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PROTOTYPICAL SPENT NUCLEAR FUEL ROD CONSOLIDATION EQUIPMENT

PRELIMINARY DESIGN REPORT

WASTE MANAGEMENT SERVICES
GENERAL ELECTRIC

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Prepared By

B.F. JUDSON
J. MAILLET
G.L. O'NEILL
J. TSITSICHVILI
D. TUCOULAT

AND THE STAFF MEMBERS OF
GENERAL ELECTRIC COMPANY
SOCIETE GENERALE POUR LES TECHNIQUES NOUVELLES
LEAR SIEGLER INCORPORATED

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WASTE MANAGEMENT SERVICES OPERATION
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GENERAL ELECTRIC

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GENERAL ELECTRIC COMPANY
SOCIETE GENERALE POUR LES TECHNIQUES NOUVELLES
LEAR SIEGLER, INCORPORATED

KEY PARTICIPANTS WERE AS FOLLOWS:

GE

E.A. AITKEN	B.F. JUDSON	S.Y. OGAWA
H.W. BASSETT	D.A. KAYE	G.L. O'NEILL
T.B. BENDER	F.E. KEMMERER	D.J. RUSH
R.E. BUTLER	C.E. KING	R.K. STITT
J.A. DEAR	D.D. LAW	G.L. STIMMELL
A.W. FANNING	L.C. LAWRENCE	J.K. USSERY
F.J. FAZZIO	R.R. MILES	W.C. WHEADON

SGN

P. CHAUVIRE	B. LABESSE	J. TSITSICHVILI
J.P. DELETTRE	G. LAFITTE	D. TUCOULAT
O. GUIBAL	R. LECERF	P. VONFELD
M.A. HERICOURT	S. LECOCQ	
C. HUTCHISON	J. MAILLET	

LSI

T. de CHAMBEAU
S.J. HULL

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P. LEMAISTRE (SGN)
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PCDP PHASE I - GE/SGN/LSI

PRELIMINARY DESIGN REPORT

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EXECUTIVE SUMMARY

INTRODUCTION

The purpose of the Prototypical Consolidation Demonstration Project (PCDP) is to develop and demonstrate the equipment system that will be used to consolidate the bulk of the spent nuclear fuel generated in the United States prior to its placement in a geological repository. The equipment must thus be capable of operating on a routine production basis over a long period of time with stringent requirements for safety, reliability, productivity and cost-effectiveness.

Four phases are planned for the PCDP. Phase I is the Preliminary Design of generic consolidation equipment that could be installed at a Monitored Retrievable Storage (MRS) facility or in the Receiving & Handling Facility at a geologic repository site. Phase II will be the Final Design and preparation of procurement packages for the equipment in a configuration capable of being installed and tested in a special enclosure within the TAN Hot Shop at DOE's Idaho National Engineering Laboratory. In Phase III the equipment will be fabricated and then tested with mock fuel elements in a contractor's facility. Finally, in Phase IV the equipment will be moved to the TAN facility for demonstration operation with irradiated spent fuel elements.

General Electric Company (GE) under Contract No. DE-AC07-86ID12648, along with Societe Generale pour les Techniques Nouvelles (SGN) and Lear Siegler, Inc. (LSI) as subcontractors, has prepared the Phase I Preliminary Design of Prototypical Spent Nuclear Fuel Rod Consolidation Equipment as part of a competitive multiphase project (PCDP) sponsored by the Idaho Operations Office of the U.S. Department of Energy (DOE-ID). The Preliminary Design is based on a Conceptual Design developed by SGN and supported in part by proprietary work conducted by SGN in France, including fabrication and testing of key equipment components.

The purpose of this Preliminary Design Report (PDR) is to document the GE/SGN/LSI Preliminary Design of generic consolidation equipment that could be installed in a MRS or geologic repository. The PDR is made up of four major sections of text and five appendices. The four major sections describe the generic system design bases, the process equipment and facility interface, systems operation and system performance evaluation. A section which describes the TAN installation is also provided. The appendices document associated design trade studies, equipment tests and operating experience, contain all Phase I flow diagrams, drawings and equipment data sheets, and summarize reliability/availability analyses.

DESIGN BASES

The objectives for the preliminary design are as follows:

a. The generic concept shall be developed in terms of drawings, descriptions, design analyses, specifications, tests and experience to an extent that verifies the feasibility of the process and the equipment design.

b. The design and the descriptions of off-normal events and recovery methods and equipment shall be adequate to verify the off-normal process and equipment design.

c. System design and performance evaluations shall be adequate to assure that DOE requirements are met at the 75% confidence level.

d. The design and description shall provide adequate detail and material call out for a 75% probability cost estimate.

The approach to concept development which meets these objectives has been to combine parts, materials, and processes with known histories in similar systems with new parts, materials and processes where required to meet unique DOE requirements. The approach to performance evaluation has been to constrain the design with performance requirements, to conduct performance tests on new designs, to conduct performance evaluations on the system design and to conduct a formal design review. The approach to confidence evaluation has been to build the confidence throughout the work by taking care to establish a strong requirements base, designing, analyzing and testing to meet that base and evaluating the finished product against the requirements baseline.

The work was completed in a relatively short time period (120 days) by partners some of whom were overseas. Iteration among the designers and system performance evaluators under these circumstances made it necessary to cause interaction on three occasions between the SGN design team and an expert evaluation team from GE and LSI. Intensive interactive working meetings were conducted initially to establish the requirements baseline, in mid-phase to guide design trade studies and review test results and finally during a formal Design Review. An independent review team made up of personnel engaged in GE's Nuclear Waste Repository Project participated in the formal Design Review and evaluated the confidence that the work meets all DOE requirements.

The chosen approach described above focuses on the DOE applicable documents, Generic Functional Requirement, and TAN Specific Requirements as the basis for all phases of the design. A comprehensive understanding of the DOE requirements was established early in the PCDP Phase I effort by synthesizing the expert viewpoints of design, operation, maintenance, licensing, producibility and reliability on each DOE requirement. This improved comprehension is documented in this report as the Preliminary Design Requirements Baseline.

