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Development of an Automated Pit Packaging System for Pantex

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Abstract

Sandia National Laboratories is developing a system that uses robots to package pits at Pantex in the AT-400A pit storage and transportation container. This report will give an overview of the AT-400A packaging process, and the parts of the overall AT-400A packaging operation that will be performed robotically. The process employed to move from development in the laboratory at Sandia to production use at Pantex will be described. Finally, important technology components being developed for and incorporated into the robotic system will be described.

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1.0 INTRODUCTION

The Automated Pit Packaging (APP) System is a robotic system being developed by Sandia National Laboratories, Intelligent Systems and Robotics Center, for the Mason & Hanger Silas-Mason, Inc. Pantex Plant. This system will perform many of the AT-400A pit container packaging operations. It will use a robot to automate radioactive part handling operations and other operations where manual involvement would have been necessary in the past. Over the lifetime of the robotic system, it is intended to process 7,000 - 10,000 pits from existing AL-R8 containers into the new AT-400A containers and could be used for AT-400A container and pit surveillance after repackaging is complete. This report summarizes the state of development of the system relative to the second quarter of FY96.

Production use has been key in the design intent on all of the robotic systems developed at Sandia for Pantex. Commercial components have been integrated for industrial reliability, with safety and operational flexibility designed in by Sandia personnel to meet the objectives of the Pantex and nuclear material handling environments. A systems approach was used to develop the workcell; this design philosophy and other aspects of development are intended to produce a system that will reduce manual radioactive and heavy part handling, enhance efficiency by greater throughput of the facility, improve quality through automatically enforcing qualified procedures, and increase flexibility with an ability to handle the variety of weapon systems in the stockpile. Further efforts to make sure Sandia robotics system will perform in the Pantex production environment include following a QC-1 quality plan during development, previewing safety and processing features of our systems with the DNFSB, and getting UL approval for the robot model intended for the APP system.

1.1 AT-400A Program and Operations at Pantex

The AT-400A is a new Type B container being designed for long term storage and transportation of pits from retired nuclear weapons. As part of weapon retirement, pits have been removed from weapons and stored temporarily in AL-R8 containers in Zone 4 magazines at Pantex. The pits in AL- R8 containers will be brought in from Zone 4, processed through the AT-400A packaging facility, and returned to Zone 4 in AT-400As for continued interim storage.

The AT-400A container consists of an overpack, a containment vessel, and an inner fixture. The overpack and containment vessel are being designed and tested by Sandia's Departments 2165 and 2167 in the New Mexico Weapon Development Center. The inner fixture is being designed by Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL), with each laboratory responsible for hardware specific to the pits that they designed.

Pantex is responsible for creating a system to package all the retired pits into AT-400A containers. This work is currently scheduled to begin in December, 1995. Pantex has developed a mechanical/manual line to begin packaging operations from the AL-R8 to the AT-400A. Sandia's Mechanical Process Engineering Department, 2484, is supplying a system for welding the containment vessel. Pantex is also currently developing equipment and processes for purge, backfill, and overpack operations which occur after the containment vessel is welded.

Sandia Department 9672, within the Intelligent Systems and Robotics Center, is responsible for supplying an automated system to Pantex for repackaging operations from the AL-R8 to the AT-400A. The robotic operations are scheduled to begin in 1998 and will enhance the mechanical/manual process operating at that time by increasing throughput and reducing operator radiation exposure.

The APP project is jointly owned Pantex and Sandia, and it is primarily funded by the Process Capability Assurance Program (PCAP). Pantex brings vast experience and expertise in pit handling to the project and is knowledgeable of regulations and requirements that govern those operations. Sandia brings experience and expertise in the automation of processes using existing and developing technologies. LANL and LLNL will contribute by bringing knowledge of their pit designs and pit handling requirements.

2.0 PROCESS OVERVIEW

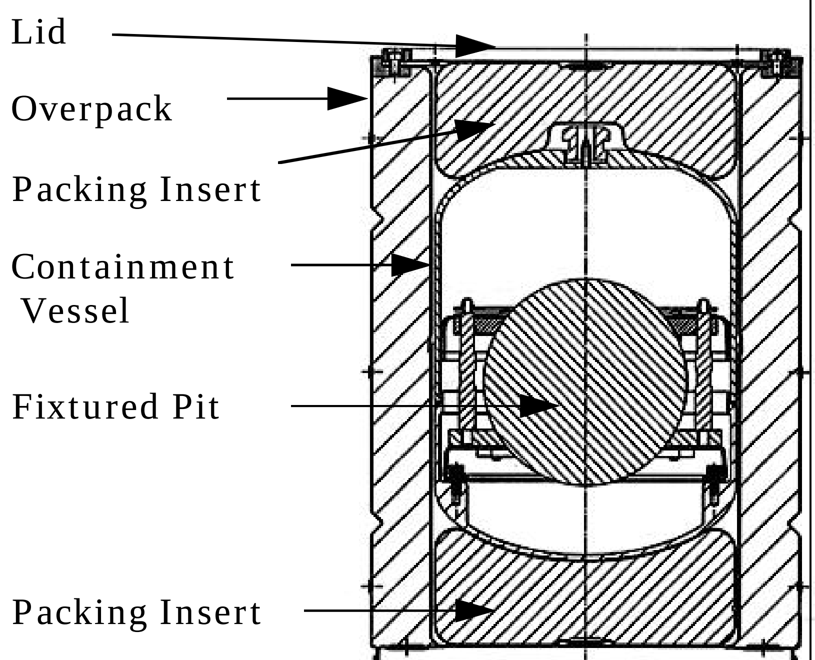

Figure 1: AT - 400A Container

2.1 APP Process Flow

The Automated Pit Packaging (APP) system will automate many of the AT-400A packaging operations at Pantex. Pits will be brought from Zone 4 storage magazines in AL-R8 containers on Stage Right pallets, or be staged after dismantlement in a temporary staging area. The individual AL-R8 containers will be disassembled from the Stage Right pallets before entering a processing line in the Pit Packaging facility. The APP system will perform, with some manual intervention, all pre-weld operations for the AT-400A packaging operations. See Figure 2.

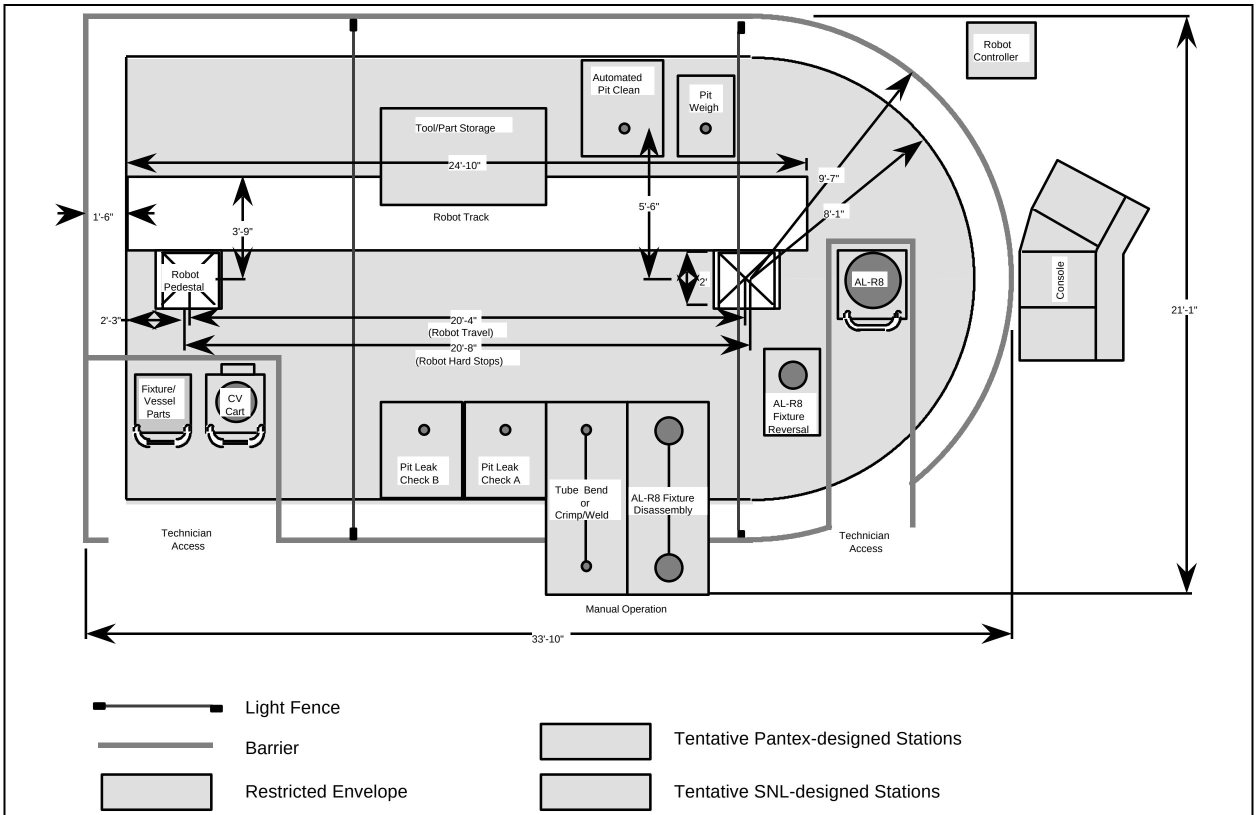

Figure 2: Conceptual APP Line Layout

The system will receive the AL-R8 containers one at a time, unpack the AL-R8 drum, and then disassemble the inner fixture using a combination of manual and robotic operations to produce a bare pit. The system is designed to accommodate both older and newer models of the AL-R8 fixtures.

