, careful consideration must also be given the entirety of the tasks required to complete this project, as well as any off-normal situations that may occur.

Thus a "systems" view of the process, including the process table, must be considered so that process arrangements that augment the efficiency of remote manipulation can be included into the process system. Or as a minimum, process arrangements that limit manipulator efficiency can be identified and eliminated from the final process specification.

2.0 Implementation

The engineering staff of SRS met to discuss possible solutions for this application. These discussions were broken into several topic areas: manipulator configuration, end effector, tooling, and process. Given the need to quickly perform a demonstration only selected solutions could be implemented. However, much of the discussions has been analyzed and included in this report.

A model of the process environment was created, including a simple ramp/staging device to position the fuel element mock-ups so that they could be acquired by the manipulator. Once this model was complete, the optimum configuration and placement of the manipulator were determined and tested via the mock-up. A kinematic analysis was performed for both the standard Hydra configuration as well as a modified Hydra configuration, in which the upper yaw joint was removed and replaced with a pitch joint (shown in Figure 1).

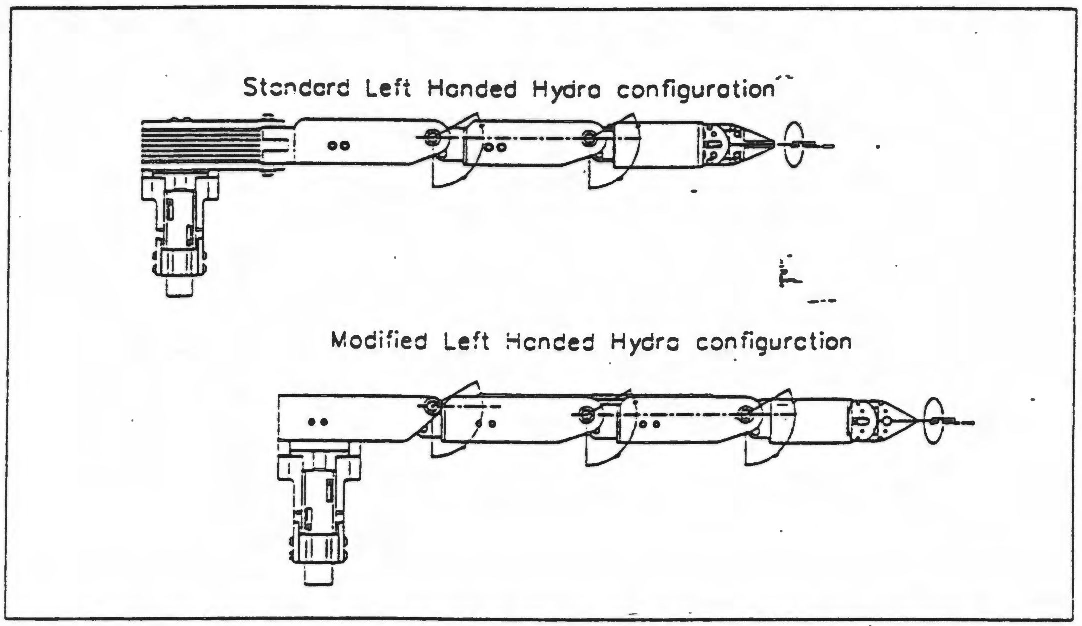


Figure 1 Manipulator configurations used for demonstration

Tools were also modeled. While many good concepts for tools were discussed, the time available to manufacture all these tools or create a reasonable conceptual models was not available. Initially, implementation was narrowed to a set of collet-type tools that could be held in a collet block, and actuated by hand for the purposes of demonstration (see Figure 2). The key feature for this test was that the tool, when attached to any element, would have to be compliantly coupled to the manipulator. This compliant coupling would allow the fuel element to hang vertically to match the alignment of its receptacle in the MCO basket.

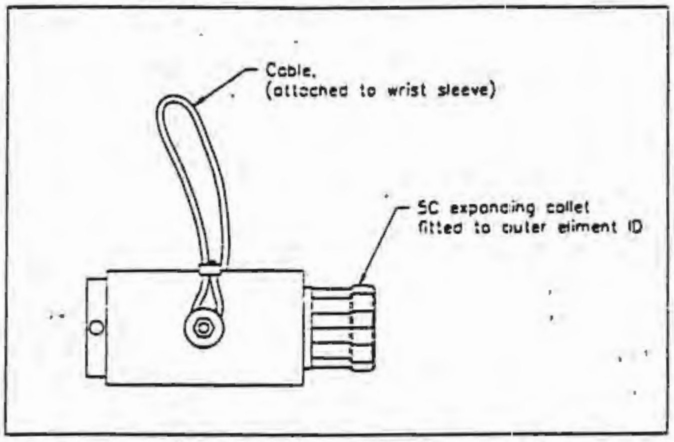


Figure 2. Collet-type tool used for acquiring outer fuel element

During tool modeling, it was determined that element wall thickness varied little between the inner and outer fuel elements, and that grabbing the wall of the element could be accomplished while the element is located adjacent to other elements. Based on the preliminary attempts at acquiring fuel elements with the collet-type tools, a compliant element-wall grabbing tool was conceived and developed based on a pair of locking pliers. An additional compliant tool was developed to pick up lead-weighted mock-ups of the fuel elements assembly. This second tool acquired the fuel assembly by engaging the outside diameter of the assembly.

As shown in the demonstration, these tools were superior to the collet tools for two reasons. First, the tool remained in the jaws at all times and did not need to be re-acquired. Second, the compliant mounting eliminated the need for exact alignment of the tool while acquiring the fuel element.

3.0 Demonstration

The demonstration was hampered by several unforeseen problems, including the need to service the HV manipulator as received from Westinghouse Hanford Company. Meanwhile, we prepared a suitable demonstration stand, the ramped fuel element delivery chute mock-up, and the set of collet-type element pickup tools. A weldment was made out of the same material used for the Hydra links that would partially model the completed boom. The repaired manipulator and its special stand were assembled and suspended from our traveling hoist rail, completing the set-up.

Two kinematic models were used for this demonstration: a standard Hydra configuration and a modified Hydra (on which the standard upper arm segment was replaced with a standard forearm segment). This modification changed the standard Roll, Yaw, Pitch, Pitch configuration into a Roll, Pitch, Pitch, Pitch configuration.

Further, these kinematic models indicated the standard 90° shoulder roll function was not sufficient to allow complete coverage of the MCO basket and the fuel element chute for any off-normal conditions that might occur during actual loading. (This could be mitigated with a mast-mounted 360° azimuth joint option, as described in section 4.1.)

On Friday, July 19, we began loading fuel into the MCO basket with the standard Hydra configuration (R, Y, P, P). While this configuration did work, the vertical reach of the manipulator was not sufficient to allow a good coverage of the MCO basket. On the afternoon of July 19 we decided to change over to the modified configuration (R, P, P, P). The following Monday the modified configuration was put into operation.

The modified manipulator worked very well. However, the collet-type tools proved to be difficult to manage because of the precise alignment required in order to acquire the fuel element and the need to re-acquire the tool after placing the element in the basket. Based on these drawbacks, we don't recommend further consideration of the collet tool concept.

We then fabricated a different set of tools, using locking pliers to simulate hydraulic actuators. One tool was configured to grasp a fuel element assembly, the other to grasp an individual fuel element. To eliminate the need for precise alignment while acquiring the element or assembly, these tools attach to the manipulator with a spring-loaded cable and socket that hold the tool in a stable orientation, but to allow it to flex and take on random orientations while engaging and grasping the element.