SYSTEM DESIGN DESCRIPTION

The system concept provides for 1) disassembly of BWR or PWR spent fuel elements, 2) consolidation and packaging of the resulting spent fuel rods, and 3) handling and packaging of scrap hardware and associated wastes. The equipment is operated remotely from within a hot cell enclosure and meets functional requirements established by DOE-ID for the types and rates of materials to be processed, safety and operational controls, materials handling and accountability, and system maintenance and recovery from off-normal events.

The system is designed to consolidate 750 metric tons (heavy metal) of spent PWR and BWR fuel per year. The design basis assumes a 60/40 split of PWR/BWR fuel on a heavy metal basis. Equipment throughput is designed to meet the yearly production based on 75% availability for operation during two shifts/day and five days/week over a 30-year lifetime.

Operations will be on a campaign basis for a given type of spent fuel. Prior to each campaign, the system will be configured for the specific type of BWR or PWR fuel to be processed using handling tools and equipment modules stored in the cell. Spent fuel is introduced into the hot cell enclosure from the site storage area through use of the cell crane and placed in a lag storage module. A batch of spent fuel is then processed through three working stations for 1) end-fitting removal, 2) fuel rod removal, and 3) rod packaging, with three supporting systems for 1) handling non-fuel bearing components (NFBC), 2) decontaminating rod and scrap canisters, and 3) providing maintenance and control services for the in-cell equipment.

The rod consolidation process flowsheet is illustrated in Figure 1. The equipment arrangement, cell layout, and facility interfaces required to execute the process flowsheet is illustrated in Fig. 2, Generic Facility Layout.

The equipment detail is provided as an appendix to the report which includes the following flowsheets and drawings.

		Drawing Numbers
A.	System Design	
	o Flowsheet	SH-1886-20-001
	o Material Balance (Generic)	Unnumbered

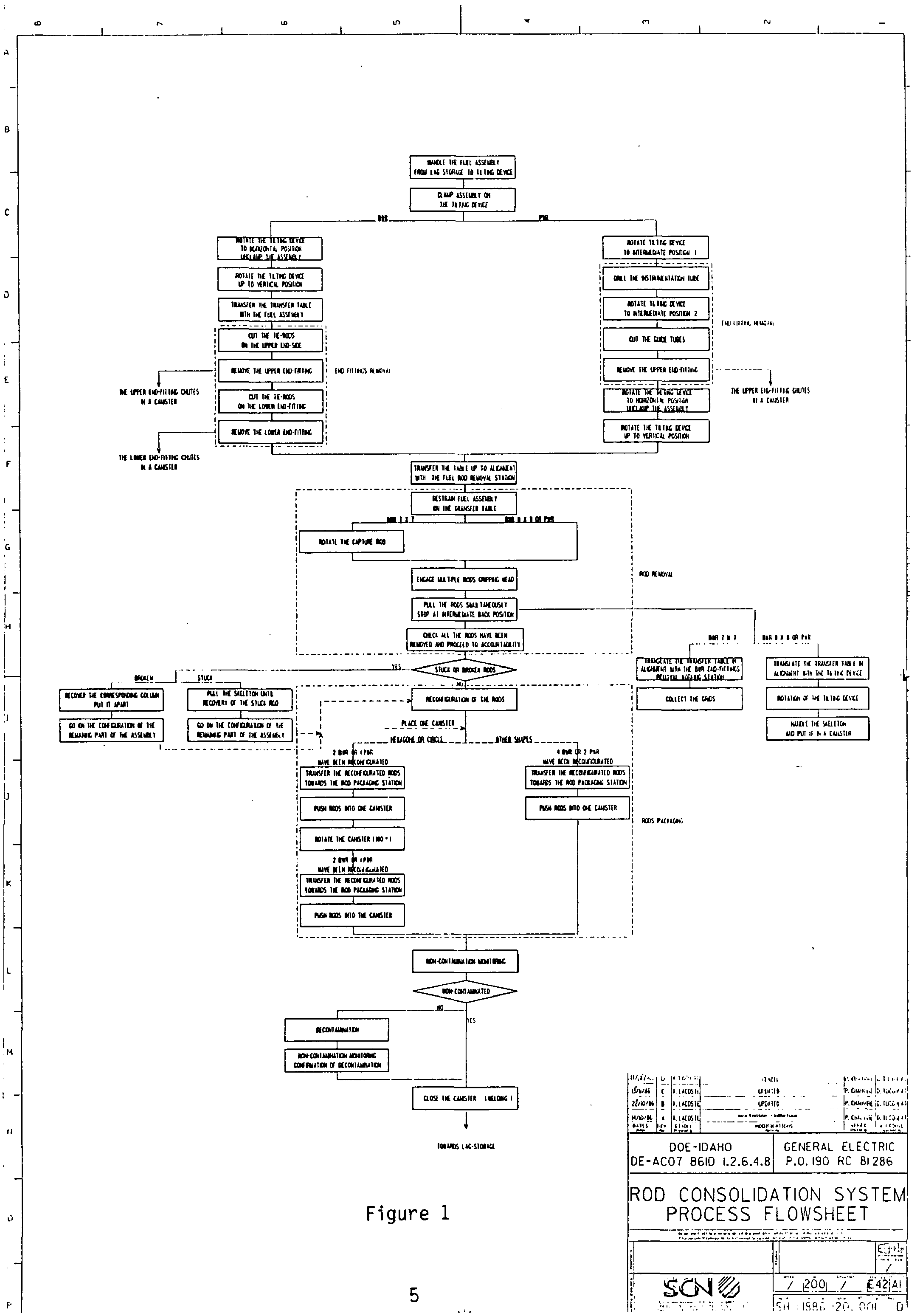

HANDLE THE FUEL ASSEMBLY FROM LAG STORAGE TO TILTING DEVICE
CLAMP ASSEMBLY ON THE TILTING DEVICE
BWR
PWR
ROTATE THE TILTING DEVICE TO HORIZONTAL POSITION UNCLAMP THE ASSEMBLY
ROTATE THE TILTING DEVICE UP TO VERTICAL POSITION
TRANSFER THE TRANSFER-TABLE WITH THE FUEL ASSEMBLY
CUT THE TIE-RODS ON THE UPPER END-SIDE
REMOVE THE UPPER END-FITTING
CUT THE TIE-RODS ON THE LOWER END-FITTING
REMOVE THE LOWER END-FITTING
END FITTINGS REMOVAL
THE UPPER END-FITTING CHUTES IN A CANISTER
THE LOWER END-FITTING CHUTES IN A CANISTER
ROTATE TILTING DEVICE TO INTERMEDIATE POSITION 1
DRILL THE INSTRUMENTATION TUBE
ROTATE TILTING DEVICE TO INTERMEDIATE POSITION 2
CUT THE GUIDE TUBES
REMOVE THE UPPER END-FITTING
END FITTING REMOVAL
THE UPPER END-FITTING CHUTES IN A CANISTER
ROTATE THE TILTING DEVICE TO HORIZONTAL POSITION UNCLAMP THE ASSEMBLY
ROTATE THE TILTING DEVICE UP TO VERTICAL POSITION
TRANSFER THE TABLE UP TO ALIGNMENT WITH THE FUEL ROD REMOVAL STATION
RESTRAIN FUEL ASSEMBLY ON THE TRANSFER TABLE
BWR 7 X 7
BWR 8 X 8 OR PWR
ROTATE THE CAPTURE ROD
ENGAGE MULTIPLE RODS GRIPPING HEAD
PULL THE RODS SIMULTANEOUSLY STOP AT INTERMEDIATE BACK POSITION
CHECK ALL THE RODS HAVE BEEN REMOVED AND PROCEED TO ACCOUNTABILITY
ROD REMOVAL
BWR 7 X 7
BWR 8 X 8 OR PWR
TRANSLATE THE TRANSFER TABLE IN ALIGNMENT WITH THE BWR END-FITTINGS REMOVAL ROTATING STATION
COLLECT THE GRIDS
TRANSLATE THE TRANSFER TABLE IN ALIGNMENT WITH THE TILTING DEVICE
ROTATION OF THE TILTING DEVICE
HANDLE THE SKELETON AND PUT IT IN A CANISTER
STUCK OR BROKEN RODS
YES
NO
BROKEN
STUCK
RECOVER THE CORRESPONDING COLUMN PUT IT APART
GO ON THE CONFIGURATION OF THE REMAINING PART OF THE ASSEMBLY
PULL THE SKELETON UNTIL RECOVERY OF THE STUCK ROD
GO ON THE CONFIGURATION OF THE REMAINING PART OF THE ASSEMBLY
RECONFIGURATION OF THE RODS
PLACE ONE CANISTER
HEXAGONE OR CIRCLE
OTHER SHAPES
2 BWR OR 1 PWR HAVE BEEN RECONFIGURATED
TRANSFER THE RECONFIGURATED RODS TOWARDS THE ROD PACKAGING STATION
PUSH RODS INTO ONE CANISTER
ROTATE THE CANISTER (180°)
2 BWR OR 1 PWR HAVE BEEN RECONFIGURATED
TRANSFER THE RECONFIGURATED RODS TOWARDS THE ROD PACKAGING STATION
PUSH RODS INTO THE CANISTER
4 BWR OR 2 PWR HAVE BEEN RECONFIGURATED
TRANSFER THE RECONFIGURATED RODS TOWARDS THE ROD PACKAGING STATION
PUSH RODS INTO ONE CANISTER
RODS PACKAGING
NON-CONTAMINATION MONITORING
NON-CONTAMINATED
NO
YES
DECONTAMINATION
NON-CONTAMINATION MONITORING CONFIRMATION OF DECONTAMINATION
CLOSE THE CANISTER (WELDING)
TOWARDS LAG-STORAGE
DOE-IDAHO
DE-AC07 86ID 1.2.6.4.8
GENERAL ELECTRIC
P.O. 190 RC 81286
ROD CONSOLIDATION SYSTEM
PROCESS FLOWSHEET
SGN

Figure 1

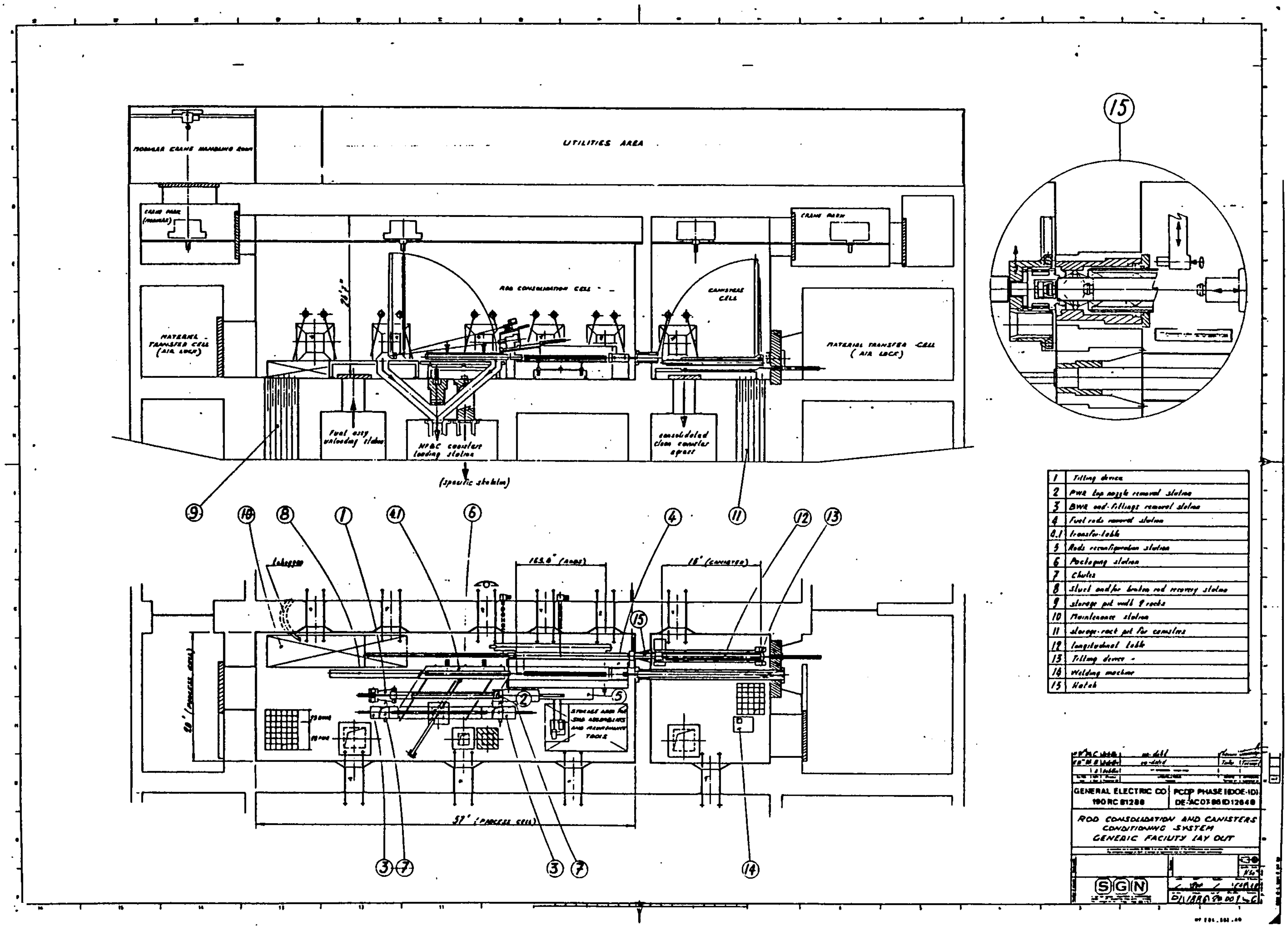


Figure 2. Generic Lay-out PI-'386-20-001

	o Material Balance (TAN)	Unnumbered
	o PWR Fuel Time Line	SH-1886-20-002
	o BWR Fuel Time Line	SH-1886-20-003
	o Generic Lay-out	PI-1886-20-001
	o TAN Lay-out	PI-1186-20-002
B.	Transfer Equipment	
	o TAN Process Crane	PE-1886-20-001
	o Tilting and Clamping Devices	PE-1886-20-002
	o Fuel Element Handling Grapple	PE-1886-20-003
C.	End-Fitting Station	
	o PWR Tube Cutting Machine	PE-1886-20-004
	o Detail of PWR Cutter	PE-1886-20-005
	o BWR End-Fitting Removal System	PE-1886-20-006
	o PWR Top Nozzle Removal Device	PE-1886-20-017
D.	Rod Removal Station	
	o Gripping Head System	PE-1886-20-010
	o Generic Rod Removal Work Station	PE-1886-20-009
	o TAN Rod Removal Work Station	PE-1886-20-007
	o Transfer Table	PE-1886-20-011
E.	Rod Packaging	
	o Reconfiguration System	PE-1886-20-008
	o Typical Source Configuration	PE-1886-20-013
	o Typical Triangular, Hexagon Configuration	PE-1886-20-012
	o Canister Welding System	PE-1886-20-014
F.	NFBC Handling	
	o Skeleton Handling System	PE-1886-20-016

G. Support Systems

o Operations Signal-System and Safety Interlocks SH-1886-20-005

END FITTING REMOVAL

The first step in the end-fitting removal operation is transfer of a fuel element by the in-cell crane from lag storage to a vertically-positioned tilting device that has been configured for the specific type of fuel to be consolidated. The fuel element is inspected visually as it is lifted from lag storage for obvious damage that might hinder consolidation. Once clamped to the fuel tilting device, the element can be rotated toward a horizontal position for drilling out the central instrument tube plug in PWR elements and for positioning on a transfer table for end-fitting removal. The tilting device clamps are unique to each fuel type and serve as a gauge for measuring element twist and bow.

For PWR fuels, the guide and instrument tubes at the top of the assembly are cut from the inside out with a multiple-blade cutting head and the top-end scrap hardware is removed to a container for non-fuel bearing components. The remainder of the PWR assembly is ready for transfer to the rod removal station.

For BWR fuels, two cutting heads are used sequentially to shear the tie rods at the upper and lower end-fitting locations and the scrap hardware from both ends is removed to a NFBC container.

FUEL ROD REMOVAL

The first steps in the fuel rod removal operation are lateral movement of the transfer table for positioning in line with the rod removal station and enclosure of the partially disassembled fuel such that particulates released from the surface of the fuel are contained and removed. The gripping head contains gripper jaws for each rod in a module that are unique for each type of fuel.

All rods are pulled simultaneously. As the rods are pulled, their spacing is maintained by horizontal and vertical combs placed throughout the array. After the rods are pulled, a sensor module is placed between the transfer table containing the fuel element skeleton and the comb array containing the rods. Missing or broken rods are detected by sensors and the rod configuration is compared with a memorized configuration in a computer. Item accountability is completed at this time.

If a rod is released during the rod pulling operation, the monitor detects the off-normal event and the normal sequence of operations is stopped for a rod recovery procedure in which 1) the withdrawn rods are maintained fixed by the gripper head, 2) the transfer table containing the assembly skeleton is pulled back so as to disengage the released rod from the bundle of withdrawn rods, 3) the withdrawn rods are processed through the reconfiguration system and 4) the released rod is recovered from the skeleton using custom tools and master-slave manipulators.

If a rod is broken during the rod pulling operation or if there is a broken rod initially in the element, the sequence of operations would proceed normally until the sensor module detects that there is a missing rod segment in the comb array. Recovery of the segment in the element skeleton would proceed as above. The element skeleton may need to be cut away by shearing until the broken rod is exposed enough to grasp and remove. Recovery of the segment in the comb array would involve a) moving the transfer table away and aligning a specially designed intervention system with the rod removal station, b) placing a recovery tray below the reconfiguration station, c) removing the horizontal combs from the array of rods, d) operating the reconfiguration station manually by processing one vertical row at a time until the row containing the broken rod segment is next, e) transferring this row of rods into the recovery tray, f) removing the broken rod using the master-slave manipulator, and g) placing the segment into the failed fuel rod storage container for later removal through the rod canister loading station.

FUEL ROD PACKAGING

The first step in the fuel rod packaging operation is to arrange the fuel rods from each element into a configuration compatible with the cross section of the consolidated rod storage canister. The horizontal combs are removed from the array of rods and the vertical combs are retained in position so that the rods can be transferred one horizontal row at a time into a carriage that shuttles back and forth between the comb array position and the rod reconfiguration receiver. The geometry of the receiver is configured to complement that of the storage canister. The receiver is loaded with rods one horizontal row at a time until it is filled with the rods from 2 PWR or 4 BWR fuel elements at which point the rods are ready for transfer into the storage canister. The reconfiguration system can accommodate square, round, triangular, hexagonal and trapezoidal canisters. Square, triangular and trapezoidal canisters can be loaded in one operation, while the round and hexagonal configurations require two loadings into a compartmented canister.

The canister loading operation consists of sealing a clean, empty canister against a contamination barrier wall and pushing the rods from the reconfiguration receiver through a specially designed port in the wall into the canister. An interim seal is placed over the canister opening and the loaded canister is rotated to a vertical position for a contamination check. The canister is checked for surface contamination, decontaminated if needed, and then transferred to seal welding. After closure welding the canister is transferred to lag storage.

NFBC HANDLING

Handling the non-fuel bearing components occurs twice during the rod consolidation process, once before the rods are pulled from the element and once after. The end-fittings from both the PWR and BWR fuels are placed in transfer containers immediately after they are separated from the fuel elements and prior to pulling rods. The PWR end-fitting, for example, is pulled off the element using a special clamping device attached to the guide-tube cutting machine and is released to a transfer container through a chute after the cutting machine is retracted from the element.

The skeleton from a PWR element or the water rod component from an 8x8 BWR bundle remains on the transfer table after the rods are pulled and is returned to the end-fitting removal station. The fuel tilting device is then used to grip the long element skeleton and raise it to the vertical position. The cell crane grapples the skeleton and lowers it into one of the four compartments in the NFBC canister.

When the fuel rods and the capture rod are removed from a 7x7 BWR bundle, the spacer grids remain clamped on the working table. After the clamps are removed, the spacer grids are transferred into an NFBC container using a special tool and a chute to an uncompartmented NFBC canister.

Loading of the NFBC canisters with either the skeletons or the end-fittings takes place through the cell floor through a contamination barrier to avoid decontamination requirements and minimize waste generation.

CANISTER DECONTAMINATION

Canisters containing consolidated rods may be decontaminated, if required, prior to seal welding and removal to lag storage. The canisters are replaced in the intercell transfer channel and a series of rotating nozzles spray high-pressure demineralized water over the surface. The water is collected for treatment and disposal by the facility services system. Canister decontamination is not expected to be a normal operation as the canister cells are designed to remain uncontaminated.

CELL SERVICE SYSTEMS

As illustrated in Figure 2, the rod consolidation equipment is located in two adjacent cells with each having a dedicated crane and master slave manipulator systems for remote off-normal operation and module replacement. The crane in the rod consolidation cell is a modular process crane with redundant components for reliable operation, while the crane in the rod canistering cell is a simpler unit reflecting the low cell contamination levels. The main cells are supported by other cells and access ways for canister transfer, equipment and crane maintenance, and waste collection and removal with suitable interfacing to the main facility services system. All cell operations, both automatic and remotely actuated, are monitored from a control room.

SYSTEM OPERATION DESCRIPTION

CONTROL SYSTEM

The cell operations system is designed for automatic control of normal sequences with safety interlocks and data processing systems support functions. Control is normally from a remote main control room using supervisory control over a distributed control system, coupled with visual and audio feedback and manual override capability. Control is possible from local controls which are designed to accomplish off-normal and maintenance functions with assistance from manual operation of master slave manipulators. Eight sets of viewing windows equipped with master slave manipulators are provided in the consolidation cell and two sets are provided in the canister cell. Unusual circumstances can be addressed using a servomanipulator which is attached to the modular crane in the consolidation cell.

The control system is designed to perform remote control of the process systems while protecting the safety of the staff and the environs, protecting the equipment, centralizing control operations, and monitoring cell status.

A data processing computer serves to complete a) a historical accounting of the process, its equipment failure and alarms, b) material balance information including accountability, and c) data such as tool and module status and location and process configurations for various fuel types.

This computer can also be programmed to complete certain calculations on request from the programmable logic controller.

The operating modes that the main control room operator can select are automatic, semiautomatic, controlled manual, and test manual. Automatic control is provided by combining the process operating sequences (steps) into cycles and upon operator authorization executing that cycle. Semiautomatic control is similar to automatic control except that the operator must authorize each step of the cycle. Controlled manual control allows the operator to select individual controls corresponding to each elementary step of the process. During these operations the process control subsystem and the protection subsystem function to control the remaining process functions and the safety interlocks remain active. Test manual control is the same as controlled manual with the exception that the operator may unlock the protection system and safety interlocks. This procedure can be performed only under strict administrative control.

NORMAL PRODUCTION OPERATIONS

Normal production includes those operations associated with processing campaigns of similar fuel elements. Thus, the normal campaign includes the reconfiguring of the equipment as well as normal production and service operations. Since this facility will depend on the interface facility (MRS or repository) for the logistics of accumulating the lot of fuel for each campaign, it is also necessary to provide a set of fuel acceptance criteria to that facility. The following criteria has been developed for the purpose of defining this interface between rod consolidation and the facility.

Fuel elements entering the consolidation cell shall meet the following criteria:

1. Elements of common design and operating experience shall be queued into lots for consolidation with a normal lot being at least 56 subassemblies.

2. Elements must be free of channels prior to consolidation.

3. Elements must be clampable on the initial downender upon receipt in the cell.

4. Elements must pass a visual inspection for fuel or other process sensitive damage prior to consolidation.

5. Elements shall be free of liquid waste in order to meet 10CFR60.135 requirements on the canister.

6. Elements shall be accompanied by historical data to the extent possible as an aid to consolidation screening decisions.

7. Fuel elements shall be out-of-reactor at least TBD years.

8. The consolidation Information System shall be capable of correlating element historical and observed element conditions against observed consolidation process abnormalities as an aid in assessing potential problem fuel elements.

Screening will occur within the rod consolidation cell. Each element will be visually inspected as it is lifted for processing. Next the element is clamped to the tilting device. The clamping arrangement will act as a gauge because elements with bending in excess of 5/8 inch will not enter the tilting device clamping systems which are unique to each fuel design. Also, elements with excessive twist and bow will be detected when the element is placed on the transfer table.

Prior to each production campaign, the system will be configured for the specific fuel element lot to be processed. The data processing system will contain the required configurations and storage locations for each module that must be in place.

During the preliminary design, the component designs were standardized as much as possible to minimize changeovers. Also, those component modules which must be changed have been designed for easy access and replacement using proven remote module techniques. Remote tooling required for these operations are stored in the cell. These are also standardized to handle as many modules as possible and minimize their number.

Operation time-line analyses were performed for both PWR and BWR fuel processing. The operation times given on these time-lines were estimated on the basis of SGN experience (fuel element handling), tests (fuel rod removal and PWR upper end-fitting removal) or by extrapolation from existing experience with equipment with similar functions. These time-lines show that sixteen BWR or PWR elements can be consolidated in 15 hours, 36 minutes. The required throughput of 750 metric tons of heavy metal per year is equivalent to about 14 fuel elements per day based on 75 percent availability and 2 shifts per day and some margin. Fourteen elements per day meets the requirement in 186 days with 9 days margin to accomplish 75 percent availability. Three hours per day are available for startup, shutdown, and minor maintenance.

OFF-NORMAL RECOVERY OPERATIONS

The major off-normal operations were described previously. Anticipated off-normal operations are required to recover from the presence of broken rods, released rods, jammed equipment, loose pellets, powder and parts, and loss of power and services. Detailed description of recovery modes from each of these conditions is included in the report.

MAINTENANCE

Systems are provided which permit both preventative and corrective maintenance. The total system will include a preventative maintenance program specifically designed to maintain equipment reliability using predictable failure data and statistical data gathered from manufacturers and operating experience. The system will also include procedures for corrective maintenance of all major modules.

The equipment maintenance systems include the cell maintenance area, cell cranes, master-slave manipulators, remote tooling, tooling storage areas, materials transfer cells, and ex-cell mockup facilities. The servomanipulator is also used for special maintenance tasks. Most in-cell maintenance systems are required for normal and off-normal process operation as well.

Repair in-place is expected to be the normal maintenance procedure replacing the defective module with a new module. A cost trade-off decision will be made to determine if the module will be repaired in-cell or discarded. Module repairs will be conducted using the in-cell maintenance location indicated on the cell layout. The cell maintenance area is accessible to the cell crane and to two sets of master-slave manipulators.

The process equipment will be of a modular design so as to facilitate removal and placement of all key parts. An equipment module is made up of a number of functionally and spacially linked parts which, whenever possible, will be components with similar reliability. Modularization reduces the MTTR (mean time to repair) of components which otherwise would have been too long to be acceptable and which could impact the average availability of the plant and reduce the probability of achieving the desired throughput capacity.

Generally speaking, a module performs a function or an operation. In addition to the functional parts, a module is also fitted with a base plate, a gripping system, a guiding and locking system, and male or female parts to mate with the support location. In each piece of equipment, the modules will be located so as to facilitate direct accessibility with the crane and manipulators.

The modules will be designed to have dimensions so that they will fit into a NFBC canister or are easily disassembled into parts that do not fit into the NFBC canisters.

The maintenance operations require working space and equipment. Working space is provided in the process cell specifically to perform maintenance, and equipment is provided in cell storage areas.

PERSONNEL REQUIREMENTS

The staff required to operate the rod consolidation equipment in a single production line is envisioned as part of a larger organization structure needed to operate the entire facility. Personnel assignments to the rod consolidation line would be on three levels: the first, such as operations technicians, would be fully dedicated; the second, such a manipulator maintenance technicians, would be shared by all the remote process cells in the facility; and the third, such as support and administrative personnel, would be shared with the other process and utility systems in the facility.

The facility support staff includes management and administrative personnel and the engineering and technical support personnel required for rod consolidation operations. The former would include employee relations, financial accounting and materials procurement and the latter production planning, materials accountability and equipment maintenance engineers and analytical laboratory and health physics technicians.

A staff estimate for operation of the equipment at full production levels was completed based on the operating plan and organization structure discussed above and operation 5 days per week with two shifts per day. The total is the equivalent of 30 full-time employees.

SAFETY AND LICENSING

Operations safety and licensing considerations that are described in the report include the qualifications of the personnel, the quality of operator certification programs and materials, technical specifications, materials accountability system, ALARA and quality assurance including compliance auditing.

SYSTEM PERFORMANCE EVALUATION

The GE/SGN/LSI performance evaluation covers a range of effort which includes equipment tests in support of design, reliability/availability analyses, operability evaluations and analyses and formal design review. These evaluations, tests, and reviews have confirmed the preliminary design and have predicted an 83% confidence that the throughput requirements can be met.

A design/testing effort was complemented by performance evaluations which placed emphasis on the operational considerations of the system. A structured approach was applied which balanced the sometimes conflicting input-output (throughput) aspects and the operational aspects of the design, i.e. operability, maintainability, safety, reliability and producibility. The approach was to assemble a team of experts representing each of the operational viewpoints and to cause this team to interact with the designers on three occasions - initially to assure a uniform and comprehensive understanding of the DOE requirements, in mid-phase to guide design trade studies, and finally, during the formal Design Review.

EQUIPMENT TESTING

The equipment testing effort is described and provided as an appendix to this report. This appendix describes the SGN experience and testing in the areas of fuel element handling, end-fitting removal, fuel rod pulling, fuel rod packaging and in-cell support systems. Video presentations of tests of prototypical end-fitting removal, instrument tube drilling, and

PWR rod removal equipment were effective as a verification of these tests during the formal design review. A photograph of the integrated rod pulling equipment system that was tested by SGN in a fabricator's shop is shown as Figure 3.

AVAILABILITY/RELIABILITY

System performance evaluations were both quantitative and qualitative. The quantitative evaluation was a reliability/availability analysis which used process modeling, simulation rules, key processing parameters and equipment characteristics. Two sets of calculations determined that there is 83% confidence in the preliminary designs capability to process the required 750 metric tons of fuel per year.

SYSTEM EVALUATIONS

The qualitative system performance evaluation base was the evolution of design constraints into design requirements consistent with operability, maintainability, safety, reliability and producibility aspects of the system. The process used was to conduct requirements analysis using a peer group of experts to identify these design requirements and thereby establish a requirements baseline. This requirements baseline was used as the basis for the design, for performance evaluation and for the design reviews.

System operation and maintenance was reviewed by GE experts familiar with all aspects of remote cell operation and BWR fuel reconstitution as well. Knowledge of the condition of many kinds of spent fuel was an important contribution to this design. This knowledge was converted into design requirements which impacted the end-fitting removal and crud control features of the design. The SGN approach to maintenance was found to be very sound.

Equipment component producibility was reviewed by LSI experts familiar with U.S. fabrication requirements and capability. This review was important because of the international flavor of the GE/SGN/LSI effort.

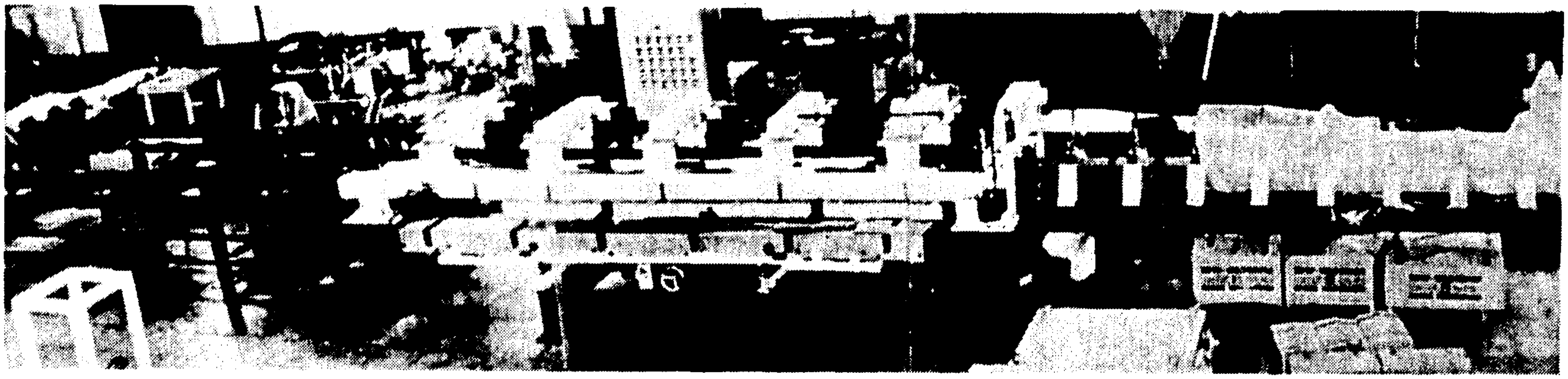


Figure 3

Producibility design requirements were developed and the resulting design evaluated as producible in the USA.

Certain special safety evaluations were conducted in the areas of shielding, criticality, crud contamination control and fines pyrophoricity control. The results of these evaluations are given in the report. The basis for these evaluations were largely prior experience and scoping analyses based on prior analysis of similar applications.

A formal design review was conducted on October 29 and 31. The basis for this review was the requirements baseline. This review was thorough and intensive with documented findings and reconciliations. An independent review was conducted simultaneously to evaluate confidence in the design by considering GE/SGN/LSI performance based on the quality and completeness of the requirements baseline, performance evaluations, test data and reports, the design including analysis, trade studies and drawings, and the design review itself. The Design Reviewers judged the preliminary design to be adequate for detail design to begin.

DESIGN REQUIREMENTS VERIFICATION

A description is provided for every DOE Generic Functional Requirement and every TAN Specific Requirement which illustrates how this preliminary design meets that requirement. The illustration is keyed to the report for further explanation if the reader desires. Every requirement is met by this design.

DESIGN CONFIDENCE EVALUATION

Finally, the report describes a design confidence evaluation which was performed by the independent review team made up of GE Nuclear Waste Repository personnel. The approach was to use six distinct areas of evaluation which together constitute confidence that the DOE requirements were met. These areas are requirements definition, performance evaluation, test data and experience, design analysis, trade studies and drawings, design review and reliability/availability analyses. The GE/SGN/LSI team was given good marks in the areas of requirements definition and design review and average marks for the performance evaluation (including reliability/availability analysis), test data and experience and design analysis, trade studies and drawings.

Through the combination of the above subjective and analytical evaluations, confidence in the design has been accumulated. In order to develop a response to the DOE request that the design exhibit at least a 75% confidence in meeting all requirements, the subjective issues were made quantitative by pre-assigning a portion of the confidence in each area. The independent review team was asked to rate the project teams performance in each area. The results were as follows:

Area	Confidence Range	Confidence Rating
Requirements Definition	7-10%	10%
Performance Evaluation	10-15%	10%
Test Data and Experience	0-15%	10%
Design Analysis, Trade Studies and Drawings	15-25%	20%
Design Review	20-35%	35%
Reliability/Availability-Simulation	*	
	Total	85%

*Included under Performance Evaluation

The independent review team rating showed that there is 85% confidence that the GE/SGN/LSI Preliminary Design of the spent nuclear fuel rod consolidation equipment meets all DOE requirements.

1. INTRODUCTION AND DESIGN BASIS

General Electric Company (GE) under Contract No. DE-AC07-86ID12648, along with Societe Generale pour les Techniques Nouvelles (SGN) and Lear Siegler Inc (LSI) as subcontractors, has prepared the Phase I Preliminary Design of Prototypical Spent Nuclear Fuel Rod Consolidation Equipment as part of a competitive multiphase project (PCDP) sponsored by the Idaho Operations Office of the US Department of Energy (DOE-ID). The Preliminary Design is based on a Conceptual Design developed by SGN and supported in part by proprietary work conducted by SGN in France, including fabrication and testing of key equipment components. The GE/SGN/LSI equipment system is described in detail in this report.

The following Preliminary Design Report (PDR) for Spent Nuclear Fuel Rod Consolidation (PCDP) has been prepared by GE/SGN/LSI in partial fulfillment of the PCDP Phase 1 work scope requirements and is complemented by the Life Cycle Cost Estimate Report. The PDR is made up of four major section of text and five appendices. The four major sections describe the design bases, the process and equipment, systems operation and system performance evaluation. The appendices document associated design trade studies and equipment tests and operating experience, contain all Phase 1 flow diagrams and drawings, equipment data sheets, and reliability/availability analyses.

In the following section, the PCDP Phase I scope and application, objectives, functional and operational requirement and safety and QA restraints are described and together constitute the design bases.

1.1 PROJECT SCOPE AND APPLICATION

The purpose of the Prototypical Consolidation Demonstration Project (PCDP) is to develop and demonstrate the equipment system that will be used to consolidate the bulk of the spent nuclear fuel generated in the United States prior to its placement in a geological repository. The equipment must thus be capable of operating on a routine production basis over a long period of time with stringent requirements for safety, reliability, productivity and cost-effectiveness.

Four phases are planned for the PCDP. Phase I is the Preliminary Design of generic consolidation equipment that could be installed at a Monitored Retrievable Storage (MRS) facility or in the Receiving & Handling Facility at a geologic repository site. Phase II will be the Final Design and preparation of procurement packages for the equipment in a configuration capable of being installed and tested in a special enclosure within the TAN Hot Shop at DOE's Idaho National Engineering Laboratory. In Phase III the equipment will be fabricated and then tested with mock fuel elements in a contractor's facility. Finally, in Phase IV the equipment will be moved to the TAN facility for demonstration operation with irradiated spent fuel elements.

As part of the work scope in each phase of the PCDP is the requirement to prepare an estimate of the Life Cycle Cost for the Spent Nuclear Fuel Rod Consolidation Equipment. Part of the PCDP Phase I work scope is the requirement to prepare this Preliminary Design Report.

1.2 PRELIMINARY DESIGN OBJECTIVES

The objectives for the preliminary design are as follows:

a. The concept shall be developed in terms of drawings, descriptions, design analysis, specifications, tests and experience to an extent that verifies the feasibility of the process and the equipment design.

b. The design and the descriptions of off-normal events and recovery methods and equipment shall be adequate to verify the off-normal process and equipment design.

c. System design and performance evaluations shall be adequate to assure that DOE requirements are met with 75% confidence level.

d. The design and descriptions shall provide adequate detail and material call out for a 75% probability cost estimate.

The approach to meeting these objectives has been to divide the effort into the areas of concept development, system performance evaluation and design confidence evaluation. The design is described in Section 2, system operation in Section 3 and performance evaluations and confidence evaluations in Section 4 of this report but it should be noted that the work was completed in an iterative manner with considerable interaction among the participants. The approach to concept development has been to combine parts, materials, and processes with known histories in similar systems with new parts, materials and processes where required to meet unique DOE requirements. The approach to performance evaluation has been to constrain the design with performance requirements, to conduct performance tests on new designs, to conduct performance evaluations on the system design and to conduct a formal design review. The approach to confidence evaluation has been to build the confidence throughout the work by taking care to establish a strong requirements base, designing, analyzing and testing to meet that base and evaluating the finished product against the base.

1.3 FUNCTIONAL AND OPERATIONAL REQUIREMENTS

This section includes the DOE specifications and functional requirements, the GE/SGN/LSI requirements baseline and the safety and quality assurance constraints.

1.3.1 DOE Requirements

The following applicable documents; functional and operating requirements and TAN specific requirements were provided by DOE.

Applicable Documents

The consolidation equipment design shall comply with the appropriate requirements of the latest edition of the codes, standards, and specifications and guides listed herein.

Federal Regulations

Although the rod consolidation demonstration contemplated by DOE does not require Nuclear Regulatory Commission (NRC) licensing in order to conduct the demonstration, it is the goal of this project to develop a fully licensable rod consolidation equipment process design. The consolidation facility must be licensable by the NRC under the appropriate parts of Title 10, Code of Federal Regulations (10CFR). Principal among these is Part 72 which deals specifically with the storage of spent nuclear fuel and other radioactive materials in facilities independent of reactors. The parts of 10CFR applicable to the design, construction, and operation of an MRS Facility are:

a. 10CFR20, Standards for Protection Against Radiation

b. 10CFR21, Reporting of Defects and Noncompliance

c. 10CFR50, Appendix B (Quