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Final Report Spent Nuclear Fuel Retrieval System Fuel Handling Development Testing

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Final Report
Spent Nuclear Fuel Retrieval System
Fuel Handling Development Testing

D. R. Jackson
P. V. Meeuwsen^(a)

September 1997

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Prepared for the U.S. Department of Energy
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Summary

Fuel handling development testing was performed in support of the Fuel Retrieval System (FRS) Sub-Project, a subtask of the Spent Nuclear Fuel Project at the Hanford Site in Richland, Washington. The FRS will be used to retrieve and repackage K-Basin Spent Nuclear Fuel (SNF) currently stored in old K-Plant storage basins. The FRS is required to retrieve full fuel canisters from the basin, clean the fuel elements inside the canister to remove excessive uranium corrosion products (or sludge), remove the contents from the canisters and sort the resulting debris, scrap, and fuel for repackaging. The fuel elements and scrap will be collected in fuel storage and scrap baskets in preparation for loading into a multi canister overpack (MCO), while the debris is loaded into a debris bin and disposed of as solid waste.

This report describes fuel handling development testing performed from May 1, 1997 through the end of August 1997. Testing during this period was mainly focused on performance of a Schilling Robotic Systems' Conan manipulator used to simulate a custom designed version, labeled Konan, being fabricated for K-Basin deployment. In addition to the manipulator, the camera viewing system, process table layout, and fuel handling processes were evaluated. The Conan test manipulator was installed and fully functional for testing in early 1997. Formal testing began May 1.

The purposes of fuel handling development testing were to provide proof of concept and criteria, optimize equipment layout, initialize the process definition, and identify special needs/tools and required design changes to support development of the performance specification. The test program was set up to accomplish these objectives through cold (non-radiological) development testing using simulated and prototype equipment.

To test the fuel handling process, a test mockup representing the process table and manipulator setup was installed at the Hanford 305 Building Equipment Testing Laboratory (ETL). The mockup included a process table sorting area, disassembly and inspection areas, fuel staging areas, basket loading stations, and the Schilling Conan manipulator. The test operators performing the test functions were experienced senior K-Basin operators. These individuals possess extensive expertise in fuel handling activities associated with K-Basin fuels and provided valuable insight to the testing program and resultant recommendations.

The test program was divided into four stages: table optimization, fuel sorting, basket loading, and primary clean machine (PCM) interface testing. The last stage did not directly involve the manipulator but was used to evaluate process interfaces between the PCM, the manipulator, and the process table. These tests were used to evaluate long reach tools used in loading/unloading operations for the PCM. Table optimization tests targeted processing time and optimization of support equipment locations and designs, including the remote camera viewing system. Fuel sorting tests were used to evaluate the functionality of the manipulator for sorting fuel, scrap, and debris on the process table. Basket loading tests were used to evaluate the manipulator system for its capability and efficiency in loading fuel

elements into the MCO fuel basket and to develop suitable methods for recovering pieces of fuel dropped into the basket or onto the floor.

Each of the three process operations involving the manipulator was divided into logical process steps. Fuel sorting was broken down into disassembly of full length fuel elements, separation of fuel segments less than three inches long (scrap), scrap basket loading and load adjustment, debris separation and loading, and processing full length fuel through the inspection station. Basket loading was broken down into evaluation of the loading sequence, dropped fuel recovery (including both manipulator and manual operation), and broken fuel loading. The latter operation was evaluated in detail to determine the best loading sequence for broken fuel pieces. Table optimization tests were performed to evaluate earlier reported timelines and identify possible process changes and tool developments. The results of these tests were used to evaluate the complete fuel handling process from the upper end of the table to loading out the baskets, including scrap and debris loading.

The manipulator tests confirmed that the Conan manipulator and Schilling proposed tools have the capability to perform the required functions to pick, move, and place fuel successfully within current time limit estimates. It was also determined that camera locations and capabilities are extremely important to the control of the manipulator and other remote operated systems, and these locations have been identified and passed on to the design agent for incorporation into the design. Finally, it must be noted that jaw and end effector tool design is crucial for the effective acquisition and handling of fuel components within the required process time limits. The final configurations for both the cameras and the end effector tool have been proven adequate for performing their required functions.

Abbreviations and Acronyms

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
MCO	Multi Canister Overpack
OD	Outside Diameter
PNNL	Pacific Northwest National Laboratory
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, a subtask of the Spent Nuclear Fuel Project at the Hanford Site in Richland, Washington. The FRS will be used to retrieve and repackage K-Basin Spent Nuclear Fuel (SNF) currently stored in old K-Plant storage basins. The system will be used to clean and remove fuel from the fuel storage canisters, repackage it into new storage baskets, and load it into a multi canister overpack (MCO). Once inside the MCO the fuel will undergo processes for hot and cold vacuum drying before the completed package is transferred for interim dry storage at the Canister Storage Building (CSB), also located on the Hanford Site. The FRS is required to retrieve full fuel canisters from the basin, clean the fuel elements inside the canister to remove excessive uranium corrosion products (or sludge), remove the contents from the canisters and sort the resulting debris, scrap, and fuel for repackaging. The fuel elements and scrap will be packaged into MCO fuel storage and scrap baskets in preparation for MCO loading, while the debris is loaded into a debris bin and disposed of as solid waste.

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. WHC/DESH subcontracted to British Nuclear Fuels, Limited (BNFL) 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 or confirm the design basis.

Pacific Northwest National Laboratory (PNNL) was requested to coordinate and lead the testing and computer simulation needs for development of the fuel handling retrieval system. BNFL provided the applicable test specifications indicating specific design needs. Tests were conducted by the Equipment Testing Laboratory (ETL) in the 305 Building at Hanford. The ETL provided necessary facility space, test equipment design and fabrication, test engineering, and technician support.

The purposes of fuel handling development testing were to provide proof of concept and criteria, optimize equipment layout, initialize the process definition, and identify special needs/tools and required design changes in support of performance specification development.

Fuel handling development testing encompassed the manipulator system, including the viewing system, and associated manual, or long reach, tool development as well as investigation of process improvements and interfacing. The manipulator system was tested for fuel element disassembly; sorting and handling of fuel, scrap (fuel less than 3 inches long), and debris (all non-fuel components); and loading fuel and scrap into an MCO basket. All these activities are to be performed on the in-basin process table being fabricated by Westinghouse Engineered Products (WEP).

This report specifically describes fuel handling development testing beginning May 1, 1997 and running through the end of August 1997. Earlier tests were performed using a Schilling HV manipulator, with

unsatisfactory results¹. As a result of those tests, Schilling provided an unsolicited proposal to use a specially designed Conan (Konan) manipulator in place of the HV unit. The Fuel Retrieval System (FRS) sub-project decided to move ahead and procure an off-the-shelf Conan system for future testing and the customized version, Konan, for basin deployment. The Conan test manipulator was fully functional for testing in early 1997 and formal testing began May 1.

During the earlier tests, a mockup of the in-basin process table was fabricated and set up in the ETL. The mockup was based on design input provided by the project design agent, BNFL, to accurately evaluate the system's ability to meet the various test objectives. This mockup was used with the Hydra manipulator in the early tests and with the Conan manipulator during the later testing.

The system tested at this stage included the off-the-shelf Schilling Conan series manipulator attached to a mocked-up bridge rail and mast system, the process table mockup, an MCO fuel storage basket, and an MCO scrap basket. The bridge rail system provided travel only in the north and south directions, or from one end of the table to the other. The system was laid out to be prototypic of the BNFL design with regard to relative elevations and dimensions. The manipulator was mounted on an overhead mast in a standard deployment configuration for the Conan product, where the arm and base-mounting configurations were based on earlier tests performed using the HV series manipulator. The bridge system was translated from end to end using a pair of foot actuated switches, which improved manipulator coordination for the operator

The process table mockup was fabricated of plywood and covered with sheet steel, as this configuration allowed flexibility to modify the table configuration in a very short period of time. On the upper end of the table, a sloped ramp allowed dummy fuel to roll or slide onto the process table sorting area and the side rails were temporarily mounted alongside the ramp and table, to allow quick modification to the table configuration. The table was modularly designed so that special handling needs could be considered and different sections could slide into various positions. The upper end of the table included openings to hold a debris bin, a fuel canister, and a scrap basket. The fuel canister opening has a removable lid installed in it to allow fuel sorting without a canister in place. Most of these tests were performed with the lid in place. The lower end of the table is separated from the upper end by a second ramp, which empties onto the fuel loading area. A fuel basket and a second scrap basket are both located in the lower end of the table.

To simulate remote conditions, the manipulator was operated using the master controller and joystick located so that the table was isolated from view. The fuel handling processes were monitored by video cameras and viewed by the operator on four or five video monitors. The bridge control was located on the floor and utilized two foot-actuated switches to move the bridge. This configuration for bridge control allowed the operator to translate the bridge at the same time he was positioning the manipulator with the joystick. Typically, the joystick is operated using a two-handed grip.

¹ Ketner GL et al., *Interim Report-Spent Nuclear Fuel Retrieval System-Fuel Handling Development Testing*, PNNL-11423, June 1997.