The bare pit will then be processed through some, or all, of the following operations:

- cleaning
- bending or cutting of the pit tube
- leak checking
- weighing (sometimes more than once)

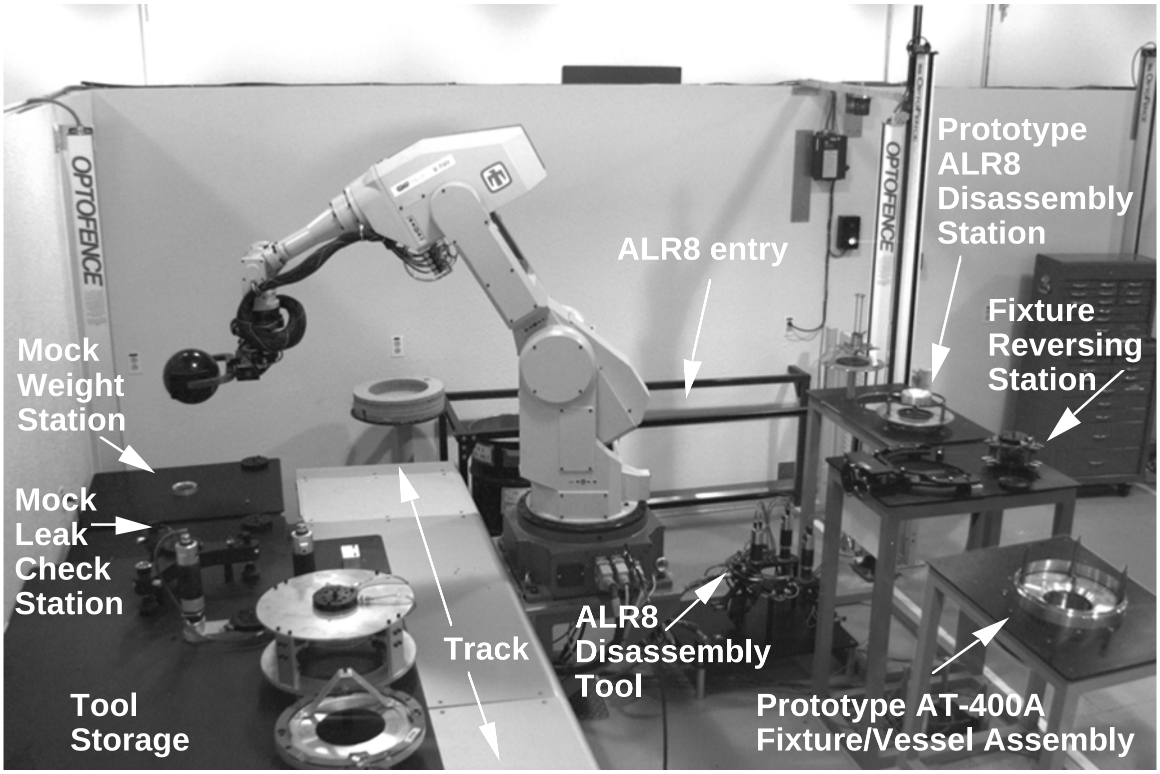

Figure 3: APP Development Laboratory

- assembly of the pit into an AT-400A shipping fixture, including clamping of the pit tube to the fixture when necessary; and
- assembly of the AT-400A containment vessel.

The assembled containment vessel will then be processed manually through the following operations:

- welding of the containment vessel,
- purge, backfill, and leak test of the containment vessel,
- sealing of the containment vessel and its fill tube, and
- assembly of the containment vessel into an overpack.

Different pit types will have different processing requirements, however. An example of a process flow diagram is shown in Appendix B. Much of the process shown in Appendix B is constant for all pit types, however, depending on the tubulation and other characteristics of a specific pit type, tube bending or cutting and the weighing of the pit may or may not be necessary. Processing requirements for specific pit types can be found in a classified document [1].

The packaging operations described above will be performed partly by the robot, partly by separate automated systems, and partly by trained technicians. When the AL-R8 containers enter the facility, a technician will perform several operations to prepare the container to enter the automated line. These will include swipes and removing several parts from the lid.

The AL-R8 container will then be introduced manually into the robotic workspace. See prototype AL-R8 entry in Figure 3. The container will be located using robot vision, and the lid of the container, a cerafelt package, and celotex plug and ring(s) will be removed. The internal fixture will then be located using robot vision and removed to the reversing station as seen in Figure 4. Another gripper must then rotate the fixtured pit 180 degrees to deliver it to the AL-R8 fixture disassembly station with its base down and the tube portion up for access to the fixture bolts.

At the AL-R8 disassembly station, the fixture will be secured to a moving platform on the station and shuttled to the manual side of the station, where clips and/or tape will be manually removed from the tube. Depictions of the shuttle table are shown in Figures 2 and 5. The fixtured pit will then be shuttled back to the robot and disassembled. To prepare for robotic disassembly, the moving platform will be locked into place. The robot will then loosen the fixture bolts and remove and store the clamping ring and extension. The bare pit will be elevated to allow its removal from the fixture base and be taken to the pit cleaning and tube-bend/cut station. Storage will be provided for the fixture base to allow unpacking of additional pits.

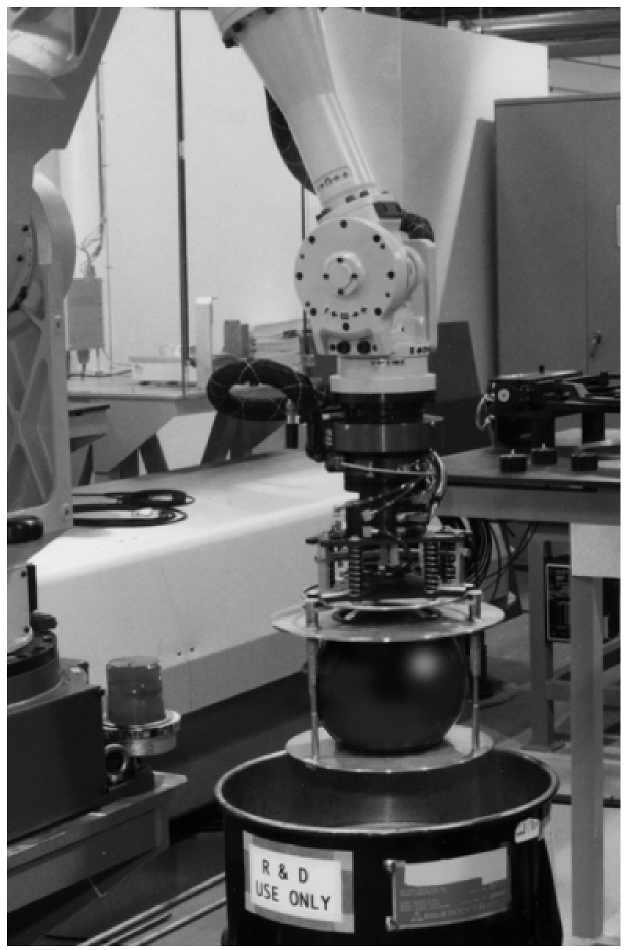

Figure 4: Removing a Fixtured Pit from an AL-R8

The cleaning and tube bending, or cutting, operations will also be performed manually. As at the disassembly station, the robot will deliver a pit to the station, and it will be shuttled to the manual side of the station. The technician will perform any manual cleaning necessary, then he/she will either bend, or cut, the pit tube, depending on the pit type. To further reduce manual operations, an automated pit cleaning station could be developed where the pit could be taken for cleaning before being taken to the tube bend/cut station; this would further reduce the radiation dose to technicians during hands-on operations. Assignment of the development work for this station has not yet taken place. When the technician has finished at the bend/cut station, he/she will signal the system and the pit will be shuttled back to the robot. See Figure 5.

