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SEGMENTATION STRATEGIES FOR THE IRRADIATED AND TRITIUM CONTAMINATED PPPL TFTR

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INTRODUCTION

The Tokamak Fusion Test Reactor (TFTR) at Princeton Plasma Physics Laboratory is scheduled to complete its final experiments in the Fall of 1995. As a result, the TFTR will be activated and tritium contaminated. After the experiments are complete, the TFTR will undergo Shutdown and Removal (S&R). The space vacated by the TFTR will be used for a new test reactor, the Tokamak Physics Experiment (TPX). Remote methods may be required to remove components and to segment the Vacuum Vessel.

The TFTR has been studied to determine alternatives for the segmentation of the Vacuum Vessel from the inside (In-Vessel). The methodology to determine suitable strategies to segment the Vacuum Vessel from In-Vessel included several areas of concentration. These areas were segmentation locations, cutting/removal technologies, pros and cons, and cutting/removal technology delivery systems. The segmentation locations for easiest implementation and minimal steps in cutting and removal have been identified. Each of these will also achieve the baseline for packaging and shipment. The methods for cutting and removal of components were determined. In addition, the delivery systems were conceptualized.

HISTORY OF TFTR

The TFTR is a tokamak, which is a magnetic confinement, toroidal shaped device for producing controlled nuclear fusion using hydrogen isotopes, i.e., deuterium and tritium, to produce a net energy release. TFTR is the US DOE's major experimental reactor in the Magnetic Fusion Energy Program. TFTR has been constructed and is operating at the James Forrestal Campus of Princeton University and is operated by the Plasma Physics Laboratory (PPPL) of Princeton University for the US DOE.

The TFTR design, construction and plasma operation extends from design initiation in 1974 to current operation in 1995. TFTR Operations were initiated with first plasma in December, 1982. Operations have progressed from hydrogen plasmas to deuterium plasmas up through September, 1993. During this period, "hands on" accessibility was available to the machine even though the Vacuum Vessel and other components had become slightly activated and tritium contaminated.[1] Experimental operations with tritium were initiated in September (Dec), 1993.[2]

The TFTR program objectives are: to demonstrate fusion energy production (approximately 1-10 MW per pulse) from the pulsed burning of deuterium and tritium (D-T) in a magnetically confined torodial plasma system; to study the plasma physics of large tokamaks; and to gain experience in the engineering of large fusion devices.

A D-T neutron production constraint of 1×10^{21} per calendar year has been planned so as not to exceed the TFTR site boundary dose limit of 100 μSv/yr (10 mrem/yr). The actual neutron production will be determined based on measurements during D-T operations. The use of tritium and the 14.1 MeV neutrons produced during this run will significantly increase the machine activation and contamination levels.

S&R PROJECT

Completion of D-T operations is scheduled for September, 1995. A two year Shutdown period will commence at that time. Dismantling of the tokamak systems and packaging and shipping operations will follow shutdown, lasting approximately 15 months. The nature of the D-T operations is such that all the radioactive waste generated as a result will be low level radioactive waste (LLRW). The S&R activities will conclude the final phase of the TFTR Project.

The primary objective of the TFTR S&R Project is to render the facility suitable for the start of construction of the next DOE experimental fusion reactor, TPX, by March, 1998. To reach this objective it will be necessary to remove activated and tritium contaminated machine components. The technical objectives for the S&R Project are similar to the objectives for dismantling of a nuclear power facility. Decommissioning technology from the nuclear fission industry will be utilized wherever possible to safely dismantle activated and contaminated systems. Due to the activation and contamination levels, it may be necessary to use remotely operable equipment to dismantle some components. Disassembled components will be packaged in compliance with DOE, Department of Transportation (DOT), and waste receiver requirements and then transported to a DOE approved waste repository for LLRW disposal. The TFTR S&R Project differs from a typical decommissioning project in that the facility will not be returned to "greenfield" condition nor will it be released for

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unrestricted use. The DOE will retain ownership and will reuse the facility for the next generation fusion reactor.