The simulated fuel handling process included the initial acquisition or picking up of the fuel assemblies, after they were dumped onto the ramp section of the table; and subsequent disassembly of the dummy fuel element pairs. The process continued with the sorting of scrap, debris, and fuel; moving the fuel down the table to the basket loading area; and finally, loading the fuel elements and scrap into MCO baskets. Scrap handling tests included picking scrap up off the table, placing it into the basket, and sweeping (with a squeegee) scrap into the MCO scrap basket. Simulated debris loading operations were also performed as well as the placing of fuel assemblies in the disassembly station mockup and the inspection station. After determining that the general processes were feasible, we performed additional tests to load damaged or broken fuel elements into the MCO fuel element basket.

Test Method and Equipment

In general, the results of fuel handling tests were used to provide design and process validation information to the FRS design agent and to support the optimization of fuel handling operations. Test specifications developed by BNFL were the basis for the earlier tests using the Schilling HV manipulator and subsequent test results were the basis for testing of the Conan system. The overall objectives of fuel handling developmental tests for the Conan manipulator system include:

- Validating time lines projected by BNFL from an individual operation basis
- Evaluating and recommending process table design modifications
- Developing techniques to load damaged or broken fuel elements and to sort out material classified as non-fuel
- Optimizing and testing the type and quantity of end effectors and small tools
- Identifying additional tooling and fixtures required for optimal fuel handling.

Testing was conducted in a non-radiologically controlled area and no radiological materials were used in either the earlier Hydra HV tests or the Conan tests. The Interim Fuel Handling Test Report, cited earlier (Ketner et al), dealt with only that portion of development testing performed with the Schilling Hydra HV manipulator, while this final report deals only with the testing of the Schilling Conan manipulator. Besides the capability of the Schilling Conan manipulator to perform fuel handling and packaging processes, the scope of testing also addressed placement of video cameras to optimize task performance by remote operation. All testing was performed in air using simulated fuel elements.

The same wood process table mockup that was used in the earlier Hydra tests was also used during testing of the Conan manipulator, but was modified by adding steel sheets to the top to protect the plywood structure (Figure 1). Other modifications were developed during, and as a result of, this testing. Three critical modifications were in how the fuel basket was situated in the lower end of the table. It was found that loading the basket was extremely difficult when the top of the basket was flush with the table top, so it was elevated to extend 3" above the table surface. It was also extremely difficult to see the fuel sockets in the bottom of the basket, and practically impossible when only one or two sockets remained empty. Placing a light under the basket to shine up through the fuel sockets solved this problem. The last of the three modifications was to install a turntable under the fuel basket. This allowed the operator to spin the basket, providing much easier access to all sections of the basket. Allowing the basket to spin also proved to aid in loading fuel into individual sockets. The light was relocated to illuminate the turntable and still shine into the lower end of the basket, but no longer up through the sockets.

Figure 1. Plywood Process Table Mockup with Steel Sheet Work Surfaces

Figure 2. Conan Manipulator Set Up in 305 Bldg. Test Area

Another modification made to the table mockup was addition of a go-nogo gage. This device is a steel plate with holes cut into it that match the size of the fuel basket sockets. These holes are slightly tapered from top to bottom to allow the fuel element to self-guide into the socket. The original function of this device was to allow for re-orientation of elements into a vertical position, which is required for proper element acquisition using the end effector fuel grapple. However, during the course of testing it became apparent that some form of sizing die or gage was also needed to ensure that an element end would fit into a fuel basket socket. It was decided to combine these two functions in one device and the design was modified as required. For testing purposes, this system was mocked up using plywood to simulate the actual gage. One unit was assembled for each of the outer and the inner fuel elements. The primary difference between the plywood mockup and the actual steel unit is that the wood grabs the dummy element as it is loaded into a socket and the steel unit will allow the element to slide down into the socket.

For testing purposes, a standard Schilling Conan manipulator (Figure 2) was used to represent the customized Schilling Konan manipulator to be deployed in the basins. Geometrically and functionally, the two systems are identical, have a maximum reach of 66.72 inches and 6 degrees of freedom, and are suspended from an overhead mast attached to a movable bridge. One difference between the two systems is that the Conan used in the tests operates at a lower pressure (2000 psig) than the Konan (3000 psig). Another more important difference is that in the test manipulator, fuel grapple is bolted inside the jaws (Figure 3). This configuration renders the jaws inoperable when the end effector is installed. In the Konan manipulator, the end effector is attached to the side of the jaw, leaving the jaws free to operate normally. Additionally on the Konan, the gripping action takes place when the jaws are opened as compared to the test manipulator (Conan), which actuates the gripper by closing the jaws. Because of this difference, the manipulator jaw operations were separated from end effector operations during testing.

The test manipulator included a bridge-mounted camera, allowing the operator to view a large area using the pan and tilt system, and providing critical viewing capability while moving the bridge. This camera was added after earlier testing identified the need, and recommendations for its placement were passed on to the design agent. A wrist camera was also evaluated on the test manipulator, but it provided no benefit and was removed. This information was passed on to the design agent and the wrist attachment was re-evaluated and redesigned for the Konan. The revised design aims the wrist-mounted camera at the end of the fuel grapple, allowing the operator to clearly see the approach to a fuel element.

Manipulator fuel handling tests were divided into three smaller process operations for initial process development and design validation. The operations consisted of table optimization, fuel sorting, and basket loading using the manipulator. In addition, manual operation and interface testing was performed using long reach tools for recovery of dropped fuel and evaluation of loading/unloading operations for the Primary Clean Machine (PCM). Each of the three manipulator process operations was further divided into logical process steps. Table optimization tests were performed to evaluate earlier reported timelines and identify possible process changes and needed tool developments. Fuel sorting was broken down into disassembly of full length fuel elements, separation of fuel segments less than three inches long (scrap), scrap basket loading and load adjustment, debris separation and loading, and processing full length fuel through the inspection station.

Figure 3. Fuel Grapple End-Effector Clamped in Manipulator Jaw

Basket loading was broken down into loading sequence evaluation, dropped fuel recovery (both manipulator and manual operation), and broken fuel loading. The latter process step was evaluated in detail to determine the best loading sequence for broken fuel pieces. These tests evaluated complete fuel processing from the upper end of the table to loading the baskets, including scrap and debris loading.

To further validate the results, fuel-handling tests were performed by senior K-Basin operators under the supervision of the ETL test engineer and the FRS test coordinator. These operators will be training other operators and eventually using the installed Konan system to recover actual fuel from the K-Basin fuel storage area. The timeline data was developed by these operators and included operational adjustments based on their past experience. Test instructions and results were also reviewed with the operators for their input and recommendations, which are reflected in this report.

Test Descriptions

Each test was laid out as a separate process and evaluated individually. Tests were administered using a graded approach, where the simple straightforward tests were performed from verbal instructions and the more detailed or complex tests were performed to a specific test instruction issued by the test coordinator.

As stated earlier, testing was divided into three main test categories, Table Optimization, Fuel Sorting, and Basket Loading. In all cases the tests were performed using 26" long dummy fuel elements as full-length fuel, a Mark 1A MCO fuel basket, and a prototype MCO scrap basket. Shorter lengths of dummy fuel elements were provided to represent scrap and broken fuel elements.

For the duration of testing, the manipulator was set up with the extended V-block jaw set (Figure 4) developed during earlier Hydra manipulator testing. As a comparison, however, one series of fuel sorting tests was run with the standard Schilling jaw and from those tests it was confirmed that fuel and tool handling was much more difficult and time consuming using the standard jaw configuration. The extended jaws were placed back on the manipulator and testing resumed. All test data in this report was produced using the extended jaw configuration.

Figure 4. Extended V-Block Jaws on Manipulator

Table Optimization

Table optimization tests were conducted to evaluate estimated throughput and were the most general of tests run with the manipulator. The main emphasis in this category was developing a viable timeline for remote table operations, and formal test instructions were not issued. Early timeline runs were each performed by the same operator, while the final runs were each performed by three different operators.

To maintain a stable baseline throughout testing, a "standard canister" was defined. The "standard canister" makeup used in the early timelines consisted of 10 standard inner elements, 10 standard outer elements, 2 stuck inner/outer element pairs, 2 short inner elements, 2 short outer elements, 7 pieces of inner element 3" in length, 7 pieces of outer element 3" in length, 1 buggy spring, 1 screw driver, and 1 rubber glove. The final timeline results were based on a revised standard canister makeup of 8 standard inner elements, 8 standard outer elements, 2 stuck inner/outer element pairs, 2 half length inner elements, 2 half length outer elements, 14 pieces of inner element under 3" in length, 14 pieces of outer element under 3" in length, 3 one-third length inner elements, 3 one-third length outer elements, 1 rubber glove, and 1 screwdriver. The standard canister makeup was revised to reflect more recent fuel characterization information presented in Engineering Change Notice (ECN) #191405; but due to an oversight, only made up a 12-element batch. After a review of the timeline results, the time to move two additional full-length elements was added to the test times, and is reflected in the final results. The contents of the revised standard canister are shown in Figure 5.

Figure 5. Standard Canister Contents Dumped on North Table Ramp

The basic timeline was developed for the time to process a single canister (14 element pairs) from the upper (north) end of the table to completion of MCO basket loading on the lower (south) end of the table. Timelines were developed for both production processes and validation processes. The production process timelines do not include the added validation steps required during validation runs. Typical production activities include: acquisition of an element pair from the north ramp of the table, separation of the inner from the outer element, transfer of complete inner and outer elements to the south table ramp, picking up large pieces of scrap and placing them in the scrap basket, collecting debris and placing it into the debris bin, and loading the full length and short fuel elements into the MCO fuel baskets.