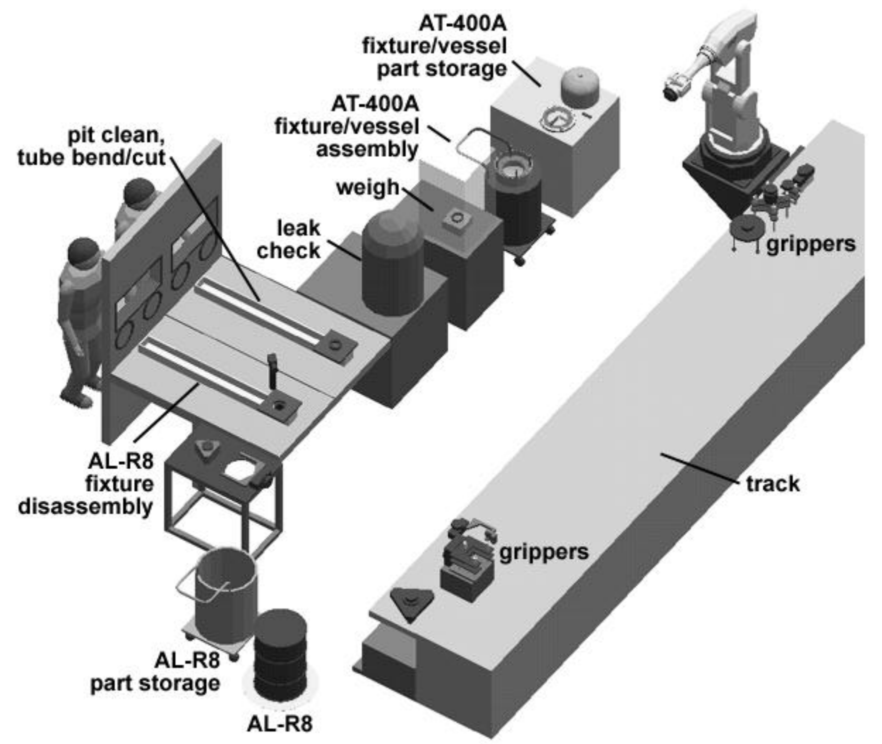

Figure 5: Conceptual Layout of the APP Line

The pit can then be transported using the bare pit gripper to automatic weigh and leak check stations. When these operations have been completed, the robot will transport the pit to the AT-400A Containment Vessel (CV) cart. See Figure 6 where the APP Bare Pit Gripper delivers a mock pit to the base of the AT-400A inner fixture and lower portion of the containment vessel.

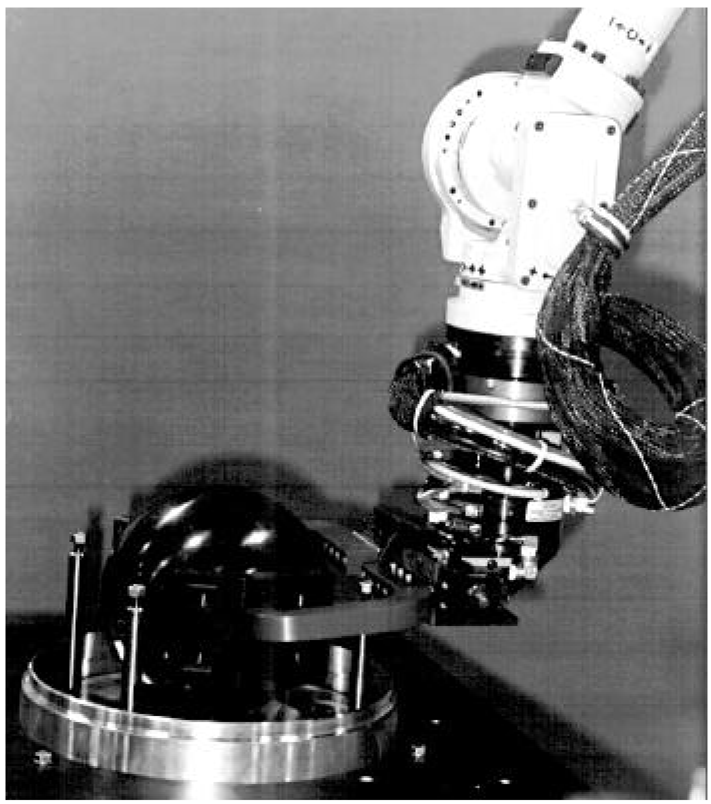

Figure 6: APP Bare Pit Gripper with Mock Pit.

The CV cart will have been placed in the robot workspace earlier by a technician with the lower half of the containment vessel and the lower part of the inner fixture preassembled in it. The rest of the fixture and vessel parts to be assembled will also have been delivered earlier by a technician. The robot will then assemble the rest of the fixture and containment vessel using tooling like that seen in Figure 7.

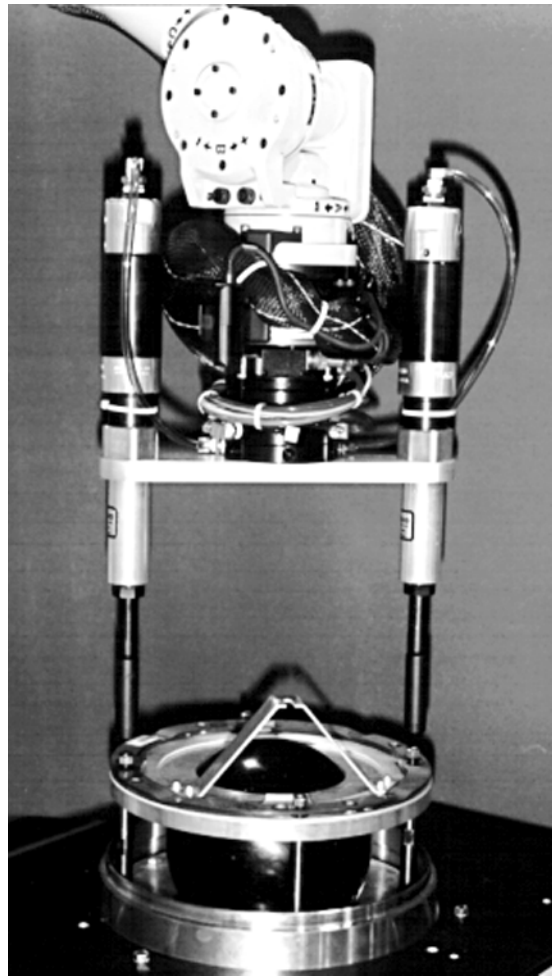
Figure 7: Prototype AT-400A Fixture Assembly

If manual access is necessary for swipes or other operations, the robot will pause at the proper place in the operation and a technician will be instructed to perform those operations. When the containment vessel has been assembled, a technician will return to remove the CV cart from the robot workspace and take the vessel to the welder. All the rest of the AT-400A processing will take place either manually or with automated gas handling equipment (e.g., vessel leak check) outside of the robot workspace.

2.2 Part Delivery and Removal from the Processing Line

As one pit is unpacked and proceeds through the rest of the line, its AL-R8 packaging will be removed from the robot workcell and the next full AL-R8 container will be delivered. Similarly, after each AT-400A fixture and vessel is assembled, the shielded CV cart, which is used to move the CV to various operations, will be removed from the workcell, and the next cart and AT-400A fixture and vessel parts will be introduced into the workcell. Consequently, once the first pit starts in the line, others will follow it in a stream on a first-in, first-out basis (termed pipelining).

All delivery and removal of AL-R8 and AT-400A containers and parts will take place in areas which are dynamically restricted by sets of light beams to be either out of, or part of, the robot workspace. When technicians are in one of these areas, the robot will be limited to a workspace that cannot reach the human workspace without crossing the light beams and stopping the robot's operation. The robot will then be able to continue working on other tasks while the technicians are delivering or removing material from the workcell.