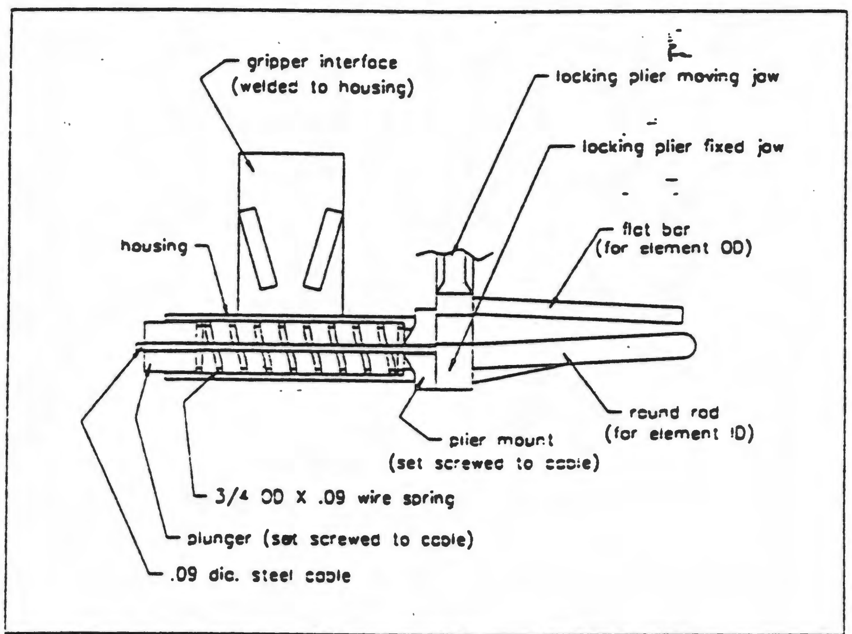


Figure 3. Fuel element wall grasping tool

The configuration of the element-grasping tool is typical. The spring-force on the cable is just sufficient to retain the tool in its socket when the tool is in an unloaded state. After the tool acquires an element, the additional weight pulls the tool from its socket, allowing the tool and element to hang freely from the cable. The element is then easily placed in the MCO basket. When the element is released, the spring returns the tool to its socket, ready for another activity cycle. The tool for grasping individual elements is shown in Figure 3.

As the study progressed, we refined the position of the MCO basket as it relates to the position and orientation of the manipulator. By Friday, July 26, the system was working at peak performance and it was demonstrated that the modified Hydra configuration, using an experienced operator, could load fuel elements into the basket in well under the 2-1/2 minutes allowed. The demonstration was witnessed by Steve Shaw of LATA and Gary Ketner of PNL, both representing BNFL. The demonstration was recorded on video by Gary Ketner and SRS.

4.0 Recommendations

While at SRS for the demonstration, Gary Ketner requested that we consider a manipulator configuration that would be able to reach from the process table to the adjacent hoist line (42 inches nominally) with the capacity to lift one fuel assembly. We have configured Hydra manipulators with this off-the-shelf option in the past, and a preliminary review indicates it would be successful in this application. However, it would change some of the parameters generated during this study and would require a greater z-axis travel on the boom than initially recommended of this report.

A different process and table configuration was also mentioned during the July 26 meeting. This process configuration would use a pick-and-place machine that is essentially a boom-mounted Hydra without the pitch joints. This 4 function, 3 degree of freedom machine would be used to process the bulk of the fuel and would be limited to loading only "good" fuel elements. Any "bad" elements would be moved to a special processing table centered along an adjacent handling trolley path, where a 5 degree-of-freedom, modified Hydra LR would be used to process bits and debris. The merits of this concept were discussed as well as its economic impact on the project. Because its design is special, rather than off-the-shelf, we concluded this pick-and-place machine would produce an adverse economic impact on the project.

As of this writing I have not fully evaluated this concept other than qualitatively. The concept of a pick and place machine relies on a specific, repetitive environment. Thus the burden on this system would be to include the appropriate mechanisms in the process table to dependably control the position and orientation of the work objects through out the environment. If something off-normal should occur, a pick and place machine might not be able to recover, while a generalized manipulator would be able to recover if the work object was still within its envelope. Specifically, the process of sorting, inspecting, and loading spent nuclear fuel is somewhat uncertain, and the ability to recover from off-normal conditions is a necessity. Given this uncertainty, we would recommend that a 6 degree-of-freedom manipulator system be used to process and load the spent nuclear fuel.

4.1 Manipulator Configuration

The manipulator we recommend for this application is the modified Roll, Pitch, Pitch, Pitch Hydra, configured with a position-controlled azimuth (Shoulder Roll) providing a minimum of 360° of motion. We also recommend that a rate-controlled z-axis translation, with a minimum of 24 inches of travel, be incorporated into the connection between the boom and its bridge trolley interface. Finally, to accommodate the requirement to offset the end effector to the adjacent trolley centerline, a rate-controlled 48-inch fourth link, with a 30 degree joint travel, should be incorporated into the boom.

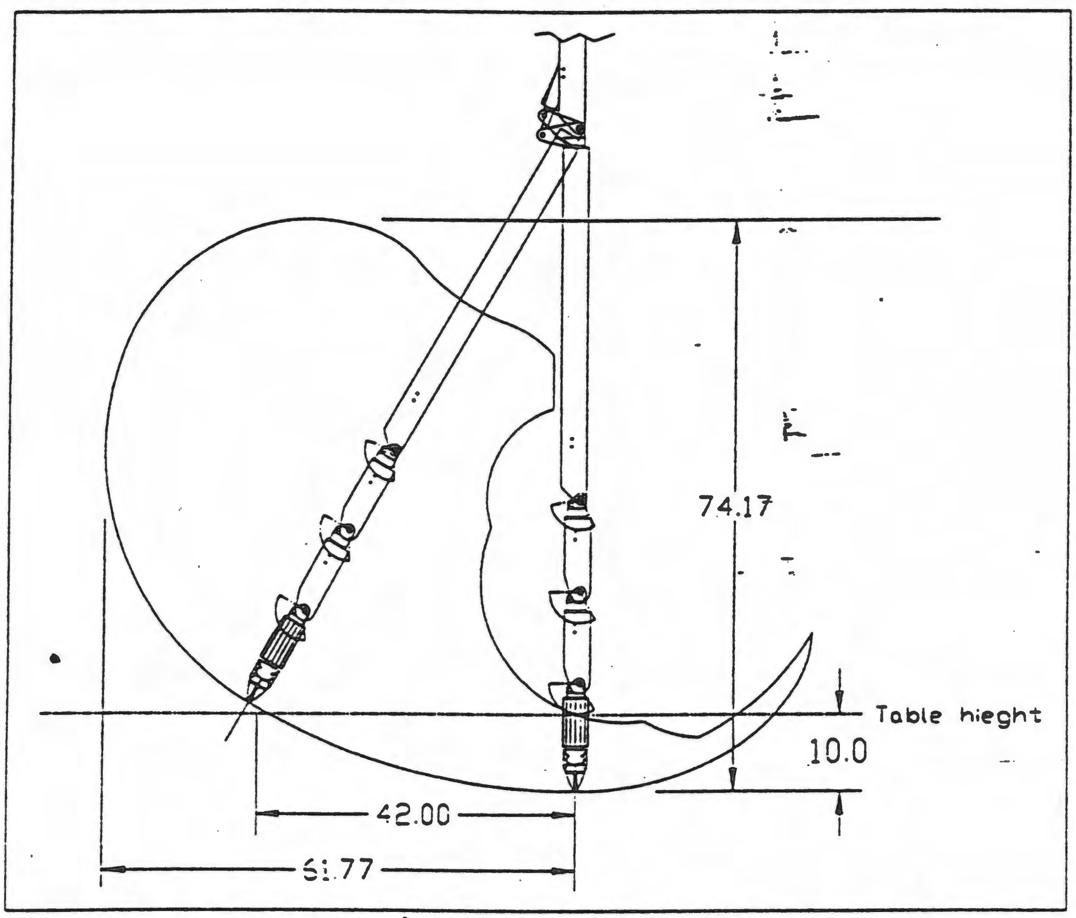


Figure 4. Recommended manipulator confiuration

Together these represent off-the-shelf systems and options. Some special design efforts and hardware will have to be incorporated to mount this unit to the x-y positioning bridge trolley, and to create a suitable linear bearing for the z-axis travel.

The manipulator system stiffness and damping ratio (including the positioning trolley) needs to be sufficient to minimize harmonic motion and minimize settling time, but deflections will not hamper system efficiency given the large clearances during robotic (pre-defined path) moves and tele-operated control (human in the loop path control (see section 4.4, Human interface/controls).

4.2.1 End Effector and Tooling, MCO Basket Loading

We recommend that a standard parallel-acting jaw gripper be used with the manipulator, and that a second, specialized end-effector be compliantly coupled to the wrist sleeve. This specialized end-effector would be plumbed into the jaw hydraulic circuit, in parallel with the standard gripper, and would serve to acquire fuel elements and assemblies.

Further, we recommend that this second end effector would be positioned to preclude it from interfering with operations next to the table while the wrist is in position mode. This dual end-effector approach will allow efficient loading of the fuel and the general use of the manipulator in both spent-fuel process roles. Moreover, this configuration will allow the manipulators to reach the full extent of the process and recover from any off-normal occurrences.

