BWR FUEL CONSOLIDATION

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ABSTRACT

Fuel consolidation offers the potential to provide the lowest cost fuel storage alternative when reracking the spent fuel pool is not possible. Fuel consolidation is conducted entirely within the reactor plant fuel pool and requires no permanently installed equipment. Long term benefits include reduced transportation and disposal costs for the Federal Waste Management System.

Nuclear Assurance Corporation has developed an automated fuel consolidation system, FUEL-PAC, that uses an industrial robot and control system to perform the repetitive operations required to consolidate fuel. An automated system greatly reduces manpower requirements and associated radiation exposure, and allows for consistently high fuel processing rates. The system can consolidate eight BWR fuel assemblies in one 12-hour shift. The PWR processing rate is approximately half, depending on the fuel type.

FUEL-PAC separates the consolidation and NFBC compaction activities into single direct operations. Quick change commercial couplings allow changing the robot extension tools without the need for manual operations. The robot, coupling, and control systems remain above the pool water surface at all times.

Fuel rods are individually pulled from a fuel assembly and transferred to a rod storage canister at a rate of three rods per minute. Fuel consolidation ratios of 2:1 can be consistently achieved. The control system automatically records fuel rod positions in both the original fuel assembly and the rod storage canister. The system computer can then provide a complete record of all rod transfers for fuel accountability.

Non-fuel bearing components (NFBC) are compacted in individual operations to achieve an overall compaction rate exceeding 10:1. The inherent flexibility in using a computer controlled robot allows placement of NFBC into 60 cm. long mini-canisters, full length canisters which fit into the fuel racks, or drums.

INTRODUCTION

Fuel consolidation offers the potential to provide the lowest cost fuel storage alternative when reracking of the spent fuel pool is not possible. It allows storage capacity to be increased without the need to construct additional plant facilities, which are often in the public view and can require additional decommissioning activities and security measures. Fuel consolidation is conducted entirely within the reactor plant and requires no permanently installed equipment or additional plant support.

Previous studies and demonstration programs conducted by NAC have led to the design of FUEL-PAC, the fourth generation of fuel consolidation equipment. The basic philosophy of FUEL-PAC is to provide a simple and reliable system that minimizes operator actions and radiation exposure. This philosophy has led to breaking the consolidation/compaction activities into single, direct operations utilizing a commercially available ABB IRB-90 industrial robot. Using a robot and automated control system eliminates inconsistencies and human error associated with fatigue and boredom when performing the hundreds and thousands of repetitive operations involved with consolidating fuel. To enhance the overall efficiency of the system, commercial quick-change couplings are utilized to change from one tool to another without manual operations. The robot, located on the operating floor above the pool surface, is easily accessible for routine checks, maintenance or repair. Changes in system operation can often be accommodated by computer software alterations, rather than hardware modifications. The entire consolidation/compaction operation is integrated to achieve a fuel rod consolidation ratio of 2:1 and a nonfuel-bearing component (NFBC) compaction ratio in excess of 10:1.

The NAC FUEL-PAC System utilizes robotic automation to consolidate either PWR or BWR fuel. The associated computer system controls the robot and records fuel movement for nuclear material accountability and quality assurance activities. The system is modular, which promotes ease of maintenance, repair, installation and removal.

A major concern about previous fuel consolidation systems has been the significant manpower required. Typically, crews of three to five people are needed. An important feature of FUEL-PAC, however, is that it only requires one operator with limited need for plant personnel to remove loaded canisters and transfer additional fuel assemblies to the system. The system operator provides any needed maintenance, initiates the operations and maintains records. The impact on plant operations and total radiation exposure to personnel are therefore minimized.

FUEL-PAC can be used to consolidate either PWR or BWR fuel. The modules, tools and principles of operation are similar for both types of fuel. NAC is currently focusing on completion of a BWR system.

DESCRIPTION OF NAC BWR FUEL-PAC OPERATION

The BWR FUEL-PAC System is shown in Fig. 1.

After installation in the spent-fuel pool or cask loading area, the operator initiates system operation by running the robot control systems through a series of diagnostic tests to ensure proper functioning of all components before beginning the consolidation operation. Only one operator is required to run the system. The operator is kept informed of the system status at the monitoring station on the operating floor. Once the fuel assemblies are loaded into the work area, plant personnel are no longer required to support the operation of the system until the loaded consolidated fuel canisters and the next set of assemblies are ready for transfer. By minimizing the number of operators required, and allowing the system operation to be controlled remotely, personnel exposure is kept as low possible.