In the August 1997 tests, timelines were developed for four different process scenarios; one validation process and three distinctly different production processes. The three production process timelines were developed to provide a basis for operating assumptions concerning the use of a single manipulator rather than the pair of manipulators used during production runs. In the project design phase, it had been assumed that using a single manipulator to unload the canister, move the fuel to the south end of the table, and load it into the MCO basket would provide a significant improvement in process time. The first production timeline, using the two-manipulator process, and the second, using a single manipulator process, were based on three different operator's test times with fuel being dumped out of the canister onto the table. The third production timeline, again using the single manipulator process, was based on a single test performed by the operator with the most hands-on experience, and processed the fuel directly from the loaded canister. Both the two-manipulator and the first single manipulator production timelines were developed based on the revised standard canister being dumped onto the north end of the process table and inner fuel elements being separated from the outer fuel elements. The same basic operation was used in the early timelines, where a single manipulator process was assumed. The second single-manipulator timeline was developed based on the same revised standard canister makeup, except that the canister was set into the center of the table instead of being dumped out onto it. This required that the fuel elements be unloaded using the end effector fuel grapple, which had been assumed to provide a significant time improvement in fuel handling. But this assumption was based on the old standard canister makeup; revision of that makeup added a significant degree of difficulty to the operation. This added difficulty was a direct result of the increased quantity of broken fuel and scrap. Because of this added difficulty, we bounded the test results by loading the extra broken fuel and scrap near the top of the canister, requiring that the small pieces be removed first and making the operation more time-consuming. This is proposed as the worst case scenario for single manipulator processing.

Fuel Sorting

Fuel sorting tests again were informal in structure and concentrated on manipulator and operator capabilities. The fuel sorting tests were structured to build the skill level of the operator while evaluating the capability of the manipulator to perform the required functions. As with the table optimization tests, no formal test instructions were issued. The initial tests were simply to pick up full-length fuel assembly pairs and separate them (Figure 6) by dumping the inner element out of the outer. This process was expanded to include setting the full-length elements onto the inspection area of the table and picking up fuel scrap (element pieces less than 3" in length) and setting it into the scrap basket. The final step in the fuel sorting tests was to separate all fuel from scrap and debris, and deposit the fuel onto the south loading ramp, the scrap into the scrap basket, and the debris into the debris bin (Figure 7). The "standard canister", as described for the early table optimization tests, was also used for fuel sorting tests since the characterization information used to update the canister makeup was not yet available. This had no effect on test results, because fuel sorting tests had no specific acceptance or failure criteria. If the operator was ultimately able to perform the process step, the test was accepted as successful. All tests were videotaped and the test coordinator reviewed the tapes after testing was completed.

Figure 6. Separating an Inner Fuel Element from an Outer Element

Figure 7. a) Loading Scrap into Scrap Basket; b) Picking Debris off Table

Basket Loading

Basket loading tests were more detailed and specific test instructions were issued. The main objective of these tests was to determine if there was a specific, or preferred, loading pattern that provided more efficient loading, prevented or reduced inadvertent dropping of fuel sections, or possibly created more difficult loading situations. The second objective was to demonstrate the ability to retrieve dropped fuel elements or pieces from inside the MCO basket and the third objective was to develop a recommended process for loading broken fuel element pieces (pieces greater than 3" in length) into the MCO basket using the manipulator.

The tests were divided into manipulator and manual operations, with the emphasis in the manipulator operations being on the actual loading of fuel elements. Manipulator tests were further subdivided into full element loading and broken fuel loading, each with its own specific test instruction. Manual operations were used to evaluate the ability to recover dropped fuel elements or pieces and to develop an improved, lighter weight, long reach fuel recovery tool.

Four different loading sequences of full-length elements were evaluated for ease of loading using the manipulator and end effector fuel grapple. In addition, fuel elements were laid over as far as they would go to determine if any particular loading pattern prevented recovery of the fuel element using a long reach tool. The manual tests evaluated the recovery of short fuel pieces (greater than 3" in length) dropped between loaded full-length elements and on the bottom of the basket. The latter tests were performed underwater in the 305 Bldg. pool, and utilized a new lighter weight design of fuel tong, developed specifically for this operation.

Broken fuel loading tests were also performed using the manipulator and were performed to a specific test instruction. The general loading test objectives were:

- To demonstrate system functionality for loading broken fuel elements into the MCO fuel basket
- To determine the minimum length of outer fuel element piece to load first into the MCO fuel basket
- To determine the minimum clearance required for the manipulator to load broken outer elements
- To identify loading issues regarding the vertical stability of broken elements
- To determine if there are limitations on loading sequences due to access restrictions

Various loading techniques were demonstrated and evaluated for general manipulator functionality and loading limitations. In addition, operations were evaluated using both the end effector fuel grapple and manipulator jaws for loading fuel pieces. These tests were documented on videotape and on test instruction data sheets.

PCM Interface Testing

The objective of the PCM interface tests was to prove, based on the current operational analysis, the feasibility of using long reach tools to load and maintain the Primary Clean Machine (PCM) and to evaluate handling operations for the fuel tipping device. A test instruction was issued to the 305 Bldg. test engineer for these tests, although they were quite simple and general process times were the only hard data collected.

The test was performed using a plywood mockup of the PCM and steel mockups of the wash basket and tipper jig. The first step was to use the 305 Bldg. overhead crane and long reach tools to install the PCM strainer basket, the wash basket, and full mockup fuel canister. The strainer basket had approximately thirty pounds of miscellaneous material loaded into it to simulate the condition expected after completing a wash cycle. Next, again using the overhead crane and long reach tools, the fuel canister, wash basket, and strainer basket were unloaded from the mockup. Process times were recorded for both steps. The strainer basket, wash basket, and fuel canister were again loaded and the process time was recorded a second time. This process of loading and unloading was repeated for a total of three runs, in order to provide an approximate average process time.

The long reach tools used were the wash basket removal tool (Figure 8) and the improved fuel tongs (Figure 9).

Figure 8. Wash Basket Removal/Installation Tool

Figure 9. Recovery Tool Used in Dropped Fuel Testing

Test Results and Discussion

Table Optimization Tests

The first optimization tests were performed early in the Conan test program and the timeline developed for a single manipulator production run resulted in a 132.75-minute process time. This was the time estimated to process the early version of standard canister from the north end of the table to the south end. Timelines developed late in the testing program averaged approximately 94 minutes for the two-manipulator production process and 125.25 minutes for the single manipulator process with the canister contents dumped onto the table. This was the same configuration used in the earlier tests. Also, using a single manipulator process and unloading the fuel directly from the canister resulted in a 198-minute processing time. The major factor in the time difference for the production runs is the amount of scrap and broken fuel loaded into the canister. Using the end effector to unload scrap and broken fuel is extremely inefficient and adds significant time to the process. As described earlier, the first version of the standard canister consisted of 10 standard inner elements, 10 standard outer elements, 2 stuck inner/outer element pairs, 2 short inner elements, 2 short outer elements, 7 pieces of inner element 3" in length, 7 pieces of outer element 3" in length, 1 buggy spring, 1 screwdriver, and 1 rubber glove. The greater quantity of full-length fuel elements provided fewer individual pieces to pick up compared to the revised standard canister with its extra quantities of scrap and broken fuel. The final timeline results are based on a standard canister makeup of 8 standard inner elements, 8 standard outer elements, 2 stuck inner/outer element pairs, 2 half length inner elements, 2 half length outer elements, 14 pieces of inner element under 3" in length, 14 pieces of outer element under 3" in length, 3 one-third length inner elements, 3 one-third length outer elements, 1 rubber glove, and 1 screwdriver. The latter version of standard canister is based on FRS design document ECN#191405.

The loading sequence for the final timeline runs started with broken fuel pieces first, then the full-length elements. It had been determined during broken fuel loading tests that a quadrant loading pattern was easier to follow with broken fuel, so this was the pattern and sequence selected for final timeline development.

All but one of the final timelines was developed using three different operators on three different days. The other timeline was developed using the process time from a single test performed by the most experienced operator. The different levels of experience directly correspond to hands-on operating time. The first operator had approximately 125 hours logged on the equipment, while the second and third operators had 75 and 35 hours, respectively. The production run times stated above, 94 and 198 minutes, are average estimated processing times based on test times from the three different runs. The individual test times, including the test time for the other single test run, are shown in Table 1. It must be noted that the total test time shown in Table 1 is not the processing time for a typical canister. Test times were used only as a basis for estimation of total process times, because many of the required process steps, including parallel operation of the north and south manipulators, could not be performed with our mockup. Times for these processes were estimated and used to adjust the test times where appropriate. Operations excluded from the north table operations were: scrap sweeping, table vacuuming, stuck fuel disassembly,

and visual inspection of the fuel elements. Performing these operations adds time to the north table operations, resulting in the estimated production and validation run processing times stated above.

In addition to the missing north end operational steps, other differences between the test mockup and the system to be deployed in the basin exist. Most notably, the manipulator to be used in actual fuel packaging will have the capability to rotate 360° at the base, will have the end effector attached where it won't block the operator's view, and will have a higher speed of bridge travel. These simple additions will reduce the operation times below those achieved during these tests.