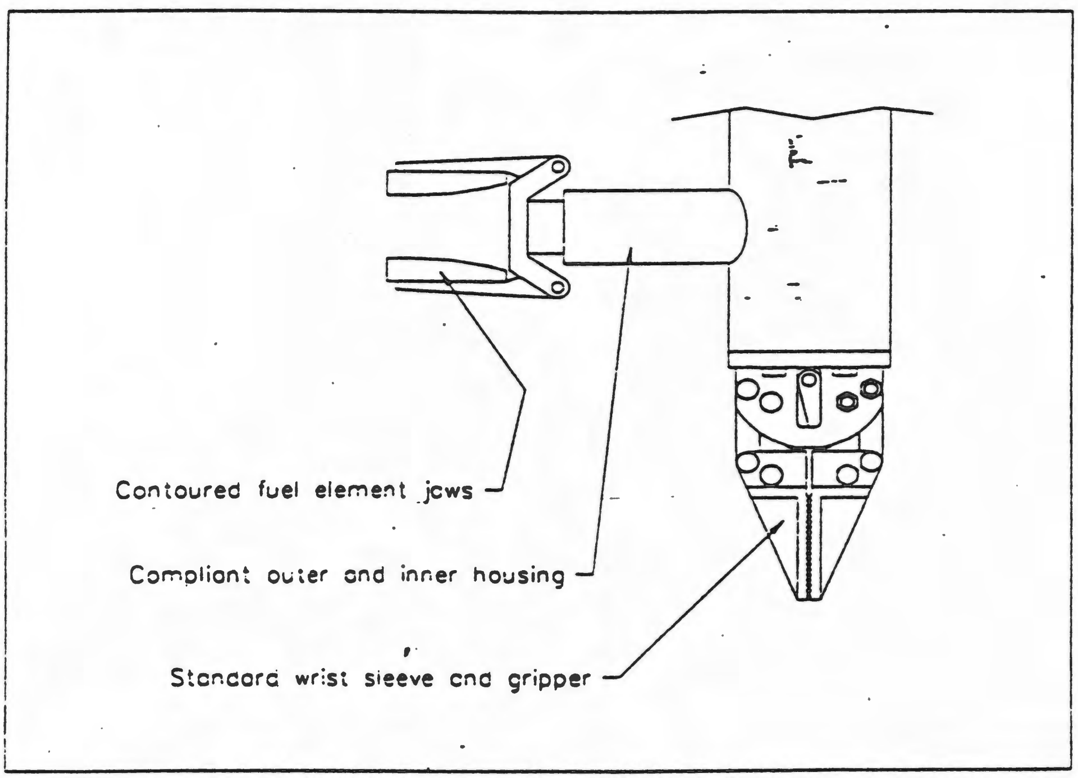


Figure 5. Wrist with end effectors

The demonstration showed the value of the compliant tool coupling, but didn't allow time enough to build and demonstrate a single tool versatile enough to acquire both individual elements and full fuel assemblies. While the tool in the demonstration was effective in grasping the fuel element mock-ups, a different tool was required for grasping the complete fuel assembly.

During the July 26 meeting we were informed that there is a low probability that any fuel assembly will stay together during the cleaning process. During the tipping and initial handling of the fuel assemblies, the cohesiveness of the assemblies will become apparent. This parameter demonstrates the need for a tool that can acquire not only a complete fuel assembly, but also the outside diameter of only the outer fuel element or the outside diameter of the inner element. This is a relatively simple tool but one that must be carefully implemented. We recommend that a prototype of this tool be built and tested in conditions as close as possible to the actual working conditions prior to actual fuel loading.

We also recommend another fixture that will have to be built in a quantity equivalent to the amount of anticipated broken fuel assemblies. This fixture is a stainless steel wire form that will hold pieces of the outer and inner fuel elements together so that they can be stored as complete fuel assemblies (see Figure 6 for the conceptual sketch).

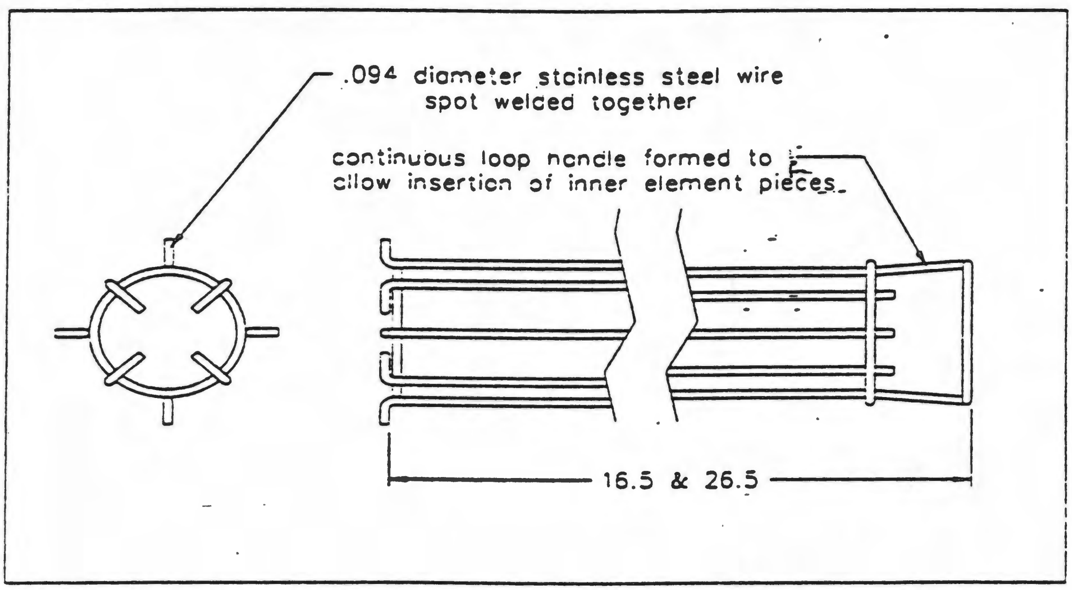


Figure 6. Conceptual sketch of a broken element form

While I'm not sure that these fixtures are suitable for inclusion into the waste stream, they will allow broken fuel elements, as they present themselves, to be stacked in this fixture in their entirety, and allow all the fuel to be processed serially. The process table should include a suitable stand to hold this fixture while fuel element pieces are stacked on it. Delivery arrangements will need to be considered as additional fixtures are needed at the process table. We are unsure whether this is a suitable solution but await your comments about this concept.

4.2.2 End Effector and Tooling: Sorting and Inspection

The sorting and inspecting manipulator will require some additional tooling to allow the removal of debris and fuel bits. The bits are defined in the specification as any fuel that is smaller than 3 inches in every dimension and larger than 1/4 inch in any dimension. While the larger fuel bits can be acquired using the gripper, the smaller pieces will require a shovel-like tool, or perhaps a mining dredge type of vacuum device, to deliver the smallest bits of fuel to the bits basket.

As of this writing I'm not sure how debris (as defined) will be identified from fuel bits, nor am I sure what the end location of the debris and fuel bits will be. If both the debris and fuel bits end up in the same place then a compliantly-mounted brush would be the tool of choice to sweep the debris and bits into the debris basket. The debris- and bits-handling tools should be holstered within reach of the manipulator while in the sorting position. These tools should be compliantly attached to a fitted handle that is designed for easy grasping by the Hydra jaws. Some representative tools are shown in Figure 7.

