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SPENT FUEL DISASSEMBLY AND CANNING PROGRAMS AT THE BARNWELL NUCLEAR FUEL PLANT (BNFP)

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ABSTRACT

Methods of disassembling and canning spent fuel to allow more efficient storage are being investigated at the BNFP. Studies and development programs are aimed at dry disassembly of fuel to allow storage and shipment of fuel pins rather than full fuel assemblies. Results indicate that doubling existing storage capacity or tripling the carrying capacity of existing transportation equipment is achievable. Disassembly could be performed in the BNFP hot cells at rates of about 12 to 15 assemblies per day.

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1.0 INTRODUCTION

Methods of disassembling and canning spent fuel to allow more efficient storage are being investigated at the BNFP. Studies and development programs reported here are aimed at the mechanical aspects of hot cell disassembly of spent fuel assemblies to allow storage and shipment of fuel pins rather than full fuel assemblies. The objective is to double the capacity for storage or triple the capacity for transportation of spent fuel as well as to stabilize the fuel for storage.

The use of the BNFP mechanical headend space for the disassembly and canning of spent fuel has several advantages as compared to "in-pool" disassembly. These advantages are:

- Eliminates possible contamination of storage pool water
- Enhances visibility via the utilization of shielding windows
- Reduces considerably operator radiological exposure and job fatigue
- Increases operational control and flexibility
- Eliminates interference with fuel receipt/storage operations in pools.

Results to date indicate that the BNFP mechanical headend can be used to disassemble spent fuel assemblies and repackage the fuel pins in a dry, remotely operated and maintained facility. Testing of individual disassembly operations has verified our belief that the process can be readily performed in the BNFP mechanical headend spaces. Using dedicated equipment (i.e., no remote crane or manipulator used for in-line processing) rates of about 12 to 15 assemblies per day (approximately 6 MTU) are projected. This process rate is believed to be 3 to 4 times greater than using a similar process in a contaminated pool.

1.1 System Description

Two separate canning options, for reference pressurized water reactor (PWR) fuel are being developed. The first option loads fuel pins from two assemblies into a 23.50-centimeter (9.25-inch) square can that fits into a single assembly storage location in an existing BNFP spent fuel pool rack. This option doubles the spent fuel storage capacity within the same pool space. The second option loads pins from three assemblies into a 32.40-centimeter (12.75-inch) diameter cylindrical can for shipment off site to a federal repository, thus, tripling the capacity of a legal weight truck cask. Similar percentage increases are possible with BWR assemblies.

Other BNFP studies of the nuclear criticality, shielding, and thermal output have verified the safety and adequacy of this concept for fuel aged greater than three years. Seismic and loading studies have also been performed on the racks which verify technical feasibility.

The BNFP mechanical headend shown on Figure 1 provides the dry, remotely operated and maintained facilities in which the disassembly and canning equipment would be installed. The facilities are shown with all the reprocessing equipment removed. The facilities, as shown in the figure, are connected to the existing storage and transferring pools of the BNFP. Under either option, the disassembly, canning, and waste volume reduction processes would be implemented in the remote cell. The waste packaging and any dry fuel receipt or dry outloading of canned fuel pins would be accomplished in the remote support cell.

Either option involves the following operations. The fuel assembly would be transferred from the pool to the remote cell. In the remote cell, the following operations would be performed:

- Cut top end fitting
- Pull out fuel pins
- Load pins into can
- Seal can
- Compact fuel skeleton.

In the remote support cell, the nontransuranic (non-TRU) end fittings and compacted skeleton would be packaged and outloaded for shipment to a commercial burial ground. The crane room permits contact maintenance of the cranes and power manipulators. The cold support areas permit shipment of the non-TRU waste and operator control and monitoring of the various processes.

For Option 1, the canned fuel pins from the remote cell are transferred back to the pool by reversing the fuel assembly delivery system. For Option 2, the canned fuel pins from the remote cell are transferred via the remote support cell to a truck cask using a dry cask loading method.