The estimated process times developed from table optimization testing are shown in Table 2.

Table 1 Table Optimization Test Times

	North Table Operations (minutes)	South Table Operations (minutes)	Total Test Time (minutes)
Operator #1	46	75	121
Operator #2	48	80	128
Operator #3	57	78	135

Figure 10. Loading Debris into Debris Bin

Table 2 Resultant Processing Times

Process Description	Fuel Dumped on North End of Table			Fuel Unloaded Directly from Canister
Test Configuration	Early Test Single Manipulator	Final Test Single Manipulator	Final Test Two Manipulators	Final Test Single Manipulator
Canister Makeup	Old Std. Canister	New Std. Canister	New Std. Canister	New Std. Canister
Production Time (minutes)	132.75	125.25	94	198
Validation Time (minutes)	146.75		106.75	

Testing also provided insight into optimum viewing locations for the color video cameras and lights used to monitor manipulator operations. The cameras each had the ability to pan, tilt, and zoom, with the exception of the camera mounted on the wrist of the manipulator. As configured in the test system, the wrist-mounted camera proved to be of no value and was removed for the bulk of the testing. However, the customized Konan manipulator will have the wrist-mounted camera repositioned to view the end of the end effector fuel grapple. This view will aid in fuel element acquisition and in basket loading operations.

Also, during testing it was found that the extended V-block jaws added to the standard Hydra HV manipulator jaws are more efficient than the standard Schilling jaws on the Conan manipulator. The standard jaws could be used successfully to complete normal process operations, but the extended jaws provided significantly more efficient fuel handling.

The Schilling-proposed end effector fuel grapple was also mocked-up and tested and found to be very effective, but it requires a multi-sized end piece to pick up both inner and outer fuel elements. A design for the end piece was developed and forwarded to Schilling for incorporation into the final product. Actuation of the end effector was achieved using jaw movement, and was used successfully to load dummy fuel elements into the basket.

Fuel Sorting Tests

Results of fuel sorting tests demonstrate that the Conan manipulator is capable of performing the required motions for sorting and loading fuel and scrap. Operations demonstrated successfully include separation of inner and outer elements, retrieving scrap fuel pieces from the table and dropping them into the scrap basket, picking up miscellaneous debris (buggy springs, gloves, small tools) and dropping it into the debris bin (Figure 10). Also demonstrated was the movement of fuel to the stuck fuel and inspection stations, sweeping scrap into the scrap basket, re-sorting scrap from one section of the scrap basket to another, and loading the full-length elements into the vertical positions in the go-nogo gages. In addition, because the mockup of the go-nogo gage (Figure 11) was built out of plywood, it was much more difficult to "slip" an element into the sockets.

Picking and placing fuel with the Conan from a horizontal position to a vertical position or back to a horizontal position is easily performed with the manipulator jaws when assisted by the translation capabilities of the bridge assembly. Picking fuel from a vertical position and placing it vertically into a fuel basket can also be easily performed with the assistance of bridge translation and by using the specially designed end effector fuel grapple tool.

Figure 11. Loading Outer Element into Go-NoGo Gage

Basket Loading Tests

Full Element Loading

Basket loading tests included four different loading patterns, as well as tests to determine if dropped fuel pieces were easily recovered. The four loading patterns tested (Figure 12) are referred to as quadrant loading, serpentine loading, in-line rotation and outside to inside loading. The operator loaded the basket in each of the four sequences using the end effector fuel grapple (Figure 13). The final recommendation is to use the quadrant loading technique, but is qualified with the observation that every operator will eventually develop a personal preference for loading pattern and will ultimately be most efficient using that preferred method.

It was further determined that during normal fuel loading operations, fuel elements will occasionally get dropped into the basket sockets from at least a few inches above the bottom of the basket. Additionally, when using the manipulator jaws to load an inner element into a previously loaded outer element, the inner element is almost always dropped from the full fuel height down into the basket socket. It is also highly probable that full length, intact, fuel element pairs will be dropped into fuel basket sockets and for this reason, the bottom of the fuel basket sockets must be capable of withstanding the dropped load of an intact fuel element pair. Note that the jaw loading technique described above presents the optimum loading process and significantly reduces loading time. It must also be understood that the manipulator is practically incapable of using the manipulator jaws to load an inner element into an outer element without dropping the inner. This is due to the incapability for straight-line movement of the jaw end of the manipulator.

Figure 12. Loading Patterns Used in Basket Loading Tests

Figure 13. Clockwise From Top: (a & b) Using the End Effector Fuel Grapple to Acquire and Lift an Outer Fuel Element. (c) The End Effector Fuel Grapple Used in Testing

Broken Element Loading

In later broken fuel loading tests it was found that a specific loading sequence was more critical to successful loading than in full-length fuel loading. It was determined that in order to prevent loading problems, the broken fuel should be loaded first, using a quadrant loading pattern, and that the first to be loaded should be broken outer elements at least 14" in length. These were loaded using the end effector fuel grapple (Figure 14a). It was additionally determined that the end effector could not be used on short pieces due to the lead-in length of the inner element picking device. It was also determined that elements shorter than 14" could not be easily loaded into the fuel basket sockets due to physical interference with the basket center post and processing table. During loading tests the manipulator would hit either of these items when attempting to load a starter piece shorter than 14" in length.

After loading of all the 14" or longer, starter (outer) elements in a quadrant pattern, a single full-length inner element was loaded into one of the previously loaded 14" outers. The full-length inner could be loaded using either the end effector fuel grapple or the manipulator jaws. The full-length inner elements were dropped in place manually to expedite broken fuel loading test operations. This effectively simulated the use of the manipulator jaws to load the full-length inners. During testing, all jaw operations were separated from end effector operations, because of the actuation system used in the test mockup (The vendor-supplied fuel grapple will attach to the side of the jaw and will leave the jaw free to operate while the end effector is attached and functional, making loading of broken fuel pieces much easier).

After loading of the first full-length inner into one of the previously loaded broken outers, shorter broken outer pieces were picked up by the jaws and set on the inner to be dropped into place. This operation continued until the full height of a normal fuel element was achieved. To avoid loading beyond the normal height, the operator measured each starter element and noted the length of the piece on a loading map. He then measured each subsequent piece of broken fuel to ensure that he did not exceed the 26" length of a full-length element. On the test mockup, black dimension lines and values were painted onto the loading area of the table and were used to measure the fuel pieces. The process continued by loading a second full-length inner into a second long broken outer and proceeding as before.

It was determined that loading one full-length inner at a time minimized physical interference with previously loaded fuel elements. Attempts to load one complete element (broken outers and full-length inner) before starting to load a second one were unsuccessful, because interference between the manipulator and the previously loaded element(s) made it impossible to reliably load the starter piece of a broken outer element (14" or longer piece). Loading the remainder of the broken outer elements continued as described, in a quadrant-loading pattern, until all had been loaded into the basket. Full-length outers were then loaded, using the end effector, to determine if the broken element stacks interfered with loading of the full-length fuel pieces. No major interferences were noted. However, broken fuel pieces do not stack perfectly and extended edges do provide minor interferences with the loading of adjacent sockets.

Figure 14. Clockwise from left: a) Picking Up a 14" Starter Element; b) Loading a Broken Piece of Inner Element; c) Basket Quadrant Loaded With Broken and Intact Fuel Elements

Loading broken inner element pieces was also performed (Figure 14b) and was found to be much simpler than loading broken outers. The broken inner element loading tests were tied to the broken outer loading operations. After all the broken outers were successfully loaded, the remaining basket slots were loaded with full-length outers (Figure 14c) using the end effector. At that point the end effector was removed and broken inner element pieces were loaded using the manipulator jaws. As before, each piece of broken fuel was measured and the additive lengths of broken pieces were noted on a loading map. Use of the map prevented mix-ups and gave the operator a suitable method to account for each piece of broken fuel.

Dropped Fuel Recovery

During the basket loading tests it was noted that having dropped fuel pieces land in the fuel basket would be common during loading operations. Every operator who ran the manipulator dropped pieces of fuel from the manipulator during normal operations. Recovery of the dropped pieces was evaluated using both the manipulator and long-reach tools.

Dropped fuel recovery tests were primarily performed using manually deployed long-reach tools and a Mark 1A MCO basket. A new tool was developed for manual fuel recovery and an approved fabrication drawing will be issued at a later date. The tool is made up of an aluminum jaw (Figure 15a) on the working end and a Visegrip®™ like handle (Figure 15b) on the operator end, and uses a cam system to actuate and lock the jaw at the bottom of the tool. The handle end of the tool also has an adjustable tensioning system built into it. The main body and handle are made of aluminum, making the total weight only 12 lbs. for a 23-foot long tool. The jaw set on the recovery tool is small enough to allow recovery of a 3" long section of inner fuel element from a fuel basket socket.