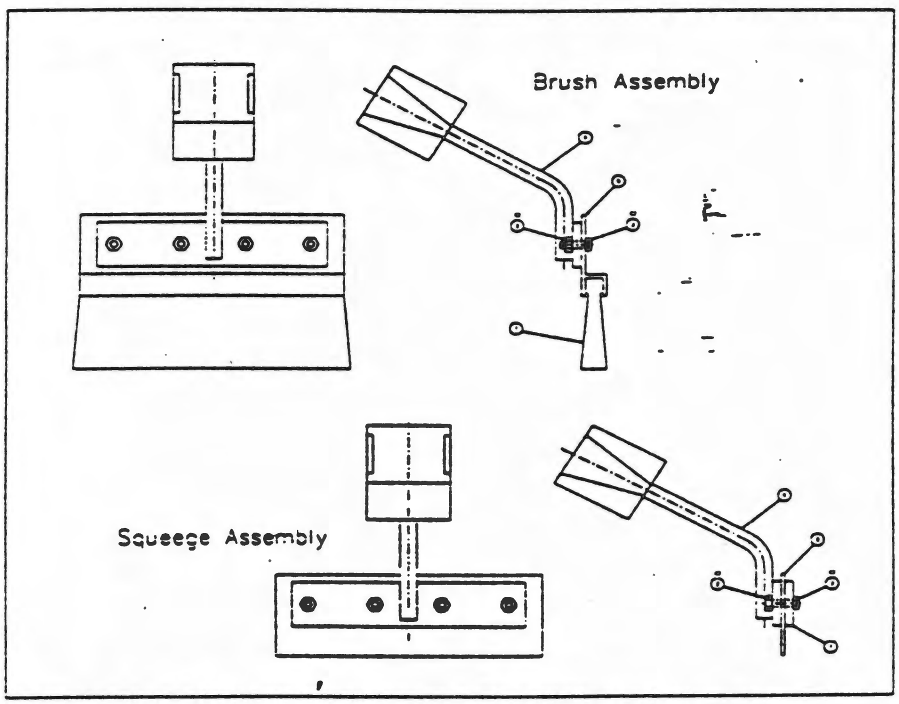


Figure 7. Previous Hydra Fitted Tools

4.3 Vision Requirements

Our vision recommendations concern the ability to efficiently use the manipulators and do not include any other special use cameras intended to support processing of the spent fuel. It is assumed that the clarity of the water will not be adversely effected by process operations.

We recommend that a camera be mounted on the 48-inch long link of the manipulators and that the field of view of this camera be large enough to include the envelope of the balance of the manipulator. A 6X zoom function would be beneficial but is not a necessity.

We further recommend that a second camera, mounted on a pan & tilt stand, be placed off the loading end of the process table in a horizontal orientation, and at a sufficient distance above the table to allow a view of the MCO basket that is 10° to 20° above the horizontal. This second camera should be placed far enough away from the table so that at its least magnification the entire loading end of the process table can be viewed. Also, this camera should have a zoom function of approximately 12X or greater. Another 12X zoom camera, mounted on a pan and tilt stand, should be placed at the other end of the table and provide similar visual coverage.

4.4 Human Interface and Controls

The control console for each manipulator should include a minimum of two monitors: one for the boom mounted camera and another for the loading or sorting camera as specified above. A 3-axis joystick should be provided for the loading or sorting camera: two axes to be used for the pan and tilt function; the third axis for zoom function. Other monitors many be needed for specialized inspecting and processing site views.

A 2-axis joystick should be used to operate the bridge trolley. The z-axis travel of the boom should be controlled by an potentiometer-adjustable proportional valve that uses an up-down, self-centering rocker switch to control the direction of motion. Similarly, the motion of the offsetting link should be rate-controlled, but its joint velocity should be preset. Lastly, the position-controlled axes of the manipulator should be controlled using the SRS master control arm.

To derive the maximum benefit from the SRS master control arm, it must be kinematic replica of the manipulator and positioned in the same orientation as the manipulator it controls. This will provide a highly intuitive method of control for the operator.

The control scheme for this manipulator system should include automatic positioning of the bridge trolleys to predetermined, advantageous positions, e.g. basket loading position for manipulator #2. Various methods of collision avoidance will need to be incorporated into the system to prevent inappropriate hardware encounters in the process environment (such as dragging of the manipulator, or collision of the bridge units). A collision avoidance "map" is currently being implemented on another SRS project.

4.5 Special Maintenance Provisions

The Hydra LR should not require maintenance during the life of the fuel retrieval sub-project. However, the manipulator interface to the bridge trolley should allow for quick and simple removal of the manipulator and its slave controller from the trolley. The trolley should also be quickly removable, with the manipulator attached or removed.

Other quick disconnect features should be part of the design for the bridge trolley and the manipulator interface, e.g. hydraulic quick disconnects and in-line electrical connectors that allow major components to be removed without electrical disassembly. Specific system interconnections are too vague to be identified at this time, but the break-apart, quick-disconnect concept should be part of the design.

Similarly, decommissioning or repair will require that the major components of the manipulator system be bagged. Provisions for quickly and efficiently bagging major system components should be included in the design.

4.6 Process Table Considerations

The following recommendations will make it possible the manipulator to access the entire MCO basket and the fuel pick-up point from a single position.

1. The MCO basket-stand at the end of the process table should position the centerline of the MCO basket on the centerline of the table. The basket should be held so that the top of the leading edge of the perforated metal grid is at the same elevation as the fuel. The bottom of the fuel basket should be tilted at 10° to 15° toward the table. The stand for the MCO basket should be lighted to provide high contrast indications of the position of the receptacles in the bottom of the basket. Preferably, the basket-stand should be lighted from below the basket. In this position and orientation, basket loading should proceed from the side closest to the table to the side away from the table.

2. The fuel element positioning and delivery system should be passive, relying on gravity to move the fuel into the pick-up position. We recommend that a compound-angled ramp be used to deliver the fuel to the pick-up point. This ramp should be angled, end to end, to roll the fuel from the sorting end of the table to the pick-up point and be slightly angled, side to side, so as to align the ends of the elements. The surfaces of the ramp must be stainless steel to reduce friction.

3. It is further recommended that a passive gate and tipple be incorporated into this ramp so that when the leading element rolls through a gate at the bottom of the ramp, the element, thought its own weight, will be rotated to a near vertical orientation and the

gate will close to the next element. When the element is removed from the tipple, the tipple will, by its own weight, rotate back and open the gate for the next element. It is also possible to load the fuel without this mechanism, but efficiency would be reduced.

4. For the broken fuel elements, a wire fixture (described previously) should be used to re-assemble the broken elements back into the form of a complete fuel element. The process table should include a stand to hold this fixture vertically to facilitate loading the element pieces. Further the fixture should be in a location where it can be lifted and loaded by the basket-loading manipulator without interrupting the sorting manipulator.

5. In general, the features of the process table need to be designed with the manipulators in mind. We recommend minimizing the size and number of vee-blocks used to position the fuel elements in the inspection tray in order to maximize the acquisition area for the grasp of the manipulator. At this time no detailed designs exist, nor am I certain how the disassembly station will hold an fuel assembly (or its elements), but these all must be designed using the same paradigm as the inspection tray: that these process stations must allow the greatest variation of grasp orientation possible in order to maximize spent-fuel throughput.

5.0 Conclusion

The use of the modified Hydra LRs as the loading and sorting manipulators for the Spent Fuel Retrieval Sub-Project will, depending on operator efficiency, meet or exceed the stated performance and availability goals. The manipulator is well suited to the tasks and known loads and its control system is arguably the most intuitive commercially available system on the market today. SRS's Hydra manipulator has a ten year history demonstrating, in most environments, a working life well beyond the required life of this application.

We have successfully shown that the manipulator, master control arm, and tooling, even in less-than-optimum configurations, were able to beat the stated performance goals by a factor of almost two. Additionally, the system is so intuitive that it is possible for a person, with no experience on the system, to load fuel element mock-ups into the MCO basket within the stated goals.

We request that BNFL and WHC review and comment on our recommendations. Also we would like the opportunity to comment on any changes in the process that might occur as a result of our study.

Appendix D

Test Procedure for SNF Fuel Retrieval Mockup

Appendix D

TEST PROCEDURE
For
SNF FUEL RETRIEVAL MOCKUP

1.0 OBJECTIVE:

To quantitatively and qualitatively evaluate the capabilities of different configurations of the HV (Schilling) manipulator arm, and its mode of deployment, in picking up and handling simulated inner and outer fuel elements.