Four BWR fuel assemblies are transferred to the fuel assembly holders through the top of the worktable (Fig. 2), which is installed approximately 7.6 meters below the pool water surface. The assembly identification and orientation is checked, and the grid clamps within the holders are activated to secure the fuel assemblies in position. The identity of each fuel assembly is logged into the computer at the monitoring station. Two empty fuel rod canisters, one off-spec rod canister, and a set of NFBC mini-canisters and their associated lids are also loaded into the holders through the worktable.

The robot arm moves to the reach tool storage rack at the edge of the pool and connects with the grasp reach tool through the quick change couplings without any manual operations. The upper coupling half on the end of the robot arm mates with the lower half on each reach tool. The coupling contains water hydraulic and electrical connectors to automatically link the tool with the tool control system and power supplies. The fail safe coupling halves are locked together using compressed air to actuate the locks. After receiving positive indication of coupling, the robot lifts the tool from the rack. The tool then removes the lids of the empty fuel rod canisters and places them into a temporary storage receptacle. The tool is then returned to the tool rack and disconnected.

The robot then connects with the rod access tool, which is used to shear the threaded tie rod ends with the attachment nuts and locking tabs still attached. The tool shears two tie rod ends at a time, capturing and depositing them into the appropriate NFBC canister. When all the tie rods have been cut, the top end fittings are free and the tool is returned to the storage rack.

With the end fittings freed from the fuel assemblies, the bails are cut using the bail cutting tool. This tool pinches the lifting bail at its two vertical bar sections to allow more compact packaging with other components. The pinching is powered by a water hydraulic cylinder. The grasp reach tool is used to support the bail during cutting and to position it in the NFBC canisters.

The top end fittings are lifted off the assemblies using the grasp reach tool and are moved to a temporary location on the worktable.

With the top end fittings removed, the fuel rods are exposed for pulling and transfer. To assist in guiding the rod transfer tool onto the fuel rods, the grasp tool positions a funnel guide plate over each of the assemblies to be consolidated and over the top of the fuel rod storage canister. The guide plates provide a "lead in" for the final travel of the transfer tool, and are machined with holes for one fourth the number of fuel rods. Therefore, the plates will be repositioned periodically during the operation to expose additional fuel rods or storage locations.

With the guide plates in position, the robot connects with the rod transfer tool. The first step with this tool is to precisely determine its position relative to the worktable, robot arm, and fuel assemblies. The robot moves the tool to various positions on the worktable which have position sensors. Based on the position of the tool end within the sensor, an electrical signal is generated, which gives the robot and control system the precise location of the tool. Since all the permanent positions of the worktable surface relative to the robot are contained within the robot control program, the robot can determine where the tool end is located.

After determining the tool positioning information, the transfer tool is moved to the first fuel assembly. The robot control program moves the robot arm to locate the tool above the desired funnel guide plate and associated fuel assembly based on preprogrammed information corrected for the positioning signals. The tool is lowered to make contact with the guide plate, and the grasp collet is extended through the funnel shaped hole to grasp the fuel rod located below. An ejector/sensor rod is displaced within the tool when the rod is in position to be engaged, and generates a signal to stop lowering the collet and grasp the rod. When locked onto the rod, the electric servo motor located at the top of the tool (above the pool surface) is actuated to pull the rod from the assembly. The reaction force from pulling the rod is transferred from the tip of the tool to the guide plate and worktable support structure. The robot does not exert or experience any pull forces. The servo motor and control system continuously monitor rod pulling force and the length of the rod as it is pulled up within the rigid mast of the tool. Rod pulling force data is used to determine if a rod is sticking and is also used to determine any trends that

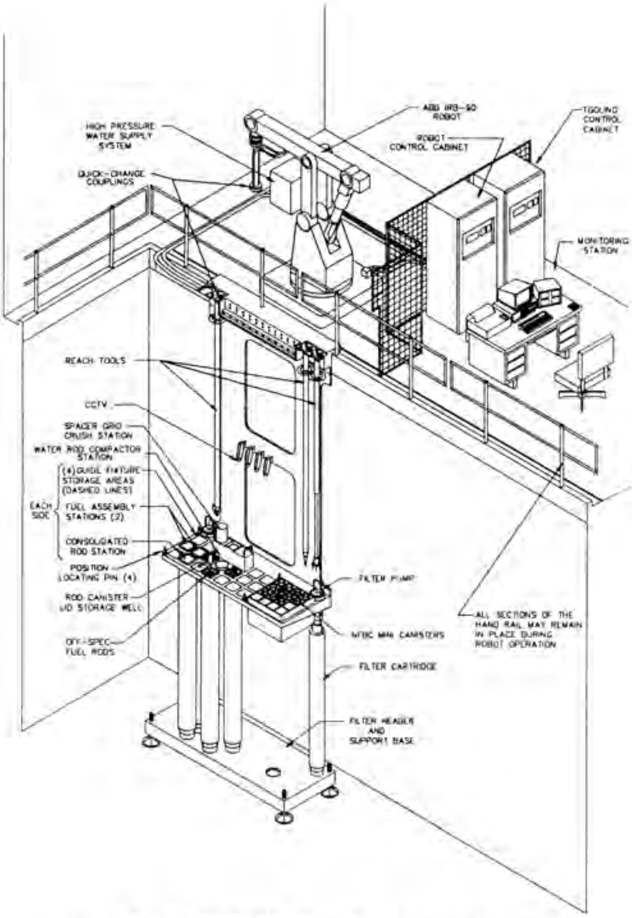

Fig. 1. BWR FUEL-PAC system.