1.2 Component Development

As a first step in hardware development, specific remote disassembly and canning steps were isolated that required design criteria definition. These included:

- End fitting removal methods
- "Fuel pin-from-skeleton" removal methods
- "Fuel pin-to-can" loading methods.

Other steps either involved existing remote equipment, or rather straightforward remote material handling devices, and demonstration has been deferred for the present. The intent of these development efforts was to demonstrate proof-of-principle and narrow the range of design parameters.

Removal methods were investigated to cut the top end fitting from the fuel assembly. The desired cutting plane is between the end fitting and the top of the fuel pin bundle. In this region, only control rod thimble tubes (and in some case, sheet metal shrouds) are found in the assembly cross section. As a result of an initial literature review of various candidate mechanical and thermal cutting methods, demonstration effort focused on friction sawing and laser cutting.

Two aspects of "fuel pin-from-skeleton" removal methods required investigation. These were how to engage the fuel pin and with how much force to pull. Various design parameters of a "puller-to-fuel pin" engagement device, or "biter," required definition.

Questions concerning the configuration of the "biter" tooth (i.e., its rake and relief angles), necessary hardness, and biting force to grab the pin for pulling had to be answered. Included were the forces required to pull fuel pins from various fuel assembly skeletons. The fuel pin is retained in the skeleton by the spacer grid via friction to allow for growth in the reactor. The pulling force must overcome this friction.

Once the fuel pins are pulled from the skeleton, a row at a time, they must be collected and loaded into a can. In an effort to minimize powered systems that would increase remote maintenance, a gravity feed collection system was selected consisting of a sloping surface terminated by a collection trough. First, the slope of the surface was defined to ensure a reasonably level pin stacking in the trough. Also, selected trough cross sections were tested to see which reduced the can loading force to reasonable levels. This force develops during the axial push of the free pin bundle into the can. Also, the range of these loading forces needed definition to fix the design of the can loading drive. As an associated study, testing was done to develop a relationship between the loading force required for a given collection of fuel pins versus the cross-sectional area of the can section being loaded.

1.3 System Development

The system development for the disassembly and canning options consisted of both hardware demonstrations and integrated concept layouts and designs.

One hardware demonstration consisted of defining the problems associated with transfer of an intact dummy fuel assembly through the remote cells. Another considered the integration of as many steps as feasible in the disassembly and canning process to provide an initial refinement of estimated throughput capacities.

A fuel assembly transfer system to convey fuel from the storage pool to the remote cell already exists. It is usable "as is" in either disassembly/canning option. Using it with the various existing hardware items generated via component development, an initial refinement in throughput time was generated by measuring the implementation time of these steps.

To ensure that adequate space and viewing requirements could be met, initial equipment layouts for both the disassembly and canning options were made. Initial design concepts to support these layouts were established to define the spatial envelopes of the individual equipment items that would constitute the integrated system.

1.4 Results

The essence of the disassembly/canning process development is shown in Figure 2. All fuel pins from two prototypic fuel assemblies are shown loaded into a can. The upper right half section contains the pins from a dummy Westinghouse 17 x 17 fuel assembly; the other half section, the pins from a dummy Babcock and Wilcox 15 x 15 fuel assembly. The can was loaded using component development equipment and subsequently demonstrated to fit within a mock-up section of a typical PWR rack. This demonstrated the doubling of pool storage capacity by putting the fuel pins from two PWR assemblies into a rack section that would normally hold only one PWR fuel assembly.

Proof-of-principle demonstrations for removal of end fittings using a laser and a friction saw have been successfully completed.

The investigation of laser and friction saw cutting have demonstrated their application to the cutting of stainless steel tubes arranged in a geometrical array. This array of 20 thin-walled tubes simulates the basic configuration of the control rod thimble tubes in that section of a PWR type assembly immediately adjacent to the bottom of the top end fitting. Other cutting processes and methods for this application were not included because of prior investigation by others or because of incompatibility with the varied constraints of a remote cell, tube cutting application.

In using a laser for cutting, only the few optics involved in beam directing and focusing, their support structure, and an inert gas jet nozzle that displaces the laser melted metal would be located in the hot cell. These minimal in-cell equipment requirements enhance remote maintainability.