2.0 CONFIGURATION OF HARDWARE BEING TESTED:

The Test Engineer shall select one configuration item from each column of the table below to define the overall configuration to be tested. The alphanumeric numbers defining the configuration of the hardware being tested shall be entered in the upper right corner of each data sheet to document the Test Configuration used for the respective data sheet. Example of a Test Configuration Number: 1A.2B.3B.4A.5A

1.0 Arm Base Orientation	**2.0** Arm Joint Config.	**3.0** Mast Config.	**4.0** Fingers Config.	**5.0** Special Tools	**6.0** Other
A. Arm Base Horizontal	***A.** Base Joint Yaw; Two End Joints Pitch	**A.** No vertical translation, azimuth rotation by Schilling yaw only	**A.** 3" wide Parallel Jaws	**A.** No special Tools	
B. Arm Base Vertical	**B.** All Three Joints Pitch Up	**B.** Azimuth Rotation and Vertical translation.	**B.** 3" wide V-block Jaws	**B.** Expanding Collet	
	C. upper joint pitches up, other two joints Pitch Down	**C.** Vertical Translation Only (no azimuth rotation)		**C.** Rod/Clamp Style Gripper	
		D. No Vertical Translation: No Azimuth Rotation			
		E. No vertical translation, azimuth rotation by mast only			
		F. Vertical translation, azimuth rotation by mast only			
		G. Base rolled out, azimuth & vertical			
		H. Base rolled in, azimuth & vertical			
		I. Base roll active, azimuth & vertical			

3.0 TEST ARRANGEMENT:

- Opaque curtains will prevent the operator from having direct visual contact with the Schilling arm or objects being handled by it.
- The operator shall have visual access of the arm operations by three video cameras: 1) video camera (ref. VCR B) located near the manipulator base approximately 10 ft. Above the table surface, 2) video camera (ref. VCR C) mounted on the wrist of the arm, 3) video camera (ref. VCR A) mounted on tripod to provide an elevation view.
- Dummy specimens made of steel will be provided to simulate inner and outer fuel elements on top of a simulated operating table made of wood.

4.0 GENERAL TEST PROCEDURE:

The Test engineer shall assign a unique test number to be entered in the upper right corner of each data sheet, and shall enter his name and the date of test completion for each respective data sheet. This unique test number shall be referenced in the test log book by the Test Engineer. The Test Engineer shall also select the configuration of the hardware to be tested from the table provided in section 2.0, and enter the alphanumeric number indicating his selection in the upper right corner of each data sheet as the Test Configuration Number.

The same Test Configuration may appear on more than one data sheet. To allow the limited amount of test time to be used efficiently, some tests may be repeated more than once for certain hardware configurations, while other tests may be omitted, at the Test Engineers discretion.

Unless otherwise directed by the Test Engineer, each test configuration shall be subjected to the tests in the following subsections and the data entered into the appropriate place on the data sheet where so indicated. Video recordings shall be made of each test, with the test number being displayed at the beginning of each test sequence.

4.1 Dummy Outer Fuel Element Tests:

1) With the dummy outer fuel element lying on the table in a horizontal position, grab it by the middle. Record time to acquire engagement in the data sheet, and note observations.
2) After engagement has been acquired, orient the dummy outer fuel element into a vertical position. Record time to achieve orientation in the data sheet, and note observations. Repeat steps 1 and 2 as requested.
3) With the dummy outer fuel element laying on the table in a horizontal position, grab it by one of its ends. Record time to acquire engagement in the data sheet, and note observations.
4) After engagement has been acquired, orient the dummy outer fuel element into a vertical position. Record time to achieve orientation in the data sheet, and note observations. Repeat steps 3 and 4 as requested.
5) With the dummy outer fuel element placed on the table in a vertical position, grab it by the middle. Record time to acquire engagement in the data sheet, and note observations.
6) After engagement has been acquired, orient the dummy outer fuel element into a horizontal position. Record time to achieve orientation in the data sheet, and note observations. Repeat steps 5 and 6 as requested.

7) With the dummy outer fuel element placed on the table in a vertical position, grab it by the end. Record time to acquire engagement in the data sheet, and note observations.

8) After engagement has been acquired, orient the dummy outer fuel element into a horizontal position. Record time to achieve orientation in the data sheet, and note observations. Repeat steps 7 and 8 as requested.

4.2 Dummy Inner Fuel Element Tests:

1) With the dummy inner fuel element laying on the table in a horizontal position, grab it by the middle. Record time to acquire engagement in the data sheet, and note observations.

2) After engagement has been acquired, orient the dummy inner fuel element into a vertical position. Record time to achieve orientation in the data sheet, and note observations. Repeat steps 1 and 2 as requested.

3) With the dummy inner fuel element laying on the table in a horizontal position, grab it by one of its ends. Record time to acquire engagement in the data sheet, and note observations.

4) After engagement has been acquired, orient the dummy inner fuel element into a vertical position. Record time to achieve orientation in the data sheet, and note observations. Repeat steps 3 and 4 as requested.

5) With the dummy inner fuel element placed on the table in a vertical position, grab it by the middle. Record time to acquire engagement in the data sheet, and note observations.

6) After engagement has been acquired, orient the dummy inner fuel element into a horizontal position. Record time to achieve orientation in the data sheet, and note observations. Repeat steps 5 and 6 as requested.

7) With the dummy inner fuel element placed on the table in a vertical position, grab it by the end. Record time to acquire engagement in the data sheet, and note observations.

8) After engagement has been acquired, orient the dummy inner fuel element into a horizontal position. Record time to achieve orientation in the data sheet, and note observations. Repeat steps 7 and 8 as requested.

TEST No. ________
DATE OF TEST ________
TEST CONFIG. ________
Test Engineer ________

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel			
4.1.2	Rotate outer fuel to vertical position			
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel			
4.1.6	Rotate outer fuel to horizontal position			
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

TEST No. ________
DATE OF TEST ________
TEST CONFIG. ________
Test Engineer ________

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.2.1	Engage middle of horizontal inner fuel			
4.2.2	Rotate inner fuel to vertical position			
4.2.3	Engage end of horizontal inner fuel			
4.2.4	Rotate inner fuel to vertical position			
4.2.5	Engage middle of vertical inner fuel			
4.2.6	Rotate inner fuel to horizontal position			
4.2.7	Engage end of vertical inner fuel			
4.2.8	Rotate inner fuel to horizontal position			

Appendix E

Phase 2 Testing Data Sheets

September 9, 1996

TEST No. 001
DATE OF TEST 9/10/96
TEST CONFIG. 1B, 2B, 3A, 4A, 5A
Test Engineer J D POTTER

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	2-0 1-45" ∞	1) COULD NOT PICKUP "HEAVY" DUMMY 2) O.K. INITIAL POSITION OF FUEL IS CRITICAL 3) ROLLED AWAY BASE SET AT 42.5" ABOVE TABLE	PAUL
4.1.2	Rotate outer fuel to vertical position		NO. GO COULD NOT HOLD ON	PAUL
4.1.3	Engage end of horizontal outer fuel	1) ∞ 2) ∞	COULD NOT GET TO END - ROLLED AWAY " " " " " " " INITIAL POSITION OF FUEL IS CRITICAL	PAUL
4.1.4	Rotate outer fuel to vertical position		N/A	
4.1.5	Engage middle of vertical outer fuel	1) 0-39" 2)	INITIAL POSITION IS CRITICAL	PAUL
4.1.6	Rotate outer fuel to horizontal position	1) 0-40"	ROTATED HORIZ. THEN DROPPED	PAUL
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

TEST No. 002
DATE OF TEST 9/10/96
TEST CONFIG. 1B, 2B, 3B, 4A, 5A
Test Engineer J D POTTER

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	1) 1'-8" 2) 0'-9" 3)	EASIER TO ENGAGE FUEL. INITIAL POSITIONING OF FUEL LESS CRITICAL HYDRAULIC FAILURE (O-RING BLEW)	PAUL 9/10/96
4.1.2	Rotate outer fuel to vertical position	1) 0'-35" 2) ∞	DROPPED	
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel			
4.1.6	Rotate outer fuel to horizontal position			
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

September 9, 1996

TEST No. 003
DATE OF TEST 9/11/96
TEST CONFIG. 1B, 2C, 3B, 4A, 5A
Test Engineer JD POTTER

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	1'-28"	GOOD	PAUL
4.1.2	Rotate outer fuel to vertical position	0-26"	WORKED O.K. (WITH LIGHT DUMMY OUTER)	PAUL
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel			
4.1.6	Rotate outer fuel to horizontal position			
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

September 9, 1996

TEST No. 004
DATE OF TEST 9/11/96
TEST CONFIG. 1A, 2C, 3B, 4B, 5A
Test Engineer

DATA SHEETS FOR SNF FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	0-55" 1'-12" 0-44"	GOOD (OUTER) [illegible] (OUTER) (INNER & OUTER)	PAUL
4.1.2	Rotate outer fuel to vertical position	0-45" 0-13" 1-47"	GOOD (OUTER) GOOD (OUTER) (INNER SLID OUT OF OUTER)	PAUL
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel	0'-42" 1'-45"	GOOD GOOD	PAUL
4.1.6	Rotate outer fuel to horizontal position	0-32" 0-15"	GOOD GOOD	PAUL
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