2.3 Operator Interaction

As mentioned above, technicians will be working at various stations along the APP line to perform manual AL-R8 fixture disassembly, cleaning, tube bending, or cutting, and swiping operations. In addition to these workers, an operator will be needed to oversee the entire operation at the control console. Because of the "2-man rule", which requires at least two people to be present and accountable for nuclear material items that are being processed, the console technician and another technician will be required to log in to start up the system.

The user interface at the console will display operational information and will prompt for operator interaction as needed. For example, where a checklist of actions needs to be performed before a certain operation can take place, this checklist will be presented to the operator on the screen at the console and the system will wait until all items on the checklist have been checked by the operator before continuing.

2.4 Process Throughput

The throughput of the system will be affected by the pipelining strategy described above and by the time it takes the pit to make it through all the operations on the line. The line may have pits on it overnight and over the weekend, so operations can continue at the beginning of each shift directly from where they stopped at the end of the previous shift. Within the APP line, it is anticipated that the longest single operation will be the bare pit leak check. The throughput of the system will be limited by the time that pits spend at this station, which is expected to take as long as 30 minutes. With this operation plus start-up, breaks, and lunch, coordinating a stopping point at the end of each shift will present a scheduling issue. The expected throughput is approximately eight pits per shift. Currently, much uncertainty surrounds the throughput of this line and the post-weld AT-400A processes, as well as the logistics of bringing pits to and taking pits from the packaging operations and how much time will be taken up with administrative procedures during the day. A nominal throughput of 1500 pits per year has been assumed for scheduling purposes until these uncertainties can be resolved. This is a conservative estimate which corresponds to processing six pits a day.

Pit handling capabilities will focus on pit types that have the highest radiation output and the highest number. This division of tasks between the manual/mechanical and the robotic lines is intended to result in the robotic operations reducing the largest amount of human radiation exposure possible. The specific pit types to be processed are being determined by a subcommittee on the AT-400A Container Program. Given recommendations from this committee, a Program Control Document (PCD) has been issued by DOE which dictates the

AT-400A repackaging schedule. This PCD directs that all available pits of one type be processed before the next pit type can begin, and that robotic processing will occur during the period of 1998 to 2007 in the order shown in Figure 8.

1) W68	10) W80
2) B61-0	11) W76
3) W55	12) B61-3, 10
4) B61-2, 5	13) B61-7
5) W56	14) W80
6) W79	15) W84
7) W71	16) W87
8) W62	17) W78
9) B61-4	18) W88

Figure 8 Pit Type Scheduling Order

If the weapon systems scheduled for robotic processing were to change in future revisions of the PCD, it is anticipated that the robotic system will be capable of handling all pit types with a few exceptions. Because of tooling incompatibilities, the robotic system will not handle the pits from the B83, W70-3, W70-2 and W48 weapon programs.

3.0 SYSTEM IMPLEMENTATION

3.1 Facility Considerations

As stated above, AT-400A operations will begin an interim phase of production in Building 12-99 at Pantex with a mechanical/manual line. The long-term intent is to have the AT-400A processing consolidated in Building 12-116, the Special Nuclear Material Component Staging Facility (SNMCSF). It should be noted here that the robotic system can be located, if desirable for other considerations, in other facilities at Pantex. The critical determination for the choice of a robotic facility is that the one piece 25 foot track that the robot moves on can be delivered and mounted in the chosen facility. Another important characteristic of the facility is that the descriptions of the operations in the facility's Safety Analysis Report (SAR) is broad enough to encompass planned AT-400A operations, including robotics and welding. Currently, the AT-400A operations are planned to take place in Rooms 146, 147, and 148 in Building 12-116. The 12-116 facility is large enough for the robotic and other AT-400A operations, and will also house other robotic operations, so the facility SAR will meet the above criteria. If necessary or desirable, the mechanical/manual line will move from Building 12-99 to Room 145 of 12-116. If greater throughput is needed, a second robotic line could be installed in Room 145 instead of the manual/mechanical line. An overall layout of the AT-400A operations in Building 12-116 is provided in Appendix C. APP and CV welding operations will take place in Room 146. Post-weld and container preparation operations will take place in Rooms 147 and 148, respectively. If Room 145 is used, the operations will be the same as Room 146.

Facility modifications, including changes to the HVAC, electrical, and other systems, will be necessary to accommodate these pit processing operations in Rooms 145 - 148. These rooms were originally intended as part of the SNMCSF for storage of Oak Ridge items. Changes will be necessary for processing, as opposed to storage, of SNM to take place. Currently, line item funding is being requested for FY97 to support these modifications and much of the post-weld capital equipment for the AT-400A operations. These rooms will be ready for operation after these modifications are completed in July, 1998.

It is planned that cold operations, much of the training, procedure development, and preliminary reviews on the APP system will take place in a training facility in another building while the construction in Building 12-116 is being completed. When construction is completed, the APP line will be moved from the training facility to Room 146, other AT-400A equipment will be moved into rooms 147 and 148, and operations will begin as soon as all remaining approvals can take place. This start-up is currently scheduled for October, 1998. If, as mentioned above, another facility is chosen, production operations would not need to wait for the conclusion of construction in 12-116 and could begin as early as March, 1998.

How training will be accomplished after production starts has not yet been resolved. With just one robotic line, training will take some time away from production capability. It is envisioned that to train technicians, the line will have to be cleared of pits by ramping down the operations until no pits are on the line. Then the line will be restocked with mock pits for training. Completion of training will require a ramp-up of the pit pipeline at the next start of production operations. At least part of the training time will likely be scheduled in the downtime between pit types when this ramp down of operations will occur anyway.

Throughput will also be affected by upgrade, pit type changeovers, maintenance, or other shutdown conditions. Throughput could be improved with a second robotic line. Plans made earlier in the project originally called for two robotic lines and portions of the capital equipment to support 2 lines have already been purchased and delivered to Pantex. If two lines are used, one line could be used for production, while training on actual process equipment for the current pit type could be achieved on the second line. When a pit type changeover approaches, the second line could be outfitted with parts for the new pit type. Then process and equipment training plus approvals for the new pit type could take place without interrupting the first line. When it is time for the changeover, what had been the training line could change to production on the new pit type, and the first line could take over the training capability. This type of alternation could reduce the changeover time to accommodate different pit types which is now estimated to take a month. With a second robotic line, equipment will be available to keep throughput as high as possible, meet appropriate ALARA conditions, and provide sufficient backup capability for shutdown conditions. Alternately, methods of training for all robotic systems at Pantex using computer simulations are being looked into.

3.2 Integration and Installation in the AT-400A Facility

The robotic system will be fully developed and tested at Sandia before being shipped to Pantex. Stations supplied by Pantex in the production facility will be imitated in function by mock stations during the development and testing at Sandia. Sandia will demonstrate robotic and system control capabilities using unclassified dummy components, adapters, fixtures and mock stations. Any classified tooling, fixturing, or adapters associated with specific programs will be developed by Pantex and incorporated during installation at Pantex. The development of the robotic operations listed earlier will be performed by Sandia while the following operations will be developed by Pantex:

- cleaning and/or tube-bend/cutting station,
- the CV cart and lifting mechanism,
- the weight station,
- the leak check station, and
- all post - weld processing equipment.

After delivery of the Sandia system components, which is currently scheduled for May 1997, several operations will need to take place to ensure smooth progression from installation to production use of the system. These robotic operations are intended to be integrated with hardware provided by Pantex in a “prove-in/training” facility. Because of the construction described above, integration and training will not be possible in Room 146 of 12-116.

Following integration with equipment supplied by Pantex, the following procedures will take place:

- system testing,
- operational procedure development,
- operator training,
- Operational Readiness Reviews (OR and ORRs) or Readiness Assessments, and
- conditional Qualification Evaluation Reviews (QERs).

Many different organizations at Pantex will be involved in these various tasks, and the QE teams will have additional participants from LANL and LLNL.

Once all procedure development, training and ORR/RA, and conditional QER approvals have been completed, the system will be moved from the training facility to Room 146 of Building 12-116. Here, final operational approvals, such as the QER, will be granted and production operations will begin.

3.3 Integration with Operations Outside of the AT-400A Facility

Finally, before operations begin, tooling, container parts, and the proper pit input streams must be present as well as the logistical processes to get those parts to the facility at the right time. The AT-400A container program is responsible for procuring sufficient numbers of AT-400A containers and will arrange for appropriate staging areas. Similarly, the LANL and/or LLNL inner fixture designers will develop pit-specific inner fixture hardware designs at a time such that the parts can be ordered and be at Pantex in time for production operations on that pit type. Integration of the AT-400A operations with the Stage Right operations will be necessary to manage the logistics of getting the appropriate pit stream into and out of the AT-400A facility and, if necessary, to any intermediate staging areas.