The laser cutting demonstration was performed using the facilities of a laser vendor. A 15-kilowatt, continuous wave, CO_2 laser was used to cut the tube array. A range of cutting parameters were investigated to establish cutting rate, laser power requirements, and gas jet nozzle positioning relative to top tubes of the array. The tubes were severed, demonstrating that an array of 20 tubes can be cut by the laser. The need for an improved gas jet nozzle, as well as refinement of other laser cutting control parameters, indicated the need for further development. The control of smoke and fumes must also be addressed. These developments should improve the observed kerf width and minimize the dross formation.

During the friction sawing tests at the BNFP, feed rate, saw band speed, chip and fines generation, and burr characteristics were investigated. In terms of burr characteristics, chip and fines size and collectability, and cutting time, the most favorable cutting results were obtained with high-feed pressure and low-blade speed.

Three prototypic PWR fuel assemblies were available for the development effort. All assemblies were used to establish force ranges required to pull fuel pins from the spacer grids. The pins from the Westinghouse 17 x 17 assembly were used for biter tooth development as a "worst case" demonstration (i.e., smallest diameter and smooth side walls at pin termination). Various pin puller and biter tooth criteria were developed. The pins from both the Westinghouse 17 x 17 and the Babcock and Wilcox 15 x 15 assemblies were used to select the pin collector slope to establish limits on the forces required to load the free pin bundles into both square and round can sections. Table 1 summarizes the component development effort for the reference PWR fuel.

Development of a biter tooth configuration for a device to pull the fuel pin free from the assembly spacer grids has indicated that approximate values of hardness-60 Rc, relief angle-10°, and rake angle-30° will result in a successful biter. Individual pin pulling forces were demonstrated to range between 90 and 900 newtons (20 and 200 pounds) and to be approximately normally distributed. A "biter" with this tooth configuration, which grips the pin with a bite force of 310 newtons (70 pounds) will prevent slip up to a pull of 900 newtons (200 pounds), but will not develop pulling forces in excess of 1560 newtons (350 pounds) before slipping free.

A collector slope of 8° tended to level the profile of the free pins in the collection troughs. Utilizing this slope, it was found that selected trough cross sections of 45° for the selected square can and 120° for the selected round can preshape loose pin bundles, so that can loading forces do not exceed acceptable levels [less than 6670 newtons (1500 pounds)] and mechanical jams are minimized. Testing of loading forces using another can whose cross-sectional area was variable indicated that the selected cans were essentially optimal in regards to cross-section dimensions.

Using both vertical and horizontal handling of the fuel assembly, transfer of an intact fuel assembly through the headend spaces was demonstrated. Also, to the extent feasible, implementation of process steps using existing hot-cell and component development equipment have confirmed estimated throughput capacity.

The system layout and design development has shown that adequate space and remote viewing does exist in the remote cell for the installation of a fuel disassembly/pin canning process for either option.

The layout of the integrated system for Option 1 (i.e., square canning of fuel pins for increased pool storage) is shown in Figure 3. The process flow follows the numerical order of equipment labels.

Option 1 to increase pool storage was arranged for horizontal process flow. After delivery of the fuel assembly horizontally in the remote cell, this process translates the fuel assembly approximately 1.2 meters (4 feet) perpendicular to the delivery axis. The process then moves the fuel in the direction of its lengthwise axis for end fitting removal and fuel pin removal by rows. During the fuel pin collection for can loading, the process translates the fuel pins back to the delivery axis. The pin bundle is loaded into a half section of a can. A second assembly is processed similary to load the other half section. Then, the filled can is capped and reloaded into the delivery system which is reversed to carry the compacted fuel back to the pool for storage. Now the pins from two assemblies are stored in a pool rack section in which one fuel assembly had been previously stored.

The layout of the integrated system for Option 2 (i.e., round canning of fuel pins for increased truck cask shipping capacity) is shown in Figure 4. Here again, the process flow follows the numerical order of the equipment labels.