September 9, 1996

TEST No. 004
(cont'd)

tep No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.2.1	Engage middle of horizontal inner fuel	1'-0" 0-36"	GOOD GOOD	PAUL
4.2.2	Rotate inner fuel to vertical position	0-22" 0-28"	GOOD GOOD	PAUL
4.2.3	Engage end of horizontal inner fuel			
4.2.4	Rotate inner fuel to vertical position			
4.2.5	Engage middle of vertical inner fuel	0-31" 0-39"	OVER REACHING SMALLER DIA FUEL MUST BE CONSIDERED	
4.2.6	Rotate inner fuel to horizontal position	0-15" 0-13"	GOOD [illegible]	
4.2.7	Engage end of vertical inner fuel			
4.2.8	Rotate inner fuel to horizontal position			

September 9, 1996

TEST No. 005
DATE OF TEST 9/11/96
TEST CONFIG. 1B, 2C, 3E, 4B, 5A
Test Engineer

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	∞	COULD NOT DO (ELEV. NOT ALLOWED)	PAUL
4.1.2	Rotate outer fuel to vertical position			
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel			
4.1.6	Rotate outer fuel to horizontal position			
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

September 9, 1996

TEST No. 006
DATE OF TEST 9/11/96
TEST CONFIG. 1B, 2C, 3F, 4B, 5A
Test Engineer

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	2'-18"* 1-30"	(ACTUALLY HAD ONCE AT ≈1'-0" (FIXED LOCATION))	PAUL
4.1.2	Rotate outer fuel to vertical position			
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel			
4.1.6	Rotate outer fuel to horizontal position			
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

TEST No. 006
(cont'd)

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.2.1	Engage middle of horizontal inner fuel			
4.2.2	Rotate inner fuel to vertical position			
4.2.3	Engage end of horizontal inner fuel			
4.2.4	Rotate inner fuel to vertical position			
4.2.5	Engage middle of vertical inner fuel			
4.2.6	Rotate inner fuel to horizontal position			
4.2.7	Engage end of vertical inner fuel	1-30"	O.K	PAUL
4.2.8	Rotate inner fuel to horizontal position			

September 9, 1996

TEST No. 007
DATE OF TEST 9/11/96
TEST CONFIG. 1B, 2C, 3B, 4B, 5A
Test Engineer

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	0'-52" 2'-0"	SAME FUEL LOCATION AS 006	PAUL
4.1.2	Rotate outer fuel to vertical position			
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel			
4.1.6	Rotate outer fuel to horizontal position			
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

September 9, 1996

TEST No. 007
(cont'd)

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.2.1	Engage middle of horizontal inner fuel			
4.2.2	Rotate inner fuel to vertical position			
4.2.3	Engage end of horizontal inner fuel			
4.2.4	Rotate inner fuel to vertical position			
4.2.5	Engage middle of vertical inner fuel	0'-45"	OK. (SAME LOCATION AS 006	PAUL
4.2.6	Rotate inner fuel to horizontal position			
4.2.7	Engage end of vertical inner fuel			
4.2.8	Rotate inner fuel to horizontal position			

September 9, 1996

TEST No. 008
DATE OF TEST 9/12/96
TEST CONFIG. 1B.2A.3B.4B.5A
Test Engineer

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	1-56" 1'-02" 0-18" 1'-15"	FUEL SAME AS 006 POSITION DIFF FUEL POS	PAUL
4.1.2	Rotate outer fuel to vertical position	1'-0" 0-15" 0-15" 0-39"		
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel			
4.1.6	Rotate outer fuel to horizontal position			
4.1.7	Engage end of vertical outer fuel	0'-27" 0'-26"		
4.1.8	Rotate outer fuel to horizontal position	0-9" 0-10"		

September 9, 1996

TEST No. 0U8
(cont'd)

tep No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.2.1	Engage middle of horizontal inner fuel	0'-38	GOOD	
4.2.2	Rotate inner fuel to vertical position	0-56"	GOOD	
4.2.3	Engage end of horizontal inner fuel			
4.2.4	Rotate inner fuel to vertical position			
4.2.5	Engage middle of vertical inner fuel	40"	GOOD	
4.2.6	Rotate inner fuel to horizontal position	8"	GOOD	
4.2.7	Engage end of vertical inner fuel			
4.2.8	Rotate inner fuel to horizontal position			

September 9, 1996

TEST No. 009
DATE OF TEST 9/12/96
TEST CONFIG. 1B, 2A, 3E, 4B, 5A
Test Engineer

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	∞ ∞	POSITION CRITICAL	
4.1.2	Rotate outer fuel to vertical position			
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel	57" 45" 20" 1-25	→ BY END (NOT MID)	
4.1.6	Rotate outer fuel to horizontal position	N/A (NO VERT)		
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

September 9, 1996

TEST No. 010
DATE OF TEST 9/12/96
TEST CONFIG. 1A.2A.3G.4B.5A
Test Engineer

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	39" 16" 3'-3"	POSITION CRITICAL NEEDS TO BE WITHIN RIGHT ARC — EASY WHEN WITHIN ARC SUSPEND CONTROLLER (TIGHT HOSES)	
4.1.2	Rotate outer fuel to vertical position	7" 14" 14"		
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel	∞	POSITION CRITICAL — DIFFICULT NEED X-Y, ~~BUT STILL PROBABLY WOULD BE DIFFICULT?~~ CAMERA NEED TO VIEW ALL JOINTS — THEN WOULD BE EASIER	
4.1.6	Rotate outer fuel to horizontal position	N/A		
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

September 9, 1996

TEST No. 011
DATE OF TEST 1A.2A.3I, 4A.5A
TEST CONFIG. 9/12/96
Test Engineer

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	1'-39"	PROBABLY BETTER DONE IF VISIBILITY OF CARRIAGE WAS IMPROVED	
4.1.2	Rotate outer fuel to vertical position	12"		
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel	39" 45'	→ NOT FULLY IN JAWS (HARDER TO OPERATE)	
4.1.6	Rotate outer fuel to horizontal position	N/A N/A	WRIST CAMERA INTERFERED - HAD TO DROP DROPPED	
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

September 9, 1996

TEST No. 012
DATE OF TEST 9/12/96
TEST CONFIG. 1A, 2A, 3H, 4B, 5A
Test Engineer

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	1-50 (20?)	COULD GRAB - BUT COULD NOT GET PERPENDIC. TO FLOOR - NOT GOOD - COULD NOT REACH FLOOR WELL - NOT SUITIABLE FOR HORIZ. RELOCATED HIGH CAMERA HIGH & ELEV. CAMERAS	
4.1.2	Rotate outer fuel to vertical position			
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel	0-50" 26"	WORKS GREAT FOR VERT	
4.1.6	Rotate outer fuel to horizontal position	10" 8"		
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

September 9, 1996

TEST No. 013
DATE OF TEST 9/13/96
TEST CONFIG. 1A, 2A, 3B, 4B, 5A
Test Engineer

(SAME AS 008 BUT CAMERAS LOCATED DIFFERENT)

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	49 1-05	GOOD GOOD	DENNIS "
4.1.2	Rotate outer fuel to vertical position	15 8	GOOD GOOD	DENNIS "
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel	53" 1-36 1'-49" 2-37	→ NOT ENGAGED GOOD	→ (DENNIS)
4.1.6	Rotate outer fuel to horizontal position	8" 8" 12" 15"		→ (DENNIS)
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

September 9, 1996

TEST No. 014
DATE OF TEST 9/13/96
TEST CONFIG. 1A, 2A, 3G, 4B, 5A
Test Engineer ____

(SAME AS 010 BUT NEW CAMERA LOCATIONS)

DATA SHEETS FOR SNF
FUEL RETRIEVAL MOCKUP TESTS

Step No.	Task Description	Time min-sec	Observations/Comments	Operator's Name
4.1.1	Engage middle of horizontal outer fuel	2-45 3-10"	O.K. "	DENNIS "
4.1.2	Rotate outer fuel to vertical position	5" 8"	O.K. "	DENNIS "
4.1.3	Engage end of horizontal outer fuel			
4.1.4	Rotate outer fuel to vertical position			
4.1.5	Engage middle of vertical outer fuel	∞ 2'-13"	COULDN'T DO -	DENNIS PAUL
4.1.6	Rotate outer fuel to horizontal position	10"		
4.1.7	Engage end of vertical outer fuel			
4.1.8	Rotate outer fuel to horizontal position			

Appendix F

ROSEE Training Evaluation Sheets

ROSEE OPERATOR TRAINING 17

MODULE 7
ROSEE MANIPULATOR ARM

Instructor: ______________________ Date:__________

Operator: ______________________ Date:__________

Module Classroom Test

True/False (circle one)