Figure 15. Jaws and Handle on Aluminum Fuel Retrieval Tongs

The dropped fuel recovery tests were designed to demonstrate the worst case scenario of dropped fuel pieces and provide a viable and dependable method for recovering them. To determine the worst case condition, various lengths of dummy fuel element were dropped into a Mark 1A fuel basket, their relative positions noted, and the ability to retrieve them evaluated. Based on these preliminary operations, the longest and shortest pieces of fuel that could be dropped to the bottom of the Mark 1A fuel basket could be recovered with the new fuel recovery tool. To demonstrate this operation, several pieces of dummy fuel element were again dropped into a Mark 1A fuel basket which was now sitting on the bottom of the 305 Bldg. pool and which was partially loaded with full-length element pairs. For ease of viewing, the simulated "dropped" fuel was painted white. Recovery of the dropped fuel was performed using the new fuel tongs and with the operator standing on the pool grating platform. Due to the grating layout, the operator had to reach approximately 3 feet out from the grating edge to reach the fuel pieces. Even with this extended reach, the tool was easy to handle and the fuel segments were quickly recovered. One of the shorter pieces of inner element fell into a basket socket, but was still recovered. This test was videotaped.

Also investigated was the case where a piece of fuel would be dropped between full-length elements that had already been loaded into the MCO basket. Two concerns were addressed here: Could the dropped fuel piece wedge between the other fuel elements and be unrecoverable without unloading fuel? and How far beyond the outside diameter of the basket could full-length fuel elements be tipped or forced by the dropped piece of fuel? To evaluate these concerns, several short lengths of fuel were forced between full-length elements in the outside and second rows. The fuel pieces were pounded down in between the elements and, after wedging them in securely, an outside diameter was taken. The maximum outside diameter was found to be 23-1/2 inches, or 1/2 inch beyond the outer edge of the basket. In addition, it was found that by banging the full-length elements with the manipulator or a long-reach tool, the lodged pieces of fuel could be loosened and in most cases recovered by the new recovery tool. The worst case scenario is that two or three fuel elements would have to be unloaded in order to reach the dropped piece of fuel. Removing full-length fuel elements with the manipulator is comparable to the loading task, and unloading broken or short pieces is easily accomplished with the new fuel recovery tool. In addition, it was determined that a full-length (26") element could not be dropped to lay flat in the bottom of a Mark 1A fuel basket and that in most cases the leaning piece of fuel could be righted using the manipulator jaws or end effector. The new fuel tongs could recover the element in all other cases.

To verify that the new tool would pick up actual fuel, a full weight dummy outer element was laid on the bottom of the pool and picked up and moved several times with the new tool. The jaws were then examined for deformation or damage and none was found.

PCM Interface Test

The wash basket engagement tool was used to remove the basket from the PCM mockup and place it on a tipper stand mockup while the new fuel recovery tongs were used to remove the strainer basket from the bottom of the PCM mockup. To simulate filtered fines and debris, the strainer basket was filled with approximately 30 lbs. of nuts, bolts and miscellaneous debris material. Processing times for these operations were recorded and the tests were videotaped. It was found that to remove the wash basket and the strainer took less than 10 minutes and to reinstall them and load a full fuel canister into the wash basket took approximately 20 minutes.

Also evaluated was the operation of placing the tipper jig onto the top of the basket to determine what difficulties could be expected during normal PCM unloading operations. No apparent problems were identified during test operations. The actual tipper device was not tested at this time.

Conclusions

Test Results

Test results clearly indicate that the Conan manipulator is capable of effectively performing the fuel handling tasks required to retrieve and repack the spent nuclear fuel stored in the K-Basins. In addition, the use of remote cameras, although adding a degree of difficulty to the operations, does not prevent efficient operation of the Conan manipulator. It must also be recognized that the Conan manipulator tested in ETL during the summer of 1997 is less maneuverable and has a more cumbersome control system than the customized version (Konan) that will be provided by the vendor for basin deployment. The extra mobility and improved control system will undoubtedly improve fuel-processing times and reduce the amount of wasted motion during operation of the manipulator. The only exception to this is the built-in bridge control on the Konan control panel. During testing, the bridge was activated by a pair of switches actuated by the operator's feet. This configuration allowed the operator to keep both hands on the control joystick while still allowing full control of bridge movement. It was found that a two-handed hold on the joystick was the most efficient method of manipulator operation and actuating the bridge control with the feet eliminated the need to stop manipulator motion during bridge travel. Placing the control back onto the control panel for hand actuation will require the operator to let go of the joystick, thus halting manipulator motion, and reach over to the bridge control toggle to move the bridge. This action will be tested with the Konan system during Cold Validation Testing in early FY98 and a follow on recommendation will be made based on the test results.

During testing it also became apparent that the operator had to be able to form a mental model, or three-dimensional picture of the process table in his mind, to remain correctly oriented. Being able to envision the manipulator in relative position to the table provides the operator the added insight into where the manipulator is moving and what position it must be in to perform the desired operation. The level of concentration required to do this results in mental fatigue and reduces efficiency in approximately a two-hour time frame. This is the reason that the two-hour operator limit is recommended.

Also, based on testing operations, it is highly recommended that the V-block extended manipulator jaws be installed on the Konan manipulators for Cold Validation Testing and for in-basin operations. Testing results showed that this improved jaw configuration provides significant improvement in fuel handling capabilities and does not add maintenance or operational problems to the system.

Testing of the end effector fuel grapple for basket loading showed that the tool length is a critical element of design. The unit tested extended 18 inches below the manipulator jaw to the tip. The test operators requested that the end effector length be increased by as much as six inches. However, it was determined that the attachment and configuration of the Schilling-provided end effector differed sufficiently from the unit used in our tests that no changes should be made until after the new unit has been tested. The unit to be delivered with the Konan system will mount on the side of the jaw attachment and will extend approximately 2" longer to the tip. Combined with an angled wrist on the Konan, the effective length of reach will be extended beyond what was available during this series of tests.

Other recommendations concerning the process table and MCO fuel basket are:

- The top of the basket must be extended 3" above the tabletop to accommodate fuel loading, especially of broken or shorter fuel elements. This configuration has been reviewed for criticality and safety basis issues and was approved in both cases. This information was passed on to the design agent.
- The basket should be set on a turntable base to allow the basket to be rotated or spun around to accommodate fuel-loading operations. The current table design has sufficient clearance for the turntable to be set under the basket and still meet the 3" extension requirement. In addition, the turntable base should be capable of having light shine up through it to accommodate basket loading. This information was passed on to the design agent.
- A method of back lighting the fuel basket sockets must be added to the turntable design to improve visibility while loading fuel. Limitations in visibility during testing adversely affected loading operations. Adding a back lighting system solved the problem. This information was passed on to the design agent.
- Adding a bridge-mounted camera to the manipulator added significant viewing capability. This information was passed on to the design agent.
- Addition of a radiused edge on process table walls/edges allows easy access to fuel pieces that roll up against a table wall. Without the radius, it is extremely difficult to pick up an object that lies tightly against the wall, and usually the object must be pushed away from the wall before the manipulator can get a hold on it. This information was passed on to the design agent.
- During timeline development it became apparent that using both manipulators for normal production operations adds a significant process time advantage. Earlier process logic suggested using a single manipulator for production runs, but test results show that using the second manipulator will reduce overall production time requirements.
- Replacing the wash basket and strainer basket in the PCM after each load of fuel reduces the down time for the north end manipulator and helps reduce the quantity of sludge or other small particles to be dealt with on the process table. Revised logic suggests replacing the strainer basket with each load of fuel and tossing the removed strainer basket into the new washing load for cleaning. It is assured that any particles greater than 1/4" would remain in the wash basket and that smaller particles would be more likely to be discharged to the water treatment system through a clean strainer basket.

Training

During the course of this test program it was determined that it should take the average operator approximately 20 to 30 hands-on hours to become reasonably proficient, or at least proficient enough to perform all required fuel handling functions using the manipulator. In addition, it was found that although the operators who performed our tests became basically proficient in the 20 to 30 hour time frames, they continued to improve their operation in terms of fluidity of motion and smoothness of operation. Early in the training process, manipulator movements tended to be jerky and rough; after extended hours of operation (for each operator), manipulator movements became much more fluid and a great deal smoother.

The first operator to use the manipulator was practically self taught, while the following two operators learned from operator number one. The second two operators were able to capitalize on operator number

one's experience and took much less time to become proficient with the system. Based on these observations, it is recommended that hands-on training be conducted by an operator who has had extensive experience using the manipulator in repeated process simulations. This would pass on the experience of the trainer, while maintaining a standard level of input for new trainees. It is felt that the consistency of operational technique is critical in initiating fuel retrieval and repackaging operations, and that only after significant operations experience has been acquired should the operators attempt to develop alternative techniques.

References

Ketner G.L., "*Interim Report Spent Nuclear Fuel Retrieval System Fuel Handling Development Testing*", PNNL-11423, June 1997.

Schilling Robotic Systems, "*Conan Position-Controlled Manipulator System Model No. 199-0181-1 Technical Manual*", Manual Part No. 011-9135.

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Short S. M., S. Brews, and G. Kugler, "*Spent Nuclear Fuel Project Integrated Testing Strategy*," WHC-SD-SNF-CM-004, Rev. 0, March 22, 1996.

Ketner G. L., "*Test Plan and Strategy for the Fuel Retrieval Sub-Project Developmental, Acceptance and Validation Testing*," WHC-SD-SNF-TP-027, Rev. 1, March 28, 1997.