4.0 SIGNIFICANT TECHNOLOGIES

To those who do not typically work with commercially available robots, the operations described for this system would not appear difficult. However, the capabilities of robots today are very limited. We have added functionality that is not available with commercial robots to our systems because sensitive weapon parts are being handled. Features have been added through extra sensors and computing to enhance and ensure the safety and reliability of these robotic operations. The following sections will highlight examples of the technologies and procedures that have been incorporated into our systems.

4.1 System Safety and Preparation for Production Reviews

Personnel and material safety have been a prime consideration in the design and implementation of the APP system. Overall safety has been accomplished through a combination of system design features and procedures such as mechanical failsafe devices, interlocks, sensor systems, software, training, and administrative controls and procedures.

4.1.1 Safety in Tool and Pit Handling Procedures

To handle parts, the robot will retrieve an appropriate tool for its task. Activation of the tool changer at the end of the robot arm should only be necessary when the robot is picking up or putting down a tool at a tool storage location. A safety system integrated with the tool changer uses an electrical interlock circuit that prevents activation of the tool changer air system unless every tool is in its proper tool storage location in the workcell. This procedure prevents inadvertent or unintended release of a tool when the robot is not at a tool storage location. In addition, as the tool is picked up, the robot reads the tool plate identification code and performs other functions to assure that the correct gripper has been obtained [2].

Safety mechanisms have also been employed at all stations where grippers put down bare or fixtured pits. Mechanical safety interlocks on the gripper couple with mating mechanisms on the station. The safety interlock will be released before the gripper can be opened and will be latched again after closing the gripper. These safety interlocks mate physically only with parts of the stations where bare or fixtured pits are to be handled. At other locations in the workspace, including free space, these interlocks will be engaged, preventing inadvertent or unintended release of a bare or fixtured pit.

4.1.2 Pit Delivery to Stations

Before delivery of a pit to a station, the robot system will verify from system switches that the station is empty (i.e., no pit is at that station) and that the station is ready to receive a pit (if available). If either condition is not satisfied, the system will not continue with that pit delivery.

After the above system checks are completed and before a pit is taken to a station, checklists displaying operations which must take place before pit delivery may be presented to the console operator. After any checklists have been completed, the robot will deliver the pit to the intended station. While the pit is carried from one station to the next, an algorithm continuously checks the position of the robot end effector to make sure that it remains in a predefined "safety corridor" volume of space. This safety check is running any time the robot is moving from station to station and makes sure that the movement of the robot remains in the defined volume, which is away from any stations it is passing. This volume has been defined such that when the robot carrying a pit passes a station with another pit present, the distance between the two pits is greater than a distance which has been determined to be safe and prevents criticality.

A force sensor has been installed near the end of the robot arm. As pits are picked up or set down, force-compliant control algorithms are used to assure that the pit is set down gently and that it is in contact with the pit ring at the station before the gripper is opened [3]. This force sensor is also being checked continuously during station to station moves; the software will stop the robot if a force is detected above the preset limit.

The system software has been written to access database information to control operations where appropriate. This data-driven architecture will allow processing a variety of pits, fixtures, and containers with no software modifications between pit programs. Thus, the barcode of the container and of the pit type as an AL-R8 container enters the system will direct the software to use data appropriate for that container and weapon system.

4.1.3 Robot System Safety and Personnel Protection

The robot system used in APP is a FANUC S-700 produced by FANUC, a vendor who follows the RIA (Robotics Industry Association) standards for personnel safety during robot operation, namely ANSI/RIA R15.06 - 1992 [4]. A Hazard Assessment and Safe Operating Procedure have been completed and are in use for the robot system that functions in the APP operations. The standards set by the RIA Subcommittee R15.06 on Safety are followed in APP for personnel protection. If an RIA standard cannot be followed because of the robot system or APP line design, such non-conformance will be documented along with a description of the devices or procedures employed to mitigate any hazards caused by the non-conformance.

4.1.4 Probabilistic Risk Assessment

Before production use of this system, several safety reviews will be held. One of these reviews involves a Safety Analysis Report (SAR) for activities taking place in the facility where the packaging operations will be located. An analysis called a Failure Modes and Effects Analysis (FMEA) has been performed to prepare for the SAR. To create an FMEA, all possible failures of the robot in its operations in the packaging process are listed, the risk of the situations are analyzed, and a hazard level is assigned to different parts of the operations. This analysis identifies those situations where the safety features built into our system are preventing hazardous operations from occurring, and if there are any situations that our current safety features do not prevent. If such situations are found, additional features may be added to mitigate those situations. Alternately, some situations may be handled better through administrative procedures, rather than adding more technical complexity to the system. The FMEA identifies the likelihood and consequences of various events occurring and assigns hazard levels using a combination of both those measures. The analysis has shown that the hazard levels are low, in that there is a very small chance that the worst consequences will occur. The analysis also showed that the worst consequence that could occur is to rupture a pit within a bay and that any released nuclear material would be contained within the bay until normal cleanup operations could take place. With such an occurrence, no offsite impacts and no onsite health and safety impacts other than manageable personnel exposures during cleanup are expected.

4.1.5 Deliverable System Implementation

Robotic systems developed for production use at Pantex require a high level of rigor in quality and implementation of the system. The APP system is being developed under a QC-1 quality plan, which lays out the requirements for documentation and procedures associated with the development of the hardware and software for the system. A graded approach has been used where the highest level of rigor is applied to key components, such as the tools that handle bare or fixtured pits, and lesser levels can be applied to less critical parts. Software quality procedures being used in APP were derived from software engineering best practices and include documentation of software requirements, design definition, test plans, configuration management procedures and code inspections. Qualification will also include unit testing of hardware and software components, as well as documented system tests before delivery to Pantex.

4.2 System Capabilities

4.2.1 System Start Up and Initialization

Before the system is started or restarted at the beginning of a shift, several operations to check the status of the system will be performed. First, checklists and operator interaction may be required to check that the proper grippers, tooling and container parts are in position. Then a system initialization procedure will be performed prior to operations on pits. This will be a short system test to check the status of system components, if pits already populate the line. If the line is just starting up after maintenance or after a weapon system type changeover, a longer, more thorough system test will be run. Additionally, during the shutdown between pit types or for maintenance, off-normal occurrences such as a failed leak check operation or a broken switch can be run intentionally with a mock pit to assure that all system hardware and software is functioning as expected in these situations. This type of operation will likely be necessary as part of periodic training renewals and during pre-production reviews.

4.2.2 System Logs

The APP system uses a commercial database for logging information about the system. Two types of information are recorded: system information useful in the operation of the system (e.g., operator log-ins, pit part and serial numbers, operations performed), and diagnostic information useful in the maintenance of the system. For example, at the beginning of operations, two operators perform a log in sequence. Both operators and the time they started the system will be recorded in a system log. This record helps satisfy the system requirement that two certified operators must be present when working on radioactive parts. This login sequence and recording of operators is done at the beginning of each shift, and after each break and lunch.

Another example is recording of container parts, which will be done in many places in the AT-400A packaging system. The robotic system's role is to read and record the pit type and serial number from a bar-code as AL-R8 containers are brought into the robot workcell. A utility for viewing the system logs is integrated into the graphical user interface of the system and an operator can view current logging activity in real-time or review historical information from previously recorded log entries.

4.2.3 User Interface Capabilities

System status displays will be available to the operator at the control console. An example of these displays is shown in Figure 9, which is the prototype APP control console user interface. The operation of the APP line will be directed by menu selections made by the console operator at this interface, and by reference to pit database information. When the system starts up, the user interface automatically configures the workcell layout display based on a configuration file for the APP system. With this configuration file, a single software user interface can support APP and other similar robotic systems. Icons of pits and stations are displayed with each pit or station shown where it is located in the actual operations. This allows operators to tell in a glance where the pits are in the operations. The user interface can also provide more detailed displays for the operator with information about the status of each of the APP stations and the pits currently in the line. Information about the current status of the robot, including the primary function being performed, will also be displayed.