1. The optimal hydraulic flow supplied by the HPU is 3 gpm. T / F

2. The wrist stop on the slave arm stopr the wrist after 1.5 revolutions. T / F

3. The manipulator arm should not leak fluid under normal operating conditions. T / F

4. Transparent reindexing involves resetting range of motion limits. T / F

5. The master controller computer has a diagnostics mode for determining problems with the tractor unit. T / F

6. When the master controller is turned on, the first thing it attempts to do is contact the slave controller. T / F

Multiple Choice (circle all that apply)

1. To use the manipulator arm in "sweep" mode, the operator will need to do t e following:
   a) Reset "range of motion" limits on the arm
   b) Freeze some of the arm joints in the specified positions
   c) Grasp the vacuum pickup head with the arm
   d) All of the above

2. The manipulator arm will be used to perform the following types of tasks:
   a) Sweeping in corners and other smaller areas
   b) Gathering large pieces of debris
   c) Fuel identification and sorting
   d) All of the above

3. The valve block/slave controller component performs the following functions:
   a) Allows for diagnostic check using LCD display
   b) Distributes hydraulic fluid to slave arm hydraulic actuators
   c) Regulates data transfer to and from the slave arm
   d) Processes information going to and from the slave arm
   e) All of the above

4. Which of the following joints is not operated by a linear actuator:
   a) Shoulder roll
   b) Shoulder pitch
   c) Elbow swing
   d) Wrist rotate
   e) Jaw open and close

5. Hydraulic fluid level should be checked
   a) Each shift
   b) Monthly
   c) Before each use
   d) Weekly

Fill in the Blank

1. Waste disposal concerns dictated the use of a ________________ hydraulilc fluid.

2. To "Freeze" the arm temporarily, press the ______________ button, located on the ______________________ .

3. When ___________ is displayed on the LCD screen, the arm is not frozen and can operate normally.

4. Slave arm speed can be regulated by selecting ________________ under the options menu.

5. At the end of the shift, the slave arm should be placed in the ____________________ position.

Short Answer

1. If the manipulator arm is jerky or responding slowly, the first thing the operator should try to remedy the problem is:
   1)

2. Explain how the manipulator arm enhances ALARA:
   1)
   2)

3. List the four major components of the Shilling manipulator arm:
   1)
   2)
   3)
   4)

4. List the six arm functions (movements) of the manipulator arm.
   1)
   2)
   3)
   4)
   5)
   6)

5. ROSEE is an acronym for ________________________________.

6. Which mode under the Main Menu would be used to program a sapmle point drop.
   1)

ROSEE OPERATOR TRAINING

MODULE 7
ROSEE MANIPULATOR ARM

Instructor: ______________________________ Date:___________

Operator: ______________________________ Date:___________

Module Practical Test

Direct personnel to perform the following tasks or types of tasks:

- Turn on the manipulator arm system.
- Perform functional check on hydraulic power unit.
- Perform functional check on controller and arm.
- Perform routine tasks using the manipulator arm.
- Place arm in and take arm out of stow mode.
- Ready the arm for sweep mode by freezing joints in position.
- Reset range of motion limits of the arm.
- Use cameras to aid in operation of the arm.
- Use operations manual to troubleshoot a problem.
- Turn off/shut down the manipulator arm system.

ROSEE OPERATOR TRAINING

ROSEE MANIPULATOR ARM

I. INTRODUCTION

One of the key specialized components that will be used to perform many varied tasks is the ROSEE manipulator arm mounted on the tractor unit. The manipulator arm was added to the tractor unit to further enhance ALARA. Many of the tasks that the arm will perform, such as picking up and sorting debris, would have been performed by personnel inside the basin. These tasks can now be performed by personnel stationed outside the basin. The manipulator arm is model HV6F (six-function arm) manufactured by Shilling development. The arm is operated from the ROSEE command center stationed in corridor 22.

II. SYSTEM COMPONENTS

The components of the Shilling HV6F manipulator arm are as follows:

- Master Controller (joystick and computer)
- Slave Controller/Valve Block
- Manipulator Arm (slave arm)
- Hydraulic Power Unit (HPU)

Master Controller

The master controller contains all operator controls for the manipulator system, including the master arm, display screen, and keyboard. It also contains all master controller computer electronics.

The master arm is a miniature replica of the slave arm, with the same relative range of motion. Each slave arm joint or function has the same range of motion as in the master arm. The operator uses the master arm to move slave arm joints, rotate the wrist, or open and close the jaws.

The master controller also contains an LCD screen that provides the operator with information on system status and available operating options. Next to the screen are keys that the operator uses to select menus or to activate functions.

In conjunction with the slave controller, the master controller gathers and processes information necessary to execute arm functions.

The master controller is connected to the slave controller/valve block and to the electrical power source.

Master Controller Components
The master controller is composed of the master arm, the faceplate assembly, and controller electronics. An electrical on/off switch on the faceplate assembly controls power to the master controller.

Master Arm
The master arm is mounted on the master controller faceplate. The operator moves the master arm (joystick) with his/her wrist and fingers.

Potentiometers in master arm joints are used as position transducers. These potentiometers dictate the desired arm position relative to the current position.

The master arm has the following functional controls:

- Master arm joints. the operator moves these joints to actuate movement of the corresponding slave arm joints.
- Freeze button. Pressing the freeze button freezes the slave arm in its current position. Also referred to as the "shunt" or "freeze" button.
- Wrist collar. The operator rotates the wrist collar to rotate the slave arm wrist.
- Jaw bands. The operator presses the forward jaw band to close the slave arm jaws, and the aft jaw band to open them.

Faceplate Assembly
The faceplate assembly contains the following components:

- Master controller power switch
- LCD display screen
- Function keys

The faceplate assembly captures and processes the operator's function key inputs, and also displays system information.

Master Controller Electronics

The master controller contains assemblies that regulate and distribute power to the master arm and faceplate. These electronic assemblies also transfer, convert, and process signals going to and from the master arm, faceplate, and slave controller.

Further Detail on the Master controller unit can be found in the Shilling operations and maintenance manual.

Valve Block/Slave Controller

The valve block/slave controller is made up of two subassemblies: the valve block and the slave controller.

The valve block subassembly distributes hydraulic fluid to drive slave arm hydraulic actuators. The valve block is equipped with lock valves that close when system hydraulic pressure is not being applied, preventing the shoulder and elbow joints from drifting. Hydraulic fluid from the HPU enters the valve block through the hydraulic supply line.

In the valve block, each valve has two output ports on the side of the valve block, and both ports are connected to a specific slave arm actuator. One output actuates the positive movement (right, lift, extend, or open) in the affected slave arm segment. The other output actuates negative movement (left, down, retract, or close) in the same slave arm segment.

The slave controller portion of the slave controller/valve block contains system electronics for processing information going to and from the slave arm. The slave controller performs the following functions:

- Processes slave are data for transmission to the master controller.
- Controls data transfer to and from the slave arm.
- Inputs, regulates, and distributes power to electrical components in the slave controller/valve block and slave arm.
- Closes the slave arm control loop by driving slave arm joints to correspond with the commanded positions.

The slave controller/valve block is mounted on the ROSEE tractor unit. The slave controller/valve block connects to the master controller through the junction box. The slave controller/valve block connects to the slave arm through potentiometer hoses and hydraulic actuator hoses.

Further Detail on the Valve block/Slave controller unit can be found in the Shilling operations and maintenance manual.

Hydraulic Power Unit (HPU)

The hydraulic power supply provides the pressure required to generate movement in the manipulator arm. The hydraulic power unit consists of the following primary components:

- Electric motor
- Hydraulic pump
- Reservoir
- Motor controller
- Filtration System
- Heat exchanger

The HPU motor is a totally enclosed, fan-cooled system. A tether from a transformer provides power to the motor. The motor is a 7.5 horsepower three-phase motor which operates at 1750 rpm.

The electric motor drives the hydraulic pump. The pump operates at an optimal output of 3 gpm at 3000 psi. The three gallon flow rate is sufficient enough to operate the manipulator arm at full speed through any recommended range and loading. A minimum 2 gpm flow will be required for most operations.

The reservoir is a 15 gallon rectangular tank mounted above the pump/motor unit. A breather vent/fill cap and indicators for temperature, system pressure, and fluid level are located on the reservoir.