Appendix A

Process Table Operations Timelines

Two Manipulator Production Run of One C

Revised
8/28/97

Time in Minu

Manipulator #1

Disable Manipulator #1 to load tipper & tip fu

Disable Manipulator #1 to rotate scrap basket

Disable to dump strainer

Disable Manipulator #1 to change debris bin
Disable Manipulator #1 to vacuum

Sort material on North end of table
- Debris scrap loading

Manipulator #2

Disable to rotate scrap basket

Sort and load elements into MCO on South table

Method (dumped canister)

nister *

One Manipulator Process Run of One Can

Time in Minutes

Revised
9/17/67

Manipulator #2

Disabled

Production Method (dumped canister)

Canister *

* Note: Times are for K-East
Times for K-West will be
4-1/4 minutes shorter

One Manipulator Production Run of On

Time in

Manipulator #2

Manipulator #1

Disabled

Method (direct canister unloading)

Canister *

Manipulator #2

1	Disabled to rotate scrap basket
28	Sort and load elements into MCO on South table

Manipulator #1

10	Disable Manipulator #1 to move canister to well	5
3	Disable Manipulator #1 to rotate scrap basket	10
5-1/2	Disable Manipulator #1 to dump strainer	15
1.25	Disable Manipulator #1 to change debris bin	20
1.5	Disable Manipulator #1 to vacuum	25
		30
		35
		40
		45
52	Sort material on North end of table	50
	- Debris scrap loading	53
	- Pickup and move to inspection	
	- Fuel element disassembly	
	- Move assemblies to stuck fuel station	

Validation - Run 0
Time in M

Late Validation Timeline; Aug. 1997

One Canister *

es

* Note: Times are for K-East, times for K-West will be 4.25 minutes shorter

Disable to remove scrap basket

Disassemble stuck fuel

Inspection

6

1.5

28

106.75 Total Minutes

Disable Manipulator #2 to move fuel basket

Disable Manipulator #2 to move scrap basket

9

6

96 Total Minutes

Production Run of one Ca

← Time in Minu

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70

Manipulator #1

Disable Manipulator #1 to move canister to well

Disable Manipulator #1 to rotate scrap basket

Disable Manipulator #1 to dump strainer

Disable Manipulator #1 to change debris bin (4%)

Disable Manipulator #1 to vac (10%)

Dump canister on table

Move 10 scrap pieces to basket

Move 1 pieces debris to bin

Move 20 long length pieces from well to basket

5 min

3

5-1/2

1-1/2
1-1/4

8

15

1-1/2

50

Manipulator #2

Disabled

ister

(dumped canister)

Early Timeline; Spring 1997

S

80 85 90 95 100 105 110 115 120 125 130 135

Flared end ID?

Move 3 scrap pieces to scrap basket (flared ends)

Move 10 fuel portions to gauge

Load 10 fuel portions from gauge to gasket

Disable Manipulator #2 to move scrap basket (3%) of time

Total
132-3/4

Validation - Run of

Time in Min

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

Manipulator #1

Manipulator #2

the Canister *

Early Timeline; Spring 1997

es →

* Times shown are for K-East.
Times for K-West will be
4-1/4 minutes shorter.

Appendix B

Development Testing Data Sheets

Author: David R (Dave) Jackson at PNL33C
Date: 5/7/97 11:57 AM
Subject: TI Draft for Fuel Sorting

----- Message Contents -----

FRS Test Program
305 Bldg. Test Instruction

Fuel Sorting Tests

Objective:

To demonstrate system functionality for sorting debris, broken fuel, and short element pieces, using the Conan manipulator and various manipulator deployed tools.

Procedure:

1. Manually load upper end of table (ramp section) with quantity of debris, mock-element pieces, full mock-elements, and scrap mock-elements. Use the "average canister" makeup containing the following:

- 1 screwdriver
- 1 rubber glove
- 1 buggy spring
- 7 3" pieces of inner and outer fuel
- 2 short fuel (inner or outer)
- 2 stuck inners and outers (welded)
- 10 inners
- 10 outers

Following steps are all manipulator operations.

- 2. Retrieve full elements, separate the inners from the outers in the disassembly area, move each to the inspection area, and transfer all down to the MCO loading ramp. The two stuck inners and outers are to be transferred directly from front end of the table to the MCO loading ramp.
- 3. Retrieve short mock-element pieces, separate the inners from the outers in the disassembly area, move each to the inspection area, and transfer down to the MCO loading ramp.
- 4. Separate remaining scrap pieces from debris.
- 5. Place, or sweep, scrap into scrap basket. Demonstrate both actions.
- 6. Place, or sweep, debris into debris basket. Demonstrate both actions.
- 7. Remove several pieces of scrap from the scrap basket and transfer them to another quadrant of the basket. Demonstrate this process with the basket full to the top and with material loaded to 8" down from the top.

Data Points to record:

Date	Technician/Operator Name
Cog. Eng. Name	
Start/Finish time	Video Counter Start/Finish Position
Tools Used	

Tool Retrieval time

Camera Views Required or Preferred

Qty. of Materials

General observations for each step.

**FRS Test Program
305 Bldg. Test Instruction**

Basket Loading Tests

Objectives:

- (a) To determine if there is an optimum, or preferred, element loading sequence.
- (b) To demonstrate the capability to retrieve dropped element pieces from the bottom of the basket using long reach tools.

Procedure:

1. Using the manipulator, load mock-elements into the basket in different sequences and/or patterns and evaluate effects on manipulator access and camera viewing capabilities and limitations. Indicate the loading sequence used on the attached loading sketches. At a minimum use the 4 sequences indicated on page 5. Record the camera views/locations used for loading and observations made on page 2. Mark up the attached basket layouts with the specific loading sequence used.
2. Manually load mock-elements into the basket in each of the patterns indicated on page 5, leaving open spaces ranging from $\frac{1}{2}$ the basket to a single element. Drop various lengths of mock-element pieces into the bottom of the basket. Use lengths of 4, 6, 8, 13, and 18 inch long pieces. Evaluate the ability to access and retrieve the dropped elements using manually deployed tools. Three tool types will be provided, a 90° deployed inside grapple, a 45° deployed inside grapple, and a claw. Evaluate the need for additional tools or propose improvement modifications for current tools. Record descriptions of the tools used, if surrounding elements interfered with retrieval, and general observations made, on page 3.
3. Repeat step 2 in the pool using loading pattern #3 with the basket $\frac{1}{2}$ loaded. Use long reach versions of the tools used in step 2. Use highly visible white colored mock-element sections for in-pool testing. The intent is to demonstrate retrievability of small element pieces in the underwater environment. Record descriptions of the tools used, if surrounding elements interfered with retrieval, and general observations made, on page 4.

Test Title	Basket Loading Step 1	Test Operator	
Date		Cog. Engineer	
Camera Locations (Camera Nos.)			
Observations: (Record observations for each loading sequence tried. Indicate loading sequence by number as indicated on the attached sketch.)			

Test Title	Basket Loading Step 2	Test Operator	
Date		Cog. Engineer	
Tools Used	Long Reach Tools for Dropped Fuel Recovery		
Observations (Record observations for each loading sequence tried. Indicate loading sequence by number as indicated on the attached sketch.)	<p>SEE STEP 3 - NO LONG REACH RECOVERY TESTS CONDUCTED</p>		

Test Title	Basket Loading Step 3	Test Operator	TIM
Date 6/23/97		Cog. Engineer	
Tools Used	Long Reach Tools for Dropped Fuel Recovery		
LONG REACH FUEL RECOVERY CLAMP TOOL			
Observations (Record observations for each loading sequence tried. Indicate loading sequence by number as indicated on the attached sketch.)	<p>ONLY THE LONG REACH CLAMP FUEL RECOVERY TOOL WAS TESTED, THE PROPOSED INSIDE GRAPPLE TOOLS WERE NOT DESIGNED OR REQUIRED FOR THE DROPPED FUEL RECOVERY TASK. THE DUMMY ELEMENTS USED WERE MADE FROM CARBON STEEL PIPE THAT CLOSELY MATCHED TRUE FUEL SIZE BUT NOT WEIGHT. THE DUMMY ELEMENTS WERE PAINTED WHITE TO IDENTIFY THEM FROM OTHER DUMMY ELEMENT SETS, NOT FOR VISIBILITY REASONS. THE WHITE PAINTED ELEMENTS MADE THE TASK SOMEWHAT MORE DIFFICULT BECAUSE THE ELEMENTS USED CLOSELY MATCHES THE COLOR OF THE 305 POOL BOTTOM.</p> <p>A MARK 1A FUEL BASKET WAS PLACED AT THE BOTTOM OF THE POOL, 3 1/2 FEET FROM THE WORK LEVEL GRATING RAIL. THIS WAS DONE TO SIMULATE THE POSITION THE OPERATOR ON THE GRATING WILL BE RELATIVE TO THE BASKET. FOR FUEL DROPPED IN THE LOADOUT BASKET A MOVEABLE BRIDGE IS NOT REQUIRED. SOME TESTING WAS CONDUCTED USING FULL SIZE AND WEIGHT DUMMY ELEMENTS (~50LB). TO LIFT THESE ELEMENTS THE OPERATOR MUST BE DIRECTLY ABOVE THE WORK. IT WILL NOT BE REQUIRED TO PICK UP FULL WEIGHT ELEMENTS FROM THE GRATING, IF ELEMENTS</p>		

ARE LARGE (OVER 12") THE MANIPULATOR WILL BE ABLE TO PERFORM THE RECOVERY TASKS.