The major milestones for the TFTR S&R Project are:

•End of Operations/Commence Shutdown	9/1995
•Preliminary Design Review	3/1996
•Final Design Review	3/1997
•Begin Tokamak Disassembly Operations	12/1997
•TPX Occupancy	3/1998

FACILITY DESCRIPTION

General

The physical description of the TFTR facility provides information useful in determining the S&R scope of work. Facilities involved include the test cell, test cell basement, hot cell, and mockup building. The systems and components include: reactor Vacuum Vessel, machine structure, auxiliary heating systems, diagnostics, vacuum pumping system, machine area cooling water systems, and fuel-pellet injectors. The tritium handling and clean-up systems located within the tritium area will also be decontaminated and removed. Characteristics of the TFTR facility that introduce unique problems in S&R or reuse include large complex stainless steel and copper structures and tritium contamination.

Test Cell, Hot Cell, Mockup Building

The TFTR S&R Project includes the facilities and systems within the test cell and experimental support buildings. All conventional facilities will remain operational during the TFTR S&R operations. The test cell (Figure 1) is a reinforced concrete structure with interior dimensions of 45m x 35m x 16.5m. This building houses the TFTR tokamak, auxiliary heating systems, diagnostics devices and support systems. Basement space below the test cell houses diagnostic equipment, high voltage switchgear, vacuum pumping equipment, electrical bus runs, and cooling water piping. The basement areas are constructed of reinforced concrete to provide radiation shielding from the test cell. Minimal activation is expected in this area as a result of tritium operations. In the basement is the tritium area which contains the tritium clean-up and waste handling systems. The hot cell shown in Figure 1 is part of the shielded experimental complex which houses the decontamination facility, neutral beam source clean room and various diagnostic devices. It has interior dimensions of 18m x 35m x 16.5m, and is constructed of reinforced concrete. The mockup building shown in Figure 1 is of Butler-type construction. It will be used primarily as an equipment staging and storage area during S&R operations. This building is also the primary egress for all large packaged components leaving the test cell.

Vacuum Vessel Construction

The TFTR Vacuum Vessel is centrally located in the test cell portion of the experimental area. The Vacuum Vessel exterior walls are closely surrounded by the toroidal field (TF) coils (Figure 2). The TF coils consist of twenty Nitronic 33 encased, epoxy impregnated, copper coils. The Vacuum Vessel is fabricated in the shape of a toroidal shell. The toroidal vessel is constructed of a combination of bellows (Inconel 625) and ring-stiffened shells (304LN) and has ten welded closure construction joints for separation into ten segments. The parting joints are located adjacent to the original construction joints and are 1/2" thick stainless steel. Fourteen bellows assemblies are located within the shadow of the TF coils. Two of these bellows assemblies have stainless steel plates welded over them. Ports are located between the bellows to permit access to the inside. External cover plates are used to transmit loads across the bellows assemblies. Stiffening rings are used to strengthen the Vacuum Vessel where required. The Vacuum Vessel is supported by ten outboard and ten inboard support legs. Outboard supports are located at stiffening ring and bellows locations. Inboard supports are located at the ten sector parting joints. Heating/cooling ducts are attached to the vessel wall for efficient heat transfer. Thermal insulation is attached to the outside of the Vacuum Vessel.

The interior surfaces of the Vacuum Vessel are lined with many different components to protect the walls from thermally induced loads (Figure 3). These include the following:

Component	Material
RF Limiters (RFL)	Graphite/Carbon-fiber Composite
Surface Pumping Panels(SPP)	Inconel
Bellows Cover Plates(BCP)	Inconel
Protective Plates (PP)	Inconel w/Graphite Tiles
Bumper Limiters(BL)	Inconel w/Graphite and Carbon-fiber Tiles
Cooling Tubes	Inconel
Thermocouples	Stainless Steel Braided

SEGMENTATION STRATEGIES

Study Methodology

The methodology to determine suitable approaches to segment the TFTR Vacuum Vessel from In-Vessel included several areas of concentration. These areas are segmentation locations, cutting/removal technologies, pros

& cons, and cutting/removal technology delivery systems.

The first area of concentration for the study was to define and investigate the alternative types of segmentation locations In-Vessel. The PPPL baseline packaging arrangement is to have ten (10) equal-size segments of the Vacuum Vessel. For each type of segmentation location, the items to be cut/removed were determined along with the number of cuts required for each item. These were put in matrix form for comparing alternatives. TFTR Inboard and Outboard locations were included in the matrices for each type of segmentation location.

The second area of concentration for this study was to define the appropriate cutting/removal technology for each item to be cut/removed at a segmentation location. Based on discussions with PPPL personnel and review of a previously performed study,[3] Plasma Arc Cutting (PAC) was determined to be the most suitable technology for Vacuum Vessel cutting. There is insulation and a heating/cooling duct on the outside of the Vacuum Vessel therefore, PAC has to be used from In-Vessel. Due to the graphite tiles (that cannot be cut by PAC) on the Bumper Limiters and Protective Plates, a mechanical means of cutting was determined to be required. Since the graphite tiles are attached to an inconel support plate (3/8"t), the support plate and/or the tiles will most likely have to be mechanically cut, or the Bumper Limiter and Protective Plate Panels will have to be removed as units by fastener removal.

The third area of concentration for the study was to determine the pros and cons for each segmentation location. This determination not only considered the items to be cut/removed at a location but also the cutting/removal technologies to be used.

The fourth area of concentration of the study was to determine delivery systems for the cutting/removal technologies. This included a review of the existing Maintenance Manipulator Arm (MMA).[4] The MMA has been determined not to be best suited for this application due to its complexity, deflection characteristics, and unknown reliability. Alternative approaches of using delivery systems inserted through local ports were also considered. The overhead crane and long handle tools would supplement this alternative.[5] In addition, the combination of the MMA with delivery systems inserted through ports was also considered.

Cut Locations

For In-Vessel segmentation of the Vacuum Vessel, all possible segmentation locations were considered. The segmentation locations or a combination of segmentation locations should be exhaustive to give reasonable assurance that desirable and undesirable locations were properly selected or eliminated, respectively. Consideration was also given to the differences between the Outboard and Inboard sides. Cutting is to be circumferential (poloidal) around the cross-section of the Vacuum Vessel as much as possible.

The following segmentation locations were considered:

Potential Segmentation Locations	Number
Bellows	14
Stiffening Rings	6
Parting Joints	10
Left Side of Bellows-Near Large Port	8
Right Side of Bellows-Near Large Port	7
Left Side of Bellows-Near Small Top Port	7
Centerline of Large Top Port Location	10
Centerline of Small Top Port Location	10

Cutting/Removal Technologies Required

Because of the various types of materials, layers, clearances, and multiple pieces, different cutting/removal technologies will be required. PAC and mechanical cutting were the two technologies identified. In addition, in order to remove panels associated with the Bumper Limiter, Protective Plates, and other systems, fastener removal is required.

The circular parting saw can be used to cut graphite. The graphite with Inconel backing plate and Inconel components are too difficult to cut because of the configuration and, especially, the hardness of the material. It should not be used for the Vacuum Vessel because the possible "spring" in the vessel could pinch the blade and cause blade failure or kickback.

The hole saw may be able to be used to cut around the fasteners that attach the Bumper Limiter and Protective Plate Panels to the Vacuum Vessel. These cuts would be through the graphite tiles but not the Inconel support plates. The plate fasteners could then be removed. Tooling to handle the panels would need to be developed. The difficulty with this method is accurately locating fasteners that are covered by graphite tiles.

A milling head may be able to be used to cut the heads off of the fasteners that attach Bumper Limiter and Protective Plate Panels to the Vacuum Vessel. These cuts would be made after the graphite tile (or a portion of the graphite tile) was removed to allow access to the fastener head. Bumper Limiters and Protective Plates would then be removed as panels. The difficulty with this method is accurately locating fasteners that are in counterbores in the panel mounts.

Grab/crush/shear devices are required to remove miscellaneous lightweight components from the inside walls of the Vacuum Vessel. There are areas that have cables and tubes that will require removal.

Torque wrenches can be used to remove fasteners in Bumper Limiter and Protective Plate panel mounts. In locations where the fasteners are tack-welded to the panel mount, the wrenches will be required to have enough torque capacity to break the weld. In addition, if the fastener becomes seized, the wrench should have enough capacity to torsionally shear the fastener shank.

Plasma Arc Cutting can be used to cut the Vacuum Vessel and its structural members and the heating/cooling ducts because it is not affected by the "spring" of the vessel. Most cut locations are ½" thick stainless steel. This type of cutting can also be used to cut the port and neutral beam nozzles (2"t). Plasma Arc Cutting does not cut graphite so it cannot be used for tile removal. Although this method can be used for cutting inconel material, Plasma Arc Cutting is not the best choice for removal of components attached to the walls of the vacuum vessel. The dross from the cutting operations becomes a slaglike material that can be non-conductive. This could prohibit/inhibit the Plasma Arc system from cutting the vacuum vessel at the desired location. In most segmentation locations, there is a heating/cooling duct covered with one inch of insulation on the outside surface. The insulation is electrically nonconductive; therefore, Plasma Arc Cutting has to be performed from the inside of the vessel.

A laser could also be used to cut the stainless steel and inconel materials. The laser could be located several inches away from the cut surface but the gas nozzle required for particulate removal from the cut path would have to be very close to the cut. The apparatus to deliver the laser cutting device would have to be developed and is expected to be substantially more expensive than PAC equipment.

Cutting/Removal Technology Delivery Systems

Due to the numerous operations required at each segmentation location, the access and delivery location for cutting and component piece removal technologies would be best to be near each segmentation location. The PPPL preferred method of segmentation at this time is with no personnel access due to the activation and contamination levels In-Vessel. There exists substantial access to the interior by using the top ports, midplane ports, and neutral beam ducts. In particular, the large top ports provide ample access for items to be lowered or raised through them. Care must be taken to confine airborne contamination for each open port or duct and each open cut location.

The reactionary forces of the cutting technologies have to be accepted by the delivery system. PAC does not produce large reactionary forces. Mechanical cutting and torque wrenches produce greater reactionary forces, therefore, the delivery system for these methods requires more rigidity.

The 45" long large top ports, the 35" high midplane ports, and the neutral beam ducts can be used to insert locally delivered fixtures for the cutting/removal technologies. If the top ports are used, the overhead crane can be used for delivering the fixtures. If the midplane ports or neutral beam ducts are used, a combination of overhead crane, long handled tools, and possibly a delivery rail system can be used. Since the majority of cutting is in the poloidal orientation, circular frame fixtures may lend themselves to the tasks.

The 45" long by 8½" wide large top ports, the 35" high midplane ports, and the neutral beam ducts can be used to insert a locally delivered robot arm. The robot arm must have enough rigidity for the operations required by the end-effectors. The possibility of using a multi-purpose end-eff ctor connection is also feasible. The robot arm could be used for PAC, torque wrenches, and pick and place tools. The robot arm most likely would not have the rigidity required for mechanical cutting. If it is determined that toroidal as well as poloidal cuts are to be made from In-Vessel, there may be an advantage to using a robot arm with PAC. The cuts could also be angled (zigzag) to achieve segmentation with reduced effort. In addition, the robot arm could be used to unfasten or cut In-Vessel component mounts, and it could also be used to pick and place any cut pieces. The robot arm with a PAC torch could also be used to cut the port nozzles and neutral beam ducts from In-Vessel. The cuts in the top and bottom large port nozzles would be vertical while cuts in the midplane port nozzles and neutral beam ducts would be horizontal.

Preliminary Plan For Segmentation

The segmentation locations for easiest implementation and minimized steps in cutting/removal have been identified. They are the parting joint locations. These will also achieve the baseline for packaging, i.e. ten (10) segments.

PAC, torque wrenches, shears, hole saws, and circular parting saws have been defined as the baseline technologies for component removal and Vacuum Vessel segmentation. PAC will be limited to cutting the parting joints. The other technologies will be used for In-Vessel component removal.

The use of local ports to deliver fixtures, robot arms, and cutting/removal technologies appears best. Long handled tools have been effectively used in other nuclear applications to deliver fixtures and devices, and to pick and place fallen objects.[5] Robot arms have been used for tasks that require non-linear movements and multiple end-effectors. Due to the possible poloidal and toroidal PAC cut paths, a multiaxis robot arm inserted locally appears to be the proper technology to use.

CONCLUSION

There is no easy TFTR Vacuum Vessel segmentation scenario. The parting joint location has been determined to be the "best" choice for segmenting the Vacuum Vessel as it is the least difficult area from which to gain access in order to make the necessary cuts. Additionally, segmentation operations at this location have been estimated to require the least amount of time to perform. The technologies exist for cutting and removal of components and the Vacuum Vessel. The components can be cut and/or removed by mechanical means and the Vacuum Vessel can be cut using PAC. Cutting and removal technology delivery systems have to be developed for remote or semi-remote application. The use of local ports to deliver fixtures and robotic arms appears to be most effective.

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