A remote-control pendant switch operates the motor controller. The pendant control will be operated from the ROSEE command center.

The filtration system ensures the fluid is free of particulates that could hinder operation. Particiuates in the system can cause the arm to be unresponsive or jerky. A maintenance schedule for the changing of the filters is provided in the Shilling manual. Operators should be aware of the filter changeout schedule for both filters used in this system.

The heat exchanger or cooling fan is a separate, self-contained cooling loop. It is sized to maintain correct hydraulic fluid temperature under normal operating conditions. The heat exchanger has a visual flow indicator.

Due to environmental and hazardous waste concerns, the hydraulic fluid used in the basin is a water soluble fluid. This fluid will not form a permanent oily sheen on the surface of the water, but will instead dissolve into the water. This is critical because the manipulator arm is prone to hydraulic fluid weeping slowly through the joints. Introduction of any other type of fluid would require basin water to be processed as a mixed waste, adding considerable time and expense to the project.

Manipulator Arm (Slave Arm)

The slave arm structure provides a skeleton for the hydraulic linear actuators that move the slave arm. These arm segments are connected at hinge points and pivot relative to each other. This pivoting action is driven by linear actuators. the linear actuator body is mounted in one arm segment. The linear actuator rod, the stroking component of the linear actuator, is pinned to the adjacent arm segment near the pivot. The reciprocating action of the linear actuator rod causes the pivoting at the joint of the two adjacent arm segments.

The rotation of the wrist is driven by a small hydraulic motor in the wrist. As hydraulic fluid passes through the wrist motor, the drive shaft rotates, causing the rotation of the wrist sleeve and jaw assembly. This is the only arm function not performed with a linear actuator. A wrist stop has been installed to prohibit the wrist from rotating greater than one revolution in either direction. The opening and closing of the jaws is driven by a small hydraulic actuator machined into the end of the wrist sleeve. The stroking action of the actuator rod causes the parallel opening and closing of the manipulator jaws.

The manipulator arm has the following major subassemblies:

- Slave arm assembly.
- Wrist assembly.
- Jaw assembly.
- Hydraulic hoses.
- Potentiometer hoses.
- Linear actuator assemblies.

Slave Arm Assembly

The HV6F manipulator system consists of four arm segment components. These segments are the skeletal components of the system that house the hydraulic linear actuators that move the slave arm. The arm segments are linked at pivot points that create a hinged joint. All of these pivot points are similar and the following discussion applies to each joint. The HV6F consists of a base, or cradle segment, a shoulder roll segment, a shoulder segment, and a forearm segment.

Wrist Assembly

High-pressure hydraulic fluid is directed through the hydraulic motor resulting in rotation of the motor shaft. Reversing the direction of fluid flow changes the direction of rotation of the wrist motor. A mechanical wrist stop has been added to prevent greater than one revolution in either direction.

Jaw Assembly

The parallel-acting jaw is a mechanical assembly of linkages, pivot pins, an actuation rod and piston, and the two jaws, which are all fastened to the jaw nose block. The parallel opening and closing of the jaws is driven by a small hydraulic cylinder in the end of the wrist sleeve.

Hydraulic Hoses

The hydraulic hoses link the valves in the valve block to their respective linear actuators in the slave arm. Each slave arm function requires two hydraulic hoses to drive it. Each hose provides either the positive or negative movement defined above.

Potentiometer Hoses

The signals from the potentiometers, which are located in the linear actuators, are conducted back to the master controller through electrical cables housed in polymeric, flexible hoses. The potentiometers are used to determine arm position relative to the desired position.

Linear Actuator Assemblies

The hydraulic linear actuator itself is a simple piston at the center of the rod contained within a cylinder. Introduction of fluid on one side of the piston extends the rod and introduction of fluid on the opposite side of the piston retracts the rod. This linear stroking action is used at the arm segment joints to produce a pivoting action.

The HV6F manipulator arm has the following system specifications:

- maximum reach of thirty-six inches
- eighty pound lift capacity at full extension
- three-inch jaw capacity
- two-hundred pound jaw closure force
- ninety degree shoulder roll
- minus thirty to plus sixty degree shoulder pitch
- plus thirty to minus ninety degree elbow yaw
- plus thirty to minus ninety degree wrist yaw
- three-hundred sixty degree wrist rotation
- wrist torque of twenty foot-pounds
- optimal operating flow of 3 gpm; minimum of 2 gpm
- optimal operating pressure of 3000 psi; minimum of 2000 psi
- optimal operating temperature: 50°F < temp. < 130°F

III. OPERATIONAL GUIDELINES

Shilling Development has supplied a detailed operations and maintenance manual, a copy of which is stored for reference at the ROSEE command center. The operations and troubleshooting sections of this manual is required reading for all operators. The other sections of the manual are also of value as background and supporting information, but are not required for operation.

The operations section of the manual will address the following:

- operational routines
- transparent reindexing
- operating parameters
- changing limits
- locking joints
- stowing arm
- troubleshooting/diagnostics
- robotic operation

COURSE NUMBER: 105020
COURSE NAME: ROSEE

On-the-Job Evaluation Sheet
for
Remotely Operated Sediment Extraction Equipment

Part 3 and 4
Tractor Unit and Umbilical Cord and Slave Arm

Task Title: Operating the ROSEE Tractor Unit with the Umbilical Cord

Task Conditions: Equipment as installed in the 105N Metal Prep Area operable

Training Completed: Completed OJT for these Modules

References: BHI-FS-02, Vol. 2, Instructions NMI-03-017 and NMI-03-024
Installation, Operation and Maintenance Manual for Remote Operated Sediment Extraction Equipment (ROSEE), VI-95-0003
0100N-DD-J-0018, ROSEE Flow Diagram

Tools and Equipment: ROSEE-RT-1, Tractor Unit
ROSEE-HCU-1, Hydraulic Control Unit
Work Location Console

Safety Precautions:
Discuss the strength of the Tractor and Slave Arm and the care that should be exercised in moving them in the open area. Identify boundaries for tractor operation in the Metal Prep area.

Overall Task Standards:
Passing the evaluation will include a knowledge of the procedure and emergency responses. A trainee that makes an error and is able to correct the error himself and recover is considered satisfactory performance. Automatic failure occurs when a trainee makes an unrecoverable error, or does not correct the error or request assistance.

Instructions:
Evaluation begins at evaluator's direction. Evaluation ends when an automatic failure occurs, emergency conditions arise, or at the evaluator's direction. Automatic failure occurs if the trainee actions would have placed himself/herself or others in a potentially dangerous situation, or to have operated the equipment such that damage may occur. Evaluator will score with a satisfactory or unsatisfactory mark. All unsatisfactory marks are required to be explained.

The trainee should ask questions before the evaluation begins. Once the evaluation has begun, the evaluator will no longer answer questions.

COURSE NUMBER: 105020
COURSE NAME: ROSEE

Instructions to the Trainee:

Not all steps of the procedure will be performed for this evaluation. Perform the steps, unless directed to discuss or simulate them. First, you will be asked to perform cubible cleaning, then discuss cubicle inspection.

Date: ____________________ Time: ____________________

No.	Action	Standard	S	U	Mode
1	Start the Tractor and Slave arm in accordance with BHI-FS-02, NMI-03-024, section 6.1. Omit steps for starting the Moyno pump.	Perform in accordance with instructions. Fill out required Attachments.			P
2	Drive tractor forward and backward in the TRIGGER 2 mode.	Perform in accordance with instructions.			P
3	Drive tractor in a zero radius turn to the right.	Perform in accordance with instructions. Know that he must switch to TRIGGER 1.			P
4	Drive tractor in a zero radius turn to the left.	Perform in accordance with instructions.			P
5	Start slave arm and perform a shoulder roll.	Perform in accordance with instructions.			P
6	Perform a shoulder pitch with the slave arm.	Perform in accordance with instructions.			P
7	Pick up an object designated by the field superintendent and place it according to his instructions. Repeat as directed by the field superintendent.	Perform in accordance with instructions. Request direction from field superintendent.			P

COURSE NUMBER: 105020
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8	Shutdown the system in accordance with section 6.3 of BHI-FS-02, NMI-03-024.	Perform in accordance with instructions. Correctly fill out required attachment.			P

Mode: P= perform, S= simulate, D= discuss
Evaluator has the discretion to change P to S or D.
A check in column S indicates satisfactory performance.
A check in column U indicates unsatisfactory performance.

Comments:

____
____
____
____
____
____

Evaluator:_______________ Trainee:_______________

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