OVER

POSITION OR LENGTH OF THE DROPPED ELEMENTS
HAD NO EFFECT ON RECOVERY DIFFICULTY. THE OPERATOR
WAS ABLE TO RECOVER PIECES FROM AREAS AS SMALL AS
TWO OPEN SOCKETS WITHOUT DIFFICULTY. HE WAS ALSO
ABLE TO RECOVER INNERS THAT WERE DROPPED BETWEEN FOUR
OUTERS IN SOCKETS

#1. By Quadrant

#2. Serpentine

#3. In-line Rotation

#4. Outside to Inside

FRS Test Program
305 Bldg. Fuel Handling Test Instruction
Test #3

Mark-up Copy
6/18/97 DJF
Field Copy - ^{Raw}Data
Completed 4/24/97 DJF

Broken Element Loading Test

Objective:

- To demonstrate system functionality for loading broken fuel elements (pieces 3" and longer) into the MCO fuel basket.
 - To determine minimum length of outer element piece to load into basket slots.
 - To determine the minimum clearance required for the manipulator to load broken outer elements.
 - To identify loading issues regarding broken element vertical stability.
- ARE THERE LIMITATIONS ON LOAD SEQUENCE DUE TO ACCESS REQUIRED TO LOAD BROKEN PIECES.

Procedure:

For all manipulator operations during this test sequence, videotape each step using both camera #1 and the camera directly over the basket (camera #2). Record tape start/stop points and clock time start and finish on the data sheets for each step and record operator observations, concentrating on element vertical stability and manipulator access for loading. Written comments are an extremely important element of test data and results.

The purpose of the following steps is to demonstrate broken element loading techniques and to determine generalized loading issues. Use the element picking end effector for Steps 1 - 5.

1. Starting with an empty basket, use the manipulator to load dummy broken outer elements of various lengths as the starter piece. The purpose of this process is to determine the minimum length outer element piece required for manipulator loading into an open basket. Note observed interferences.
2. Using the quadrant loading pattern use the manipulator to load a single quadrant (14 elements) with dummy broken outer fuel elements. Use various sizes of starter elements and videotape the entire process, recording tape start/stop points. The purpose of this step is to evaluate the vertical stability of multiple broken elements loaded side by side and the capability of the system to be used to load broken elements in close groupings. Record starter element length used in each socket of quadrant and operator observations and net results. Use the attached basket map and table to record element lengths.

The purpose of the following steps is to determine if broken elements can be loaded into mostly full baskets. Record the minimum length dummy outer elements able to be loaded in each case.

3. Manually load a single quadrant with full-length outer elements, leaving a single row of empty sockets in the middle (surrounded by full length dummy elements). Load broken outer elements into the open row. Start with the shortest length outer as determined in Step 1. Use increasingly longer starter pieces until successful in setting the bottom piece of the first element into the basket slot. Using that length piece, repeatedly load the single broken element in the same slot a minimum of three times. Record starter element length and operator observations.
4. Expand the open area to two empty rows and repeat step 3. Continue repeating Step 3 until a single quadrant has been left empty. Record results and observations as in Step 3.
5. Manually load a single quadrant with full-length outer elements, leaving a single open socket in the middle (surrounded by full-length dummy elements). Attempt to load the shortest starter broken element used in Steps 3 and 4. Repeat this step with increasingly longer element sections until successful. Record starter element length, operator observations, and general results.

outer
3 8 12
1 17 20
How
LONG
TO CUT
BRICKS

end effector load remaining pieces
with jaws after completing step 5 & 10
→ 2B

starter only

Move these steps
perform after step 10.

The purpose of the following steps is to demonstrate the capability of the manipulator system to successfully load broken inner element pieces into full length outer elements and to determine what loading and verification problems might exist. Remove the element picking end effector from the manipulator for Steps 6 - 8.

6. Manually load a single quadrant with full length outer elements and remove the element picking end effector.
7. Using the manipulator jaws and camera views only, load short sections (3" long or longer) of inner elements into the outers until the quadrant has been fully loaded. Do not use a map to record loaded piece locations and leave inners that extend above the top of the outers. Record operator observations regarding tracking of partially filled outers and the number of times the last piece loaded into the outer was too long.
8. Using the camera views only, verify complete loading of the quadrant with broken inners by marking the map on the data sheet. After completing the remote operations, manually check each element for loaded condition and record any deviations from camera verification.

The purpose of the following steps is to demonstrate a typical basket load-out operation using fuel makeup expected to be the average for two canisters and to baseline a typical basket loading time. Use the element picking end effector for Steps 9 - 10.

9. Manually place the equivalent of two canisters worth of fuel (28 element sets) on the fuel load out area of the table (South end). Include a fuel element makeup of approximately 25% "broken" inners and 25% "broken" outers. The remaining 50% should be full length elements and may be "stuck" fuel dummies. Use solid dummies as required to fill the table out. *To load starter pieces only. Remove end effector to perform remainder of test.*
10. Using the manipulator with end effector, load the basket in a quadrant pattern. Place only full length elements in the outside circle of sockets. Replace the hollow full length elements, after they have been previously loaded with both outer and inner elements, with the solid dummies, placing the hollow dummies back on the table to allow actual loading of all basket slots with the manipulator. Record processing time, loading map, operator observations, observed difficulties in loading, and recommendations for process improvements. Markup loading map to indicate sequence of loading, where broken inners and outers are located and to simulate accountability loading record. Mark the map with a "B" to indicate the broken elements and an "F" to indicate full length elements.

Data Points to record:

Date Technician/Operator Name
Start/Finish time Video Counter Start/Finish Position
General observations for each step.

Cog. Eng. Name
Camera Views

— ARB THREE BETTER
LOADING PATTERNS?
Quad. Df

— SHOULD WE LOAD OR
STUFF FIRST OR L
Df

— SHOULD WE EMP
1 CANS WORTH OR
2 CANS BEFORE
LOAD? Df

Videotape and Time Record

Test Instruction Step	Camera 1		Camera 2		Date	Start Time	Operator
	Tape Start	Tape Stop	Tape Start	Tape Stop			
Step 1	0	9:05	0	9:05	6/18	8:20	Tim
Step 2 A	9:05	27:43	9:05	27:43	"	8:40	Tim
Step 3	27:43	42:49	27:43	42:49	"	9:20	Tim
Step 4	42:49	53:15	42:49	53:15	"	10:10	Tim
Step 5	53:15	56:41	53:15	56:41	"	10:25	Tim
Step 6	Lost Tape Counter position on Tape #2				6/24	7:30	Tim
Step 7					↓	↓	↓
Step 8					↓	↓	↓
Step 9 *	56:42	1:16:25	56:42	1:16:25	6/18	10:35	Tim
Step 10 2B	1:40:36	1:40:36	1:40:36	1:40:36	6/18 6/19	11:39 8:05	Tim
Step 2B 10	29:03	29:03	29:03	29:03	6/19	9:10	Tim
Step 2B Restart	41:26	41:26	41:26	41:26	6/29	7:20	Tim

Test Data/Results

Step 1. Section Length Loaded: 10 1/2" FAULTY 143/4 / 17.

Operator Observations:

10 1/2 FAILED 1 min { unable to load this length element into any slot in empty k due to interferences
 14 3/4 ABLE TO LOAD IN CENTER ROW 3 min
 17 ABLE TO LOAD IN CENTER ROW 3 min
 21 ABLE TO LOAD IN OVER RING

visibility problem is increased w shorter elements & Off
 Mockup manip much harder to see around for element placement due to end effector attachment

* load station/outlets only

Test Data/Results (con't)

See page 7
 Step 2. Reference Quadrant Map Below split step 2 to Step 2A & 2B } Record data from Step 2B only on pg 5

Position No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Starter Section Length													
Other Section Lengths								N/A	DPJ

Step 3. Reference Quadrant Map

Position No.	1	2	3
Starter Section Length	17 DPJ	17 DPJ	21
Other Section Lengths	N/A DPJ *	N/A	N/A

* See observations on pg 8

* minimum length able to be loaded into single row was 21

Test Data/Results (con't)

Step 4. Reference Quadrant Map

Position No.	1	2	3	4	5	6
Starter Section Length	21	17	14	21	0	14
Other Section Lengths	didn't start it could not tell N/A 21		not really loaded, very difficult due to manip interference		E W

Step 5. Reference Quadrant Map

Position No.	1
Starter Section Length	
Other Section Lengths

left short starter elements from step 4
loaded as mapped & replaced one 21"
element (slot #4) with a full length
& loaded the 21" into open slot (slot #5, from step 4)

Test Data/Results (con't)

Step 7. Load Inners

Position No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Inner Extend Beyond Outer?															
Operator Observe	<p><i>Recorded Data on back of pg 9.</i></p> <p><i>Limited test to loading only 4 elements</i></p> <p><i>DAJ</i> <i>6/24/97</i></p>

Step 8. Loading Verification, Reference Map

Test Data/Results (con't)

Step 9. Record Broken Element Mix

3" - 21" in length some with jagged cuts
others with smooth cuts

Broken Element Lengths						
Quantity						
Full Length Element Qty.						

2B

Step 10. Load Full Basket

Record positions on map. Use B for broken elements and F for full elements.

Loaded full length inners in each starter element by hand & removed end effector for remaining steps.

Inners Outers

Numbers indicate starter element sizes

Notes: • inners tend to slop around, which creates difficulty in setting broken outers over element. Operator recommended that he would most likely only load one inner, then start with loading short outers. one slot at a time.
• Short outers that stack up higher than full ht. must be removed & reloaded with ja. This is demonstrated on Tape @ about 1:30:00. Was able to recover by bumping it & placing it to settle. must use length gauge

Step 10 observations (~~cont~~)

Step 10 - Typical load pattern ~~using length gage~~
loading empty basket as if in recovery operation

- manually load all starter elements (14" & longer) in desired pattern
 - manually load 1st full length inner
 - use manip to load broken outers over 1st unit
- Repeat b & c until all broken outers are loaded

- Tape start 29:03 9:10 am 6/19 Tim

Operator would typically use length gage to determine starter element length & proceed to measure follow on pieces to match remaining space to element piece lengths. We used the map (see attached) to map out starter lengths, then measure pieces to find correct sizes.

This operation will be fairly time consuming. A length gage would reduce the time, but the v-block gage design is difficult to work with. Operator would prefer a painted line on flat surface with a stop block on one side (inverted angle) and the zero end.

* Manipulator is automatically releasing jaws again. This problem is persisting during testing. Continuous manip failures (freeze-ups, drifting, control/loss) are affecting test performance. The rate of failures noted during testing would/should prohibit equipment from being installed in basin. This is a major issue. One clarification/saving grace is that all the problems seem to be software or electronic (servo) in nature & repairs would take place in non-rad/contam. area. Jaws drift $\left\{ \begin{array}{l} \text{open} \\ \text{closed} \end{array} \right\}$

Test terminated due to gross to continuing manip failures.

Tape stop 41:28 9:50 am

One type of control/loss is where operator is asking for upward motion, manip pushes downward. This situation occurred twice in 6/19 Am testing (approx. 2 hr period).

Test Data/Results (con't)General Observations / Comments:

6-18-97

Step 2A • Tape ST 9:05 Dropped starter element manually reset after drop - simulator actual reaction of using long reach tool or would have used manipulator jaws. Unable to use jaw w end effector attached to test manip. O.P.F.

- Will record element lengths used in 2B, no length data recorded in 2A

Step 3 • Extremely difficult to see row of slots. Started with 17" piece & operator had very difficult time seeing & finding slot. Set element down & released but missed slot 33:15-33:17 on Tape. Retrieved piece from basket = end effector

- Jaws died (overheated) Stopped tape @ 38:34 for recovery
- Operator recommendation: Never load broken pieces into slots that are surrounded by other elements or that are difficult to see.

Restart @ 38:33

- Successfully loaded 21" in slot #3, only because visibility was manually regained
- 17" element was too short to "set" in slot. operator dropped it into slot #2. Terminated test

Step 4 Manipulator interference causes difficulty with loading 14" element. 17" seemed to load okay. Attempted to load a 2nd 14" & was able to do it, but manipulator kept "bottoming out" on table & baskets. Recommend using min. of 17" element. Last 3 slots were ~~very~~ difficult to load. Loaded 21" elements in 2 of the three & quit. Visibility is main.

Step 5 Very difficult to see where open socket is. Recommend against loading broken or short (less than full length) into single slots

Step 1 Were able to load 14" pieces in outer row in steps 9/10 w empty basket.

Step 2B (6/19) Jaws will drift open until fluid warms up. This is normal according to schilling. Occasionally jaws would open when switch released, dropping fuel. Will fix problem prior to further testing. Definitely do not want full length outers loaded prior to loading broken outers. The jaw will hit top of elements when lowering short pieces. Dropped pieces are going to happen frequently. Operator Recommendation: The best methodology for loading is to load a single socket at one time (starter, inner, pieces, next socket, etc.) This will reduce likely hood of short pieces hanging up during loading (something we experienced often). Recovery: It's not always possible to see hanging pieces.

General Observations (cont from pg 8)

Step 2B (cont) Experiencing continuous problems with manip. Jaws won't respond, wrist freezes up, control losses. System response is sporadic. This is the new software & although the diagnostics allow for resets @ the control panel, failures are more frequent. They are just easier to fix, although they don't stay fixed.

Tape stop @ 29:04

Step 2B Restart 6/24 7:20 AM

Schilling diagnosed jaw problem as sticky squeeze ring switch. made repairs & ran machine to assure operational condition. Testing resumed.

Tim measured each broken piece to assure that it wouldn't stick up too high. The need to be able to measure pieces must be included in test Rpt.

Camera #1 shut down & ran blank tape for shut down time: back online @ 2:12

Load #7 started w 14" piece & loaded multiple short pieces to fill out. measured each piece to assure fuel length doesn't exceed limit.

14", 4", 5", Filled out @ 23" (didn't have any 3" long pieces available)

#8 started w 15, 6, 4

Used inner w simulated spring/spacers intact

#9 started w 14, 6, 5

w springs

* Paul said fluid temp is running @ 118°F (Hotter than normal) We pulled back & spun wrist for 1 minute to cool down. Still running hot after 1 min wrist rotation.

~~#10~~

Load #10 Start w 15, 5, 4 - - (Fluid Temp @ approx 120°F)
(No springs)

Load #11 Start w 15, 6, 5*

8:50

6/24

Gross cutaway

(Fluid @ approx 119°F still)

* Placed a piece that was too long on the stack. Retrieved it, but accidentally pulled the inner out w it & both the inner & the 2nd piece (6" jagged edge) fell to the floor. manually replaced & re-
Test

Load #12 Start w 14, 6, 6" Test complete
(Just one)

Steps 6-8 abbreviated due to small quantity of work runs.

- Camera shows inner very well when the ends near the top of outer element
- Operator must pre-measure elements to avoid over-length loading.

#2 extended approx $3/4$ " above outer

Test concluded 9:55

Objective:

The objective of this test is to prove feasibility of using long reach tools to load and maintain the Primary Cleaning Machine (PCM) and fuel tipping device based on the current operational analysis.

Data Requirements: Record the following information on the attached Data Sheet.

Date Step Performed	Technician/Operator Name	Engineer Name
Start/Finish time	Video Counter Start/Finish Position	Tools Used (description & sketch)
General observations for each step		

1. *NOTE: Process Time and Operator/Engineer observations are the primary data desired from this test. Make necessary tool adjustment/modification after each step to accommodate ease of operation. Continue testing with modified tools and attach sketch of final version used.*

Procedure:

2. Set up the PCM mockup and fuel tipper mockup in the dry pit. Also set up a video camera to tape the operations.

Videotape each of the following steps and record the tape start/stop time on the attached data sheet.

3. Using the overhead crane and long reach tools, install the Strainer Basket, Primary Cleaning Basket (PCB), and full mockup fuel canister into the PCM mockup. Record process time and operator observations on data sheet
4. Using the overhead crane, long reach tools, and fuel tipper mockup unload the full mockup fuel canister from the PCM mockup. Record process time on Data Sheet.
5. Using the overhead crane and long reach tools remove the PCB and Strainer Basket from the PCM mockup and set each unit on the floor. Record process time on Data Sheet.
6. Using the overhead crane and long reach tools reinstall/reload the Strainer Basket, the PCB, and a full mockup fuel canister into the PCM mockup. Record process time on Data Sheet.
7. Repeat Steps #2 - #5 twice to determine average handling times. Record process times on the Data Sheets.
8. Identify alternative, or preferred, methods for accomplishing the above tasks.

Videotape and Time Record

Test Instruction Step	Video Camera		Process Times		Net Process Time	Date	Operator
	Tape Start Sec	Tape Stop Sec	Time Start mm	Time Stop min.			
Run #1	/	/	/	/	/	/	/
Step 2A	0132	0177 1/2	0:00	22:55	22:55	07/01/97	Bob Loper
Step 3A	0132	0177 1/2	0:00	22:55	22:55	07/01/97	Bob Loper
Step 4A	1776	05:45	0:00	10:29	10:29	07/01/97	Bob Loper
Step 5A	05:45		0:00	9:42	9:42	07/01/97	Bob Loper
Run #2	/	/	/	/	/	/	/
Step 2B	/	/	0:00	19:36	19:36	07/01/97	Bob Loper
Step 3B			0:00	18:24	18:24	07/01/97	Bob Loper
Step 4B			0:00	5:37	5:37	07/01/97	Bob Loper
Step 5B			0:00	8:50	8:50	07/01/97	Bob Loper
Run #2	/	/	/	/	/	/	/
Step 2C							
Step 3C						07/01/97	Dennis Larson
Step 4C							
Step 5C							

Ass.

- 1) Ron @ Camera
- 2) Dennis @ Rec. & Rigging

Note:

- * No video on Step 2B.
- 3C Peters tool wks. ok, used $\therefore$ 30 lbs of mat'l in basket = $\frac{1}{4}$ Full.

Record Operator Observations: Record operator and engineer observations relating to ease of operation and possible process/design improvements.

#5A) PCB removal tool: Need to be marked to help locate correct P/U position of PCM. we used white tape:

The in line opposing X legs should be started @ 90° to pivot Center Line:

3c: Refers tool lifts 30 lbs OK; problem if load lifted to high; can't reach release handle.

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