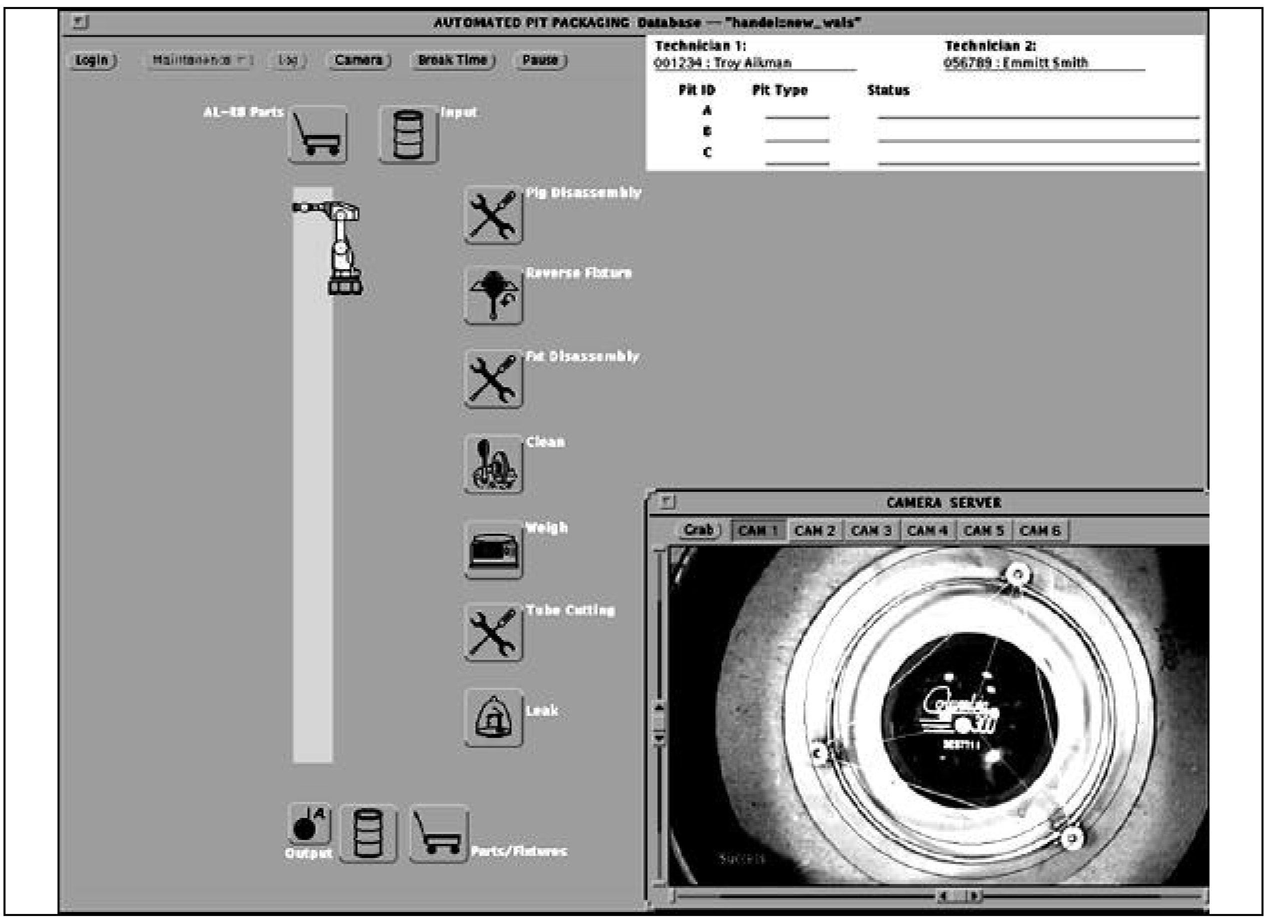

Figure 9: APP User Interface and Vision Operations

The user interface uses a consistent method for error and warning reporting and other operator interactions. Critical or safety-related operations will require operator verification prior to automated execution. The checklists mentioned above may be used in these instances.

4.2.4 Vision Operations

When the AL-R8 and AT-400A containers and parts are delivered to the system, they will be located in a general area which will be known to the robot system. However, to handle the parts and disassemble or assemble the containers, the robot needs to know precisely where the parts are. To ascertain these precise locations, machine vision operations are used. Because a general location is known, a camera mounted on the end of the robot arm can be moved above the item to be located. The camera takes a picture of the item, and image processing operations determine the exact location of the item to an accuracy sufficient that the robot can grasp input parts or deliver the pit. See the lower right hand corner of Figure 9 (labeled "Camera Server", with a bowling ball shown in the fixture) for an example of what the operator sees as vision processing occurs. As well as vision images and processing, indications of success or failure of the vision operations will be displayed in this portion of the user interface.

Whenever the robot-mounted camera requires recalibration (e.g., after end-of-arm tooling rework), an automatic camera calibration program will need to be run. The program automatically positions the robot as necessary, acquires the images needed, and determines and records the relationship between robot space and camera space. After performing this recalibration, machine vision operations can again be run successfully.

4.2.5 Telerobotic Operations

Because of the variety of tubulation configurations on various weapons systems, telerobotic operations will be desirable during the final steps in the disassembly of the AL-R8 fixture. After the robot has loosened the fixture bolts, it lifts the upper part of the fixture up off the pit. The upper part of the fixture then needs to be lifted up and guided off the tube without any collisions. The robot enters a telerobotic mode where its movement is limited to an appropriately small volume, likely no more than 1 inch in any horizontal direction. During these movements, the operator will be actively monitoring and controlling how the upper fixture is guided up off the tube and over any objects which are connected to, or over kinks in, the tube.

5.0 CONCLUSIONS

Much progress has been made in the development of the APP system. The operations and process flows for the robotic line have been determined. An appropriate facility for the APP operations has been identified, as well as funding to prepare that facility for AT-400A operations. Many steps in the process to transition from development at Sandia through delivery and installation at Pantex have been detailed. Interactions with all participants on the AT-400A program have begun and pit handling requirements have been outlined by LANL and LLNL. Because of the production system being developed, quality processes and documentation are being implemented in this project. A safety theme has been developed to assure that handling of sensitive weapon parts can be performed safely. Elements of this safety theme have been incorporated into appropriate features in the hardware and software of the system. Appropriate safety analyses have been performed and have brought out information on the ultra-high reliability of the commercial robots that we use and with incorporation of appropriate safety systems, the low hazard levels that are involved in the robotic operations.

Development in the software and hardware areas have progressed as expected, with many technological features incorporated into our system that are not typically found in commercial robotic systems. Laboratory development has also shown consistent performance with extensive logs recording our development operations. Given the progress to date, the APP robotic system has made significant steps down the path which leads from development to installation, review and approval, and finally, into production use at Pantex.

5.0.1 Epilogue

In March 1996, DOE/AL instructed that the APP project be shut down, and canceled further funding of the project through PCAP. Supplemental funding for FY97 has been supplied by Sandia as part of a Sandia/Pantex partnership. Sources for matching funds from Pantex are being investigated.

In the summer of 1996, remaining activities in the validation process to obtain Line Item funding for the Consolidated Pit Packaging System (CPPS) were addressed. Despite these efforts, various circumstances led to a decision in September 1996 to cancel the CPPS facility changes for AT-400A operations in Building 12-116 at Pantex. Other facility options will be investigated along with the project funding mentioned above.

5.1 Acknowledgments

I would like to thank all the APP team members and David Lenfest for their support in creating the APP system and in preparing this report.