Option 2 to increase truck cask shipping capacity was also laid out as a horizontal process. Fuel delivery, end fitting removal, and pin removal are identical for both options. However, during fuel pin collection under Option 2, the process centerline is translated an additional 1 meter (3-1/2 feet) from the delivery axis. This provides operational clearance so that the loaded can is unobstructed as it is reoriented from its horizontal loading position to its vertical handling position. The vertical position is necessary for delivery to the dry cask loading area.

Both options require off-line processes of:

(1) A non-TRU solid waste system that compacts and packages the fuel assembly minus fuel pins (i.e., the cut end fitting and the fuel skeleton).

(2) A "jammed-pin" assembly relocation system that allows non-standard disassembly away from the normal processing area.

(3) An empty fuel can supply system that feeds and positions cans without remote crane assistance.

These were included in the layout of both options.

A non-TRU waste system utilized the same cutting device that cuts off the forward end fitting. The fuel holder has an integral fuel assembly feed system that incrementally advances the skeleton (i.e., after removal of fuel pins) to this cutter. The cut segments consisting of thimble tubes, spacer grids, and back end fitting fall by gravity via a waste chute to the existing solid waste handling system in the head-end.

The only component of the nonstandard processing system shown in these figures is a nonstandard fuel holder. This is a temporary holding station for fuel whose pins would not pull free in the normal process for whatever reason. From this holding station, the fuel assembly is relocated to a work station in the remote support cell. Here each assembly will be handled on a case-by-case basis with a full inventory of both mechanical and thermal remote "hand tools" available.

An empty can supply system is also shown in both figures in phantom. The intent is that an automated system receive cans from a cold support area, reorient them to process, and position and secure them for loading. This frees the maintenance cranes and power manipulator from any process operation support except for a crane providing inter-cell transfer of filled cans under Option 2. This precludes process interference of these maintenance units as well as unnecessary wear and tear which would compromise their "ready-standby" status for maintenance.

1.5 Conclusions

Doubling pool storage and tripling truck cask shipping capability appear feasible based on development work performed at the BNFP. This would be accomplished by disassembly of the fuel assembly and canning of the fuel pins. The dry, remote disassembly and canning options in the headend cells, as compared to "in-pool" disassembly, offer the advantages of increased rates, elimination of disassembly contamination of pool water, enhancement of visibility, reduction of operator dose and fatigue, increased flexibility, and unlinking of fuel receipt/storage/disassembly operations.

TABLE I

COMPONENT DEVELOPMENT RESULTS

• Dummy PWR Test Assembly Types		
Westinghouse (17 x 17)		
Babcock & Wilcox (15 x 15)		
Gulf United Nuclear (15 x 15) (Westinghouse Reload)		
• Force to Pull Fuel Pins from Grids	90 to 900 newtons	(20 to 200 pounds)
• Fuel Pin Puller Parameter Development		
"Optimal" Puller Biter Force	310 newtons	(70 pounds)
Minimum "Expected" Pin Pull	900 newtons	(200 pounds)
Maximum "Expected" Pin Pull	1560 newtons	(350 pounds)
Biter Tooth Hardness	60 Rc.	
Biter Tooth Relief Angle	10°	
Biter Tooth Rake Angle	30°	
• Fuel Pin Collector Slope to Trough	8°	
• Fuel Pin Can Loading Development (Pool Storage)		
Pin Collector Trough Cross Section	45°	
Square Can Loading Force	5780 newtons	(1300 pounds)
• Fuel Pin Can Loading Development (Truck Cask)		
Pin Collector Trough Cross Section	120°	
Round Can Loading Force	6230 newtons	(1400 pounds)

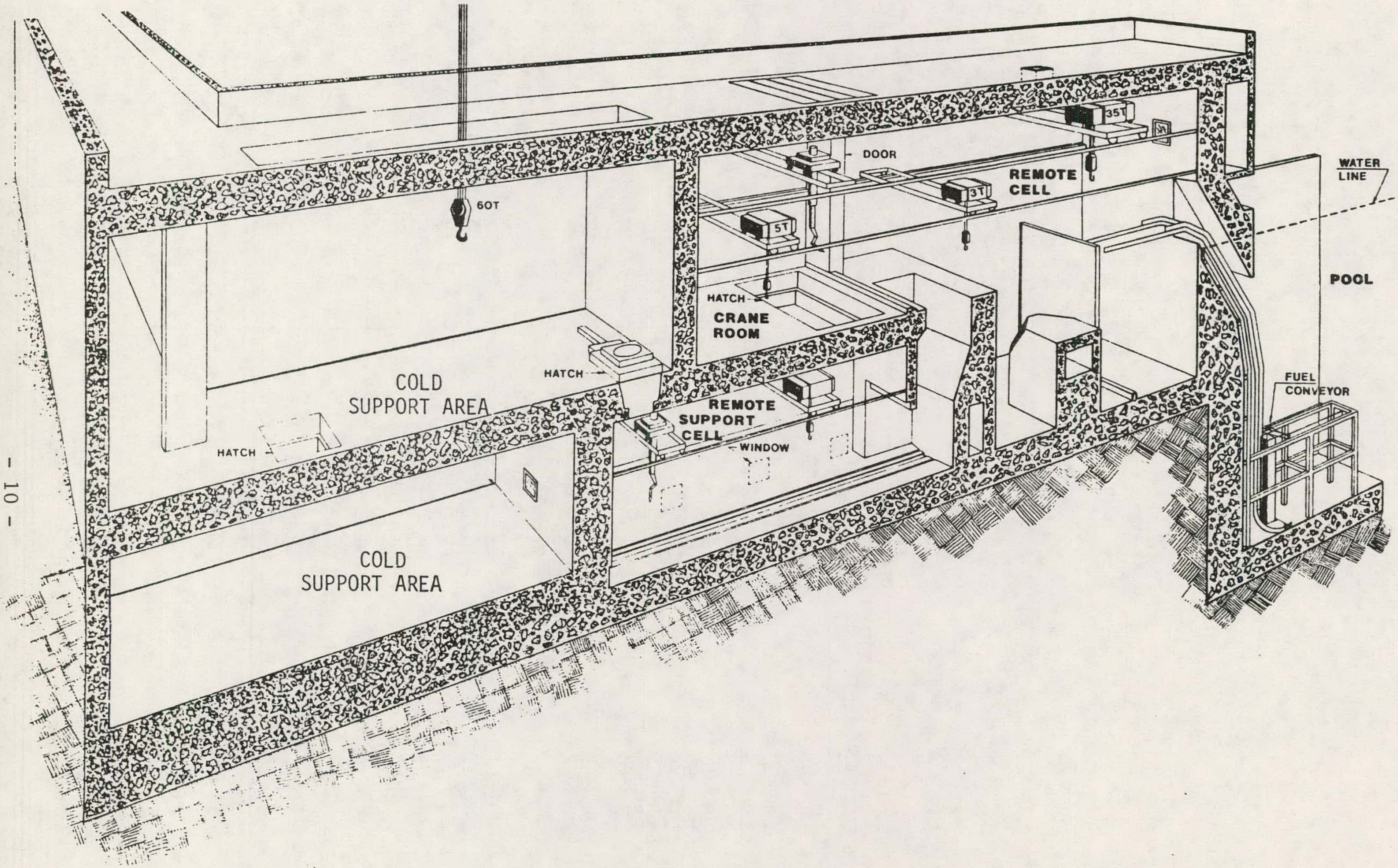
FIGURES

FIGURE 1 -- BNFP REMOTE AND COLD SUPPORT AREAS

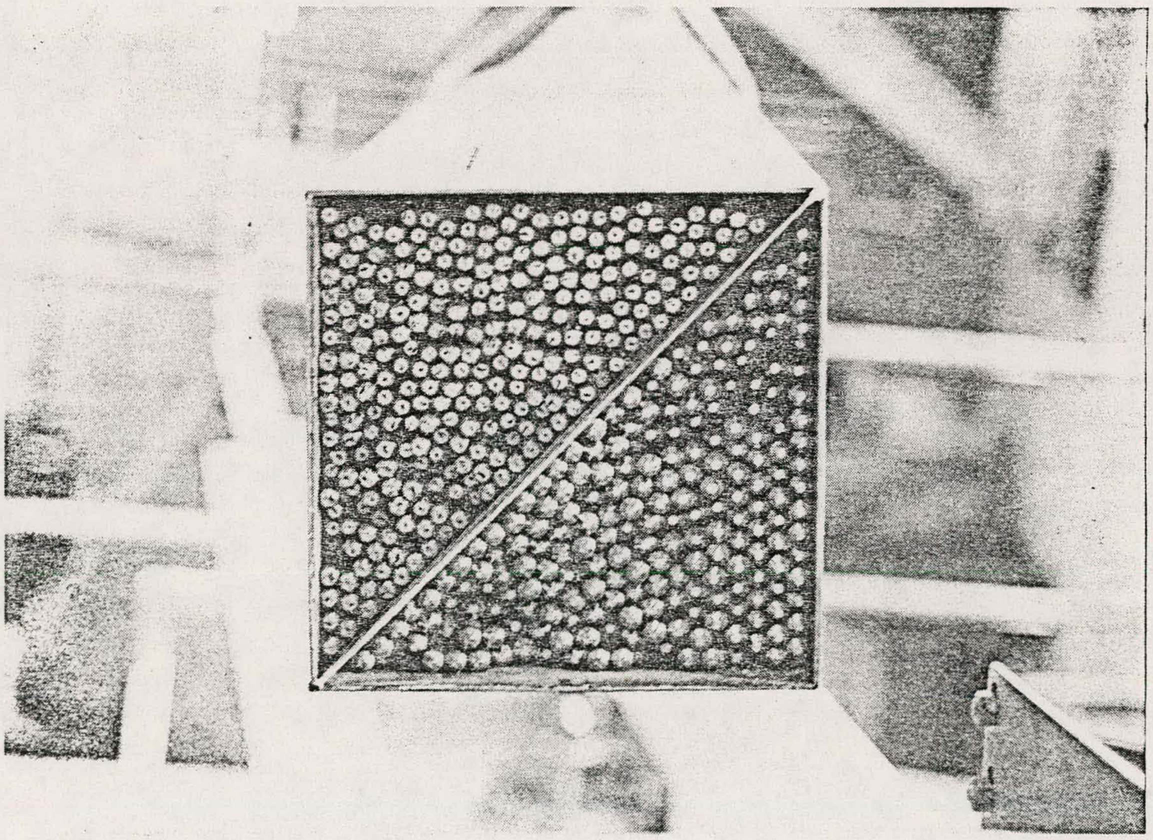
FIGURE 2 -- SQUARE CAN LOADED WITH FUEL PINS FROM TWO COMPLETE PWR FUEL ASSEMBLY DUMMIES

FIGURE 3 -- DISASSEMBLY AND CANNING SYSTEM TO INCREASE POOL STORAGE -- OPTION 1

FIGURE 4 -- DISASSEMBLY AND CANNING SYSTEM TO INCREASE SHIPPING CAPACITY -- OPTION 2



BNFP REMOTE AND COLD SUPPORT AREAS
G. A. Townes
Figure 1



SQUARE CAN LOADED WITH FUEL PINS FROM
TWO COMPLETE PWR FUEL ASSEMBLY DUMMIES
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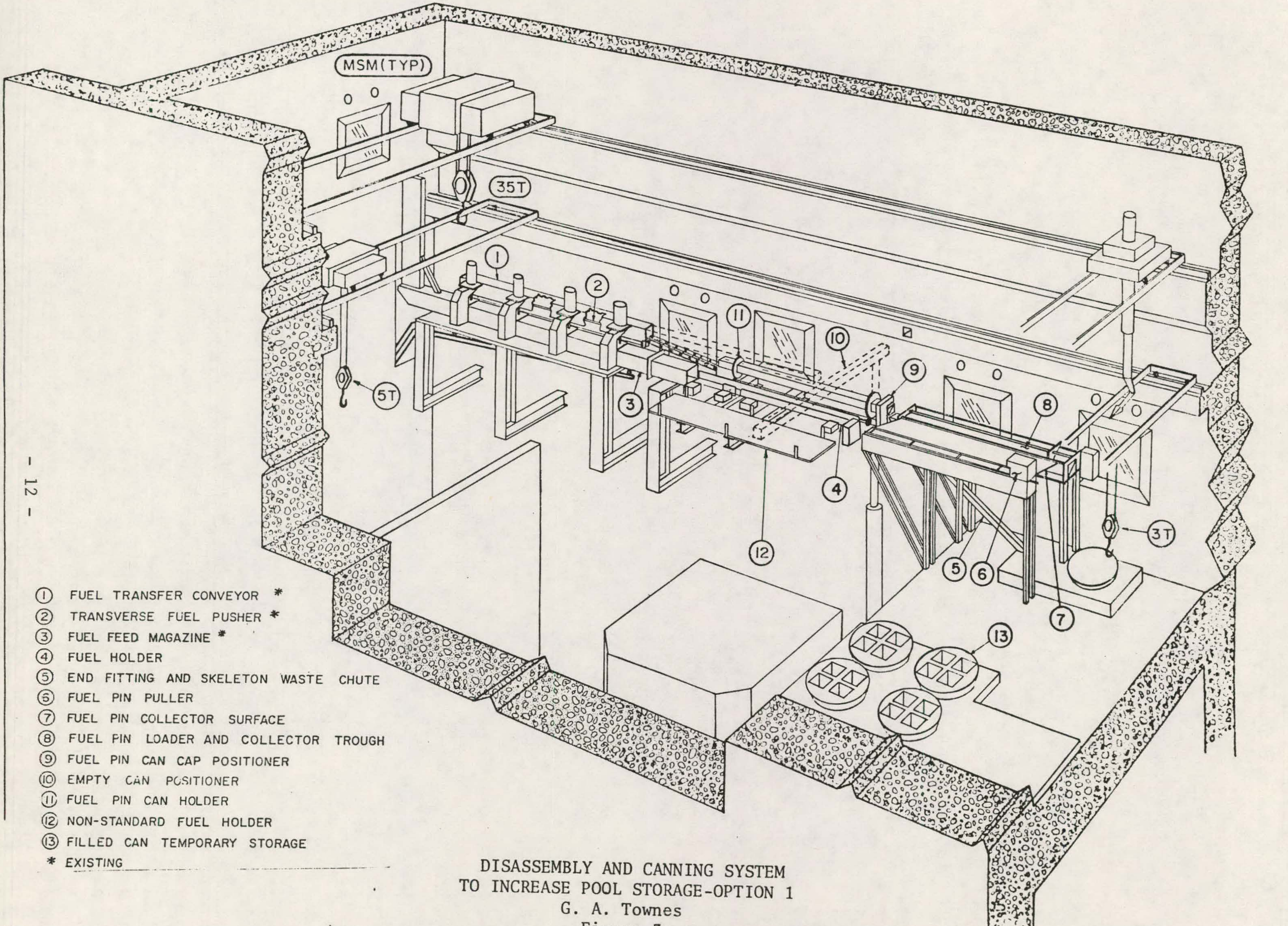
Figure 2



DISASSEMBLY AND CANNING SYSTEM
TO INCREASE POOL STORAGE-OPTION 1
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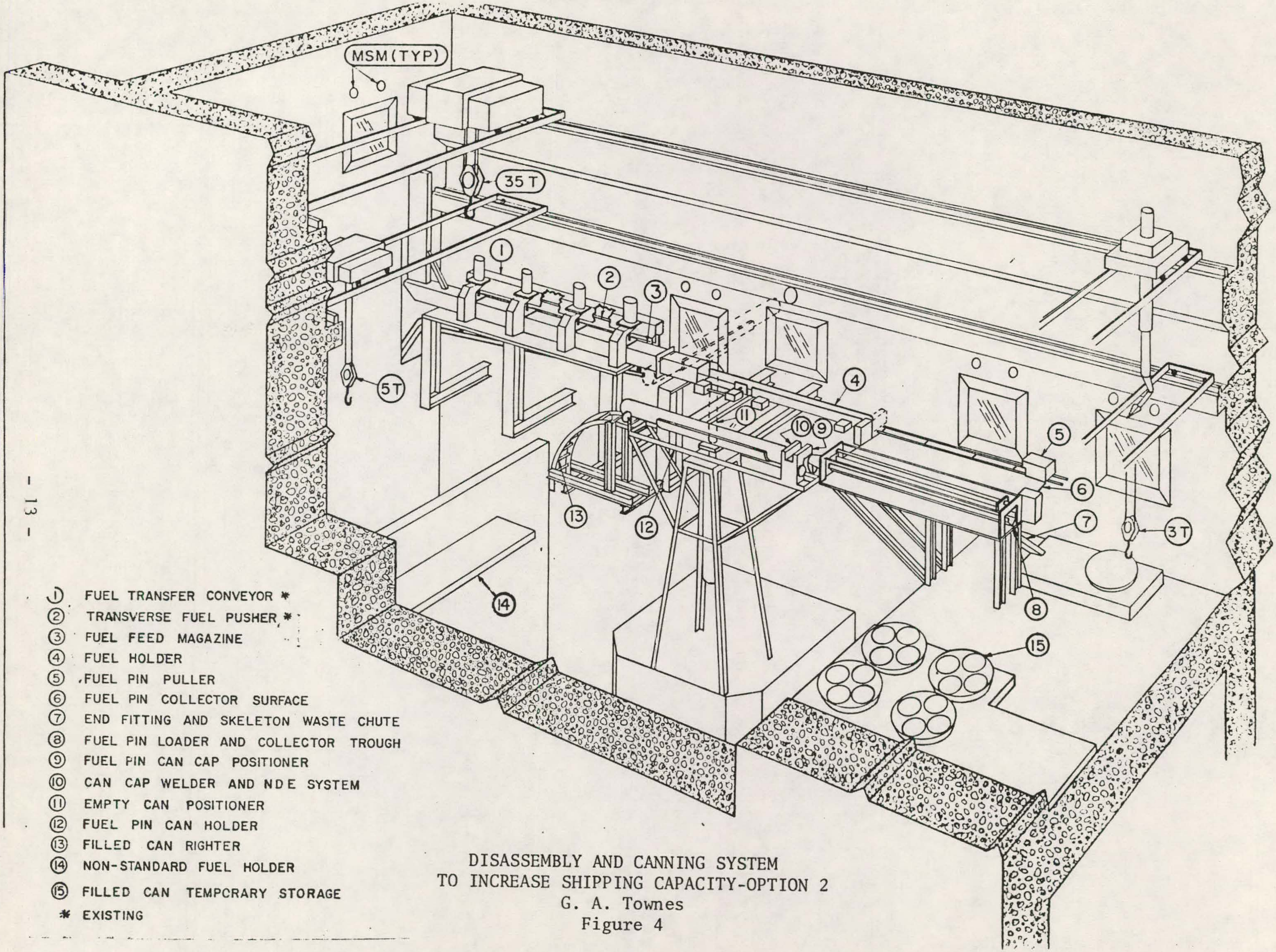
Figure 3



1. FUEL TRANSFER CONVEYOR *
2. TRANSVERSE FUEL PUSHER *
3. FUEL FEED MAGAZINE
4. FUEL HOLDER
5. FUEL PIN PULLER
6. FUEL PIN COLLECTOR SURFACE
7. END FITTING AND SKELETON WASTE CHUTE
8. FUEL PIN LOADER AND COLLECTOR TROUGH
9. FUEL PIN CAN CAP POSITIONER
10. CAN CAP WELDER AND NDE SYSTEM
11. EMPTY CAN POSITIONER
12. FUEL PIN CAN HOLDER
13. FILLED CAN RIGHTER
14. NON-STANDARD FUEL HOLDER
15. FILLED CAN TEMPCRARY STORAGE

* EXISTING

DISASSEMBLY AND CANNING SYSTEM
TO INCREASE SHIPPING CAPACITY-OPTION 2
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Figure 4

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