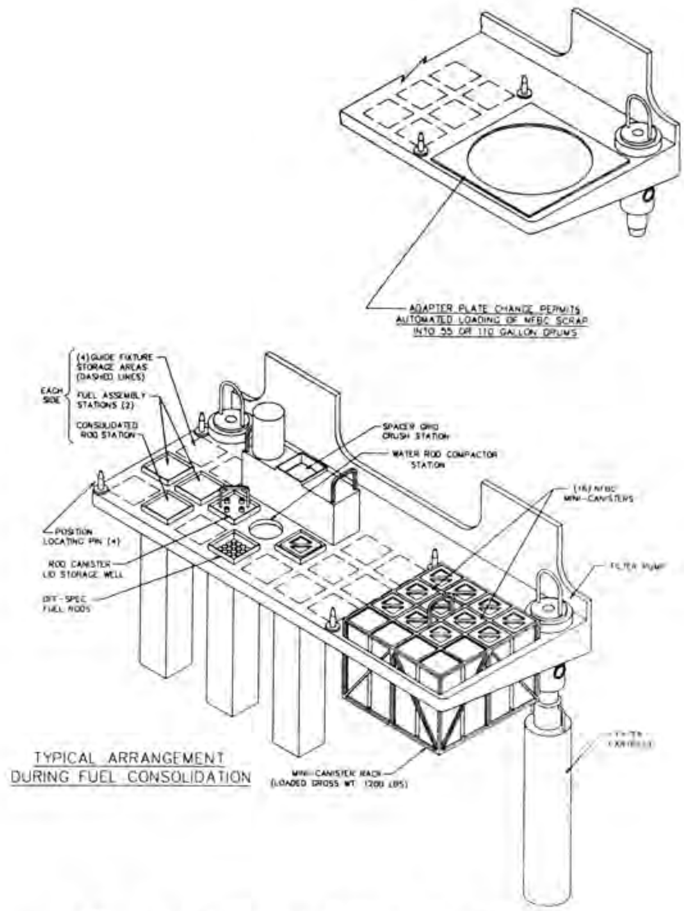

Fig. 2. Worktable BWR FUEL-PAC system.

could indicate a need for maintenance of the tool. The ejector/sensor rod also provides continuous indication of positive engagement with the rod, and generates a signal if the rod should begin to slip from the grasp collet. If the rod is stuck in the lower end fitting, the pulling force limit will be sensed by the servo motor and the tool will stop pulling. The ejector rod can then be used to tap the top of the rod to jar the lower end of the rod free. If the rod still sticks, it is left in position and the robot moves the tool to the next rod. Sensors at the rod tip actuate when the end of the rod passes the tip of the tool, and will indicate if the rod is less than full length. As the rod is pulled into the tool mast, the fuel assembly number, rod location within the assembly, pull force, date and time are automatically recorded by the computer system for nuclear materials accountability.

After the rod sensors indicate that the rod is completely within the tool, the robot moves the tool over to the rod storage canister. The tip of the tool is positioned on to the canister funnel guide plate, and the fuel rod is pushed out of the tool into the canister. As the rod is inserted into the canister, the computer records the location of the rod within the canister and the time of release. When the rod is completely withdrawn from the tool, the grasp collet unlocks from the rod, and the ejector/sensor rod taps the end of the fuel rod to ensure that it is released from the tool. With positive indication of rod release, the tool is repositioned over the fuel assembly for the next rod.

The total cycle time from one rod pulling operation to the next rod is approximately 20 seconds. The cycle time can be adjusted by modifying the robot control program.

In fuel types that have water rods that are similar in diameter to the fuel rods, the water rods can be pulled and loaded into the fuel rod storage canisters. In fuel types where the water rods are significantly larger than the fuel, the water rods are transferred to a compactor for volume reduction.

After the first pass of pulling rods, the robot must then remove the tie rods that are still threaded into the bottom end fittings and any additional fuel rods that could not be removed. The bottom end fitting cutting tool is then positioned to make a horizontal cut through the tie rod and fuel rod ends just above the end fitting. By making one gradual arc with the cutting blade, any rods that were stuck are cut free. After making the cut, the rod transfer tool is used to pull the remaining rods and load them into the storage canister.

During fuel consolidation, one of the two filter modules is in operation. The filter pump draws pool water down through each one of the active fuel assembly or canister support holders, through the lower support header, and up through a two-stage modular filter stack. The first stage filters large particles and cutting debris, while the second stage filters crud loosened from the assemblies. The water is then returned to the pool. By enclosing the operations within the full length support holders, any released crud is contained within the system. The funnel guide plates at the top of the holders act as flow restrictors that accelerate the water flow at the opening of the holder to prevent the release of "crud clouds" into the pool water. Each filter module pressure drop is monitored to indicate when the filters are fully loaded with debris. To change a filter, the module is lifted out of the support header through the worktable opening. Since the filters are self-contained units permanently sealed within the module housing, there is no handling of individual filter cartridges. Ball check valves at the inlet and outlet of the filter module automatically seal the filter as flow stops and the pump is removed. The housing can then be used as a permanent storage canister for the filters within. The plug-in module eliminates the need for hoses, couplings, and fasteners.

During the pulling and transfer operations, the system operator can observe the system using the underwater TV cameras. System performance can be checked through the robot control and tool control system cabinets.

With all the rods pulled, the spacer grids are still held in place by the capture rod and the spacer grid clamps of the support holder. The grasp reach tool, with its rotatable four finger "hand" and capture rod clamp, is used to grasp a grid and rotate it approximately 45 degrees while holding the capture rod still. The grid is rotated after the associated support holder grid clamps are withdrawn. With the grid disconnected from the capture rod, the grasp tool is withdrawn holding the grid. Supporting fingers are provided to hold the capture rod in place as the grids are removed. The grid is then moved to the grid compactor for volume reduction. The telescoping mast of the grasp reach tool allows access to each successively lower grid within the fuel assembly support holder. When only one grid remains, the robot switches to the rod transfer tool and grasps the capture rod. For this final grid, the capture rod is rotated by the transfer tool, and when disengaged from the grid, is withdrawn and placed in the fuel storage canister. The robot switches back to the grasp reach tool to grab the last grid and transfer it to the compactor. The tool then grabs the lower end fitting of the fuel assembly and moves it to an NFBC mini-canister.

The grid compactor is a single acting 100-ton water hydraulic press which flattens the grids. The grids are placed within a basket loaded into the body of the compactor. Each grid is crushed individually, with the following grid placed in the basket directly on top of the previously crushed grid. When the grids from two assemblies have been compacted, the basket is lifted out of the compactor with the grasp reach tool and loaded into an NFBC mini-canister.

The water rod compactor, when needed, is a continuous feed chopper/flattener. Each rod is fed in from the top. A water hydraulic cylinder cuts and flattens the hollow rod into approximately 1-inch long pieces. This scrap can then be loaded into the NFBC canisters. This same approach is used to compact PWR guide tubes after removal from the fuel assembly skeleton.

The grasp reach tool is used to transfer the top end fittings and lift bail that were originally moved to a temporary location to the NFBC canisters to obtain the desired stacking configuration with the lower end fittings, water rod segments, and tie rod nuts.

When the rod loading is complete and the rod storage canister is full, the robot uses the grasp reach tool to install the canister lid. The lid locking tool is then used to secure the lid in place with the tamper indicating fasteners.

The NFBC mini-canisters are sealed using the lid locking tool, and are stored in a portable rack. The rack holds 16 mini-canisters, which are approximately 2 feet long. When fully loaded, this portable rack is transported with the fuel handling bridge to the spent-fuel storage racks. The portable rack, with sled type runners to straddle the storage rack openings, is placed on top of the rack, above the consolidated fuel. With this method, the NFBC does not occupy any of the valuable fuel storage cells within the racks.

The system performs the operations described above for four BWR fuel assemblies. When completed, the computer can provide a complete record of all fuel transfers. Thus a permanent record, complete with fuel locations and time of transfer, is available for nuclear material accountability.

The two loaded consolidated rod canisters are lifted by the fuel handling bridge and transferred to the storage racks. Four more fuel assemblies and two more rod canisters are loaded into the support modules, and the consolidation operation can continue. Processing rates for various BWR fuel types are listed in Table I.

TABLE I

NAC FUEL-PAC
BWR Process Rates (Including NFBC)

	Time (Hours)		
	7×7	8×8	9×9
Fuel Movement, System Prep	1.5	1.5	1.5
Consolidation (4 assys)	3.5	3.9	4.3
Canister, Fuel Movement	1.5	1.5	1.5
Consolidation (4 assys)	3.5	3.9	4.3
Total	10.0	10.8	11.6