5.2 References

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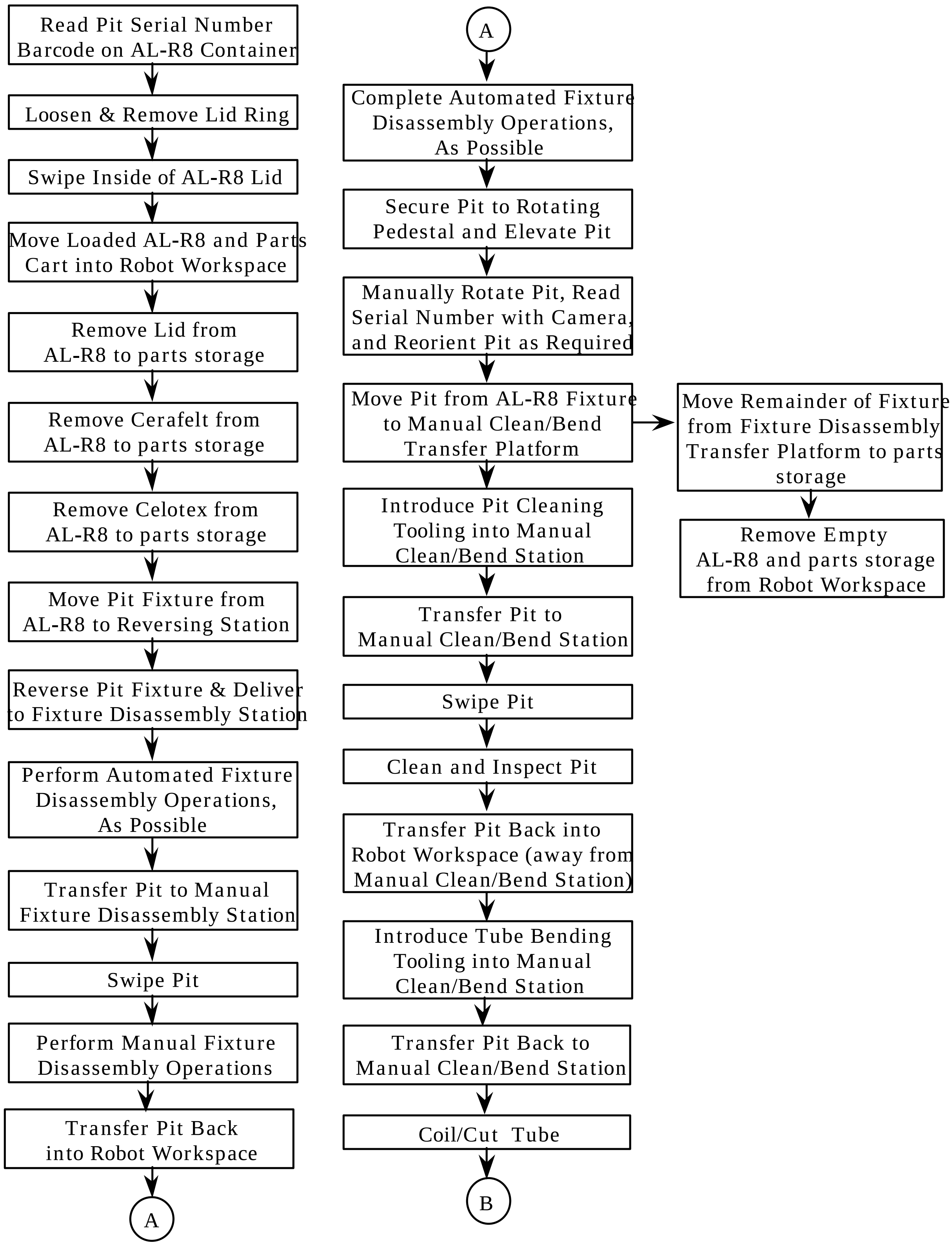
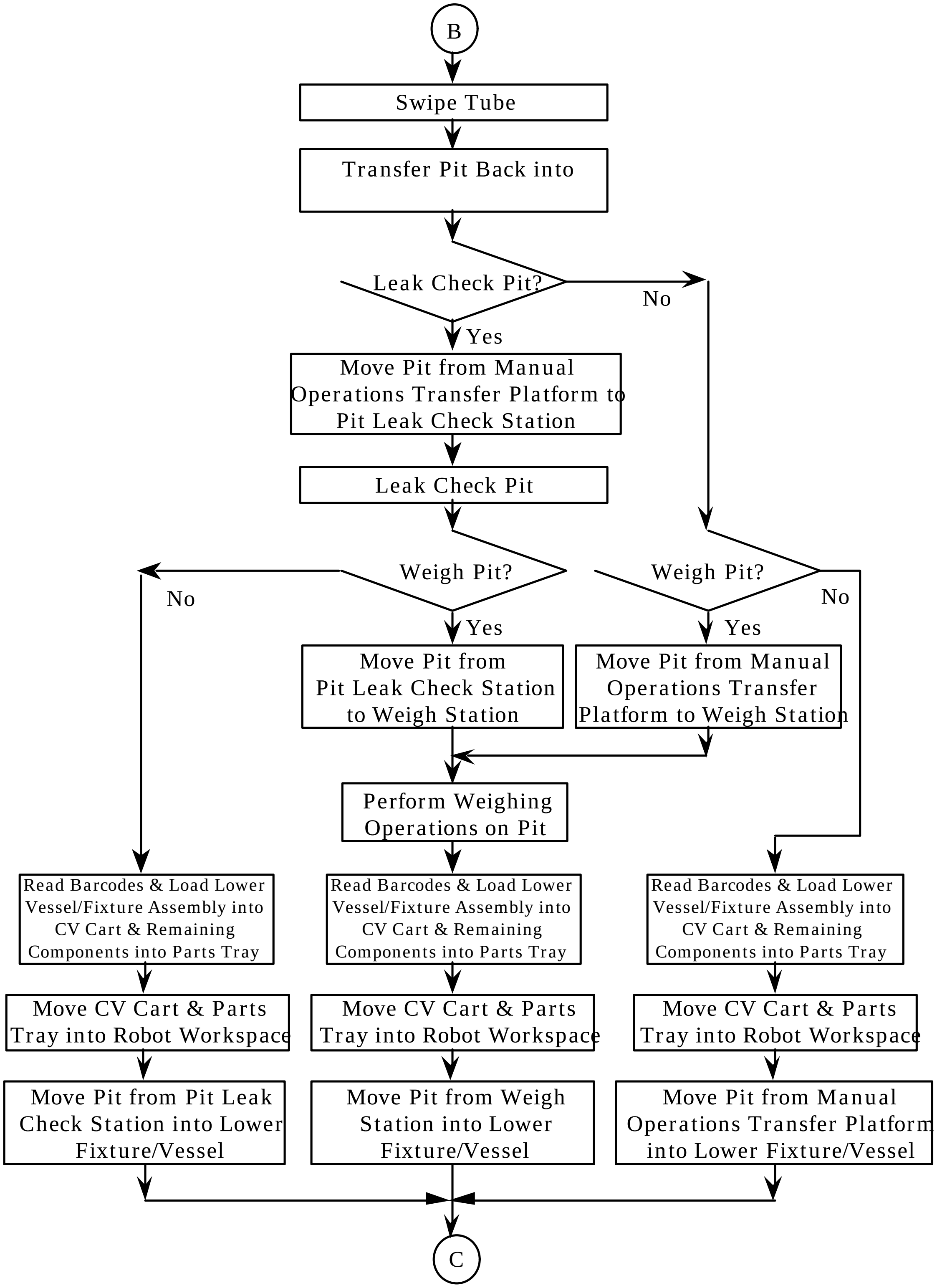
Appendix A: Definitions and Abbreviations

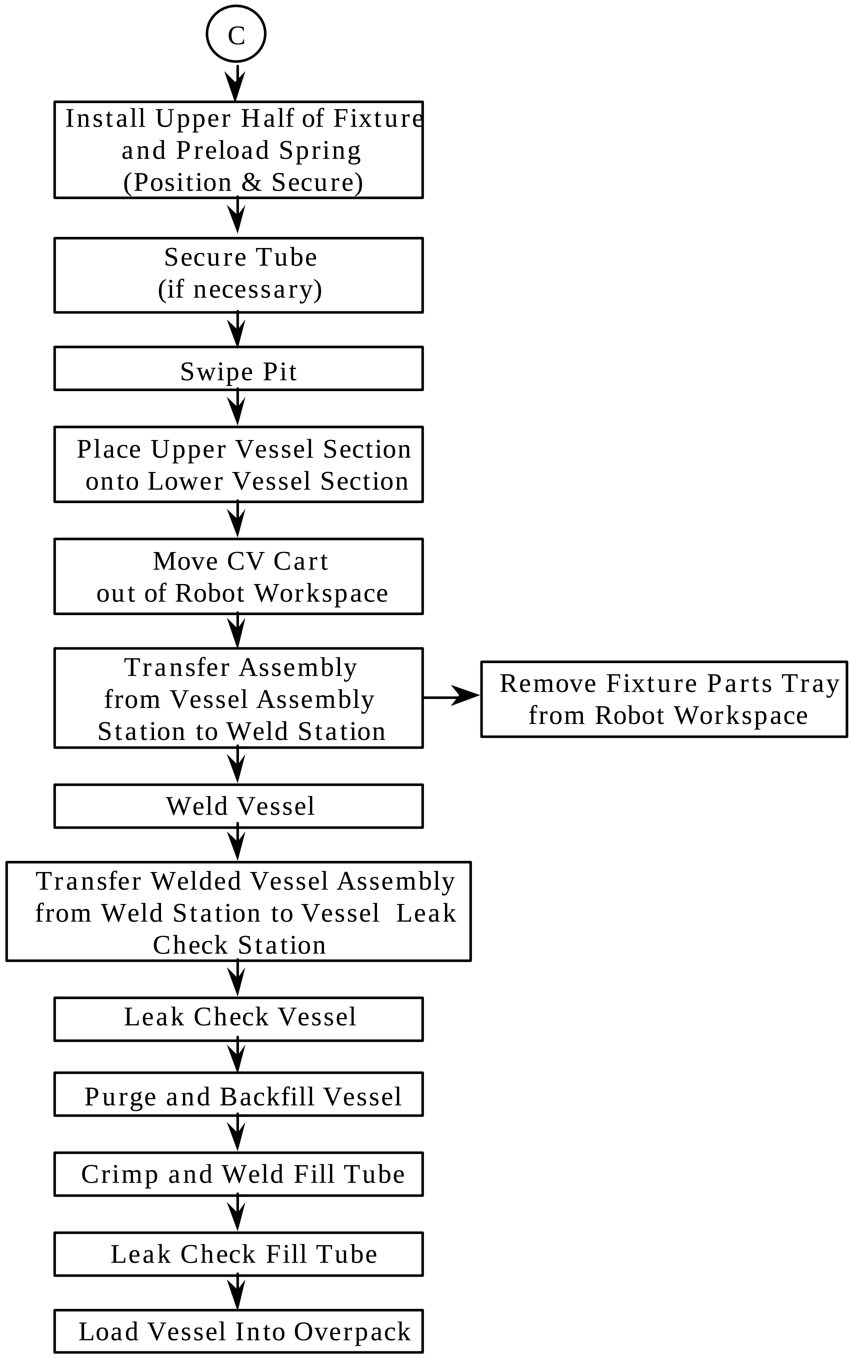
ALARA	As Low As Reasonably Achievable
AL-R8	Container used at Pantex to hold pits after dismantlement, consists of an outer drum (20" in diameter, 30" in height), inner celotex material, a cerafelt packet, and a fixtured pit
APP	Automated Pit Packaging
Console	Station with main computer interface for running the robotic operations. It will be located away from radioactive sources.
Console Operator	Extensively trained Pantex technician that can perform the pit packaging process console operations for the automated process.
Containment Vessel	See Fig. 1. The metal enclosure of the AT-400A container in which the pit and inner fixture are encased, consists of an upper and lower part which will be welded together to form a sealed enclosure in the final configuration (for storage or transportation). It may also be referred to as inner vessel.
GUI	Graphical User Interface.
Inner Fixture	See Fig 1 . The metal framework that supports the pit inside the containment vessel of the AT-400A container, also called the support structure.
Overpack	See Fig 1 . The outer drum-like part of the AT-400A container.
Packing Material	See Fig 1 . The piece of the AT - 400A container which is inserted between the top of the containment vessel and the lid of the overpack, also called a packing insert.
PCAP	Process Capability Assurance Program, funded by the Department of Energy
Pit	A sphere-like object, weighing a maximum of 12 kg, with one or two tubes protruding from the polar region of the sphere.
Pit type	An identifier designating the pit design or program.
RIA	Robotic Industries Association.
SNM	Special Nuclear Material
Stage Right	Stage Right operations use stackable pallets to stage AL-R8 and AT-400A containers in Zone 4 at Pantex. Using these pallets allows 4 or 6 containers to be handled and stored at once by automated forklifts and allows more containers to be stored in Zone 4 than in previous staging configurations.

Appendix B: APP Process (Single Pit - AL - R8 to AT - 400A)

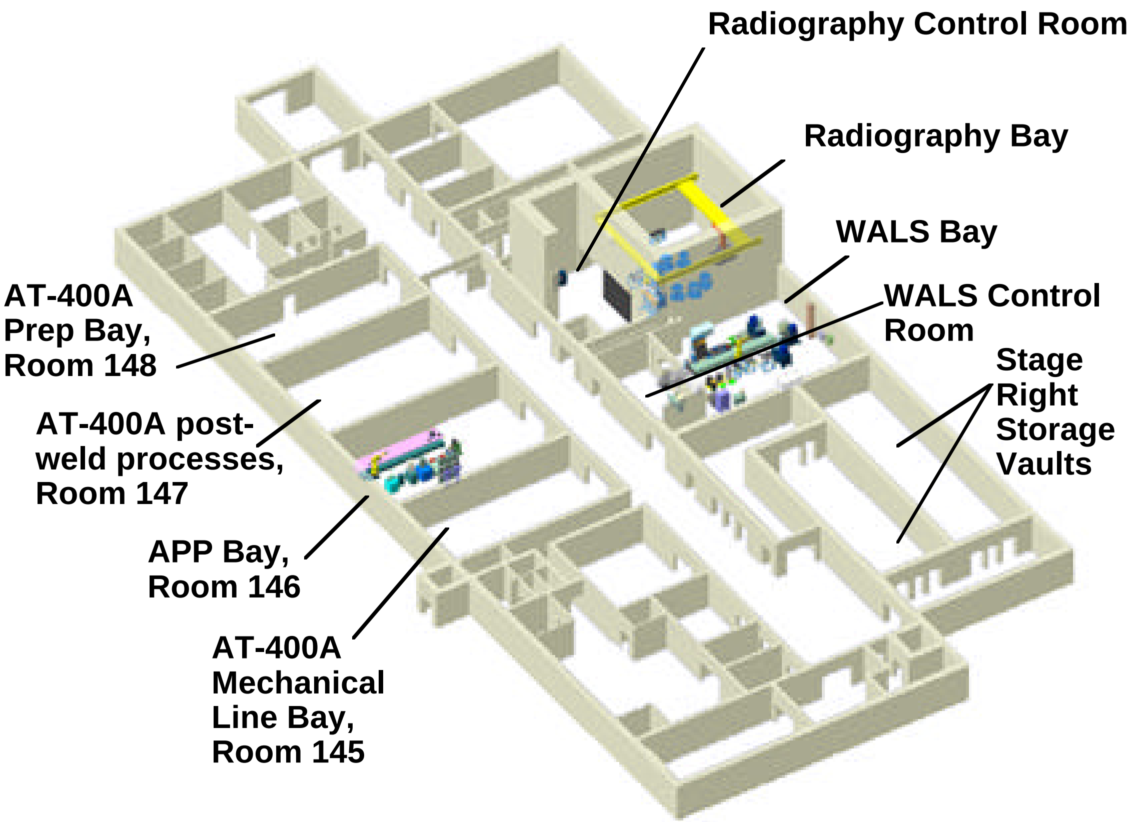




B
Swipe Tube
Transfer Pit Back into
Leak Check Pit?
No
Yes
Move Pit from Manual Operations Transfer Platform to Pit Leak Check Station
Leak Check Pit
Weigh Pit?
No
Yes
Weigh Pit?
Yes
No
Move Pit from Pit Leak Check Station to Weigh Station
Move Pit from Manual Operations Transfer Platform to Weigh Station
Perform Weighing Operations on Pit
Read Barcodes & Load Lower Vessel/Fixture Assembly into CV Cart & Remaining Components into Parts Tray
Read Barcodes & Load Lower Vessel/Fixture Assembly into CV Cart & Remaining Components into Parts Tray
Read Barcodes & Load Lower Vessel/Fixture Assembly into CV Cart & Remaining Components into Parts Tray
Move CV Cart & Parts Tray into Robot Workspace
Move CV Cart & Parts Tray into Robot Workspace
Move CV Cart & Parts Tray into Robot Workspace
Move Pit from Pit Leak Check Station into Lower Fixture/Vessel
Move Pit from Weigh Station into Lower Fixture/Vessel
Move Pit from Manual Operations Transfer Platform into Lower Fixture/Vessel
C


C
Install Upper Half of Fixture and Preload Spring (Position & Secure)
Secure Tube (if necessary)
Swipe Pit
Place Upper Vessel Section onto Lower Vessel Section
Move CV Cart out of Robot Workspace
Transfer Assembly from Vessel Assembly Station to Weld Station
Remove Fixture Parts Tray from Robot Workspace
Weld Vessel
Transfer Welded Vessel Assembly from Weld Station to Vessel Leak Check Station
Leak Check Vessel
Purge and Backfill Vessel
Crimp and Weld Fill Tube
Leak Check Fill Tube
Load Vessel Into Overpack

Appendix C: Building 12 -116 AT - 400A and other Automated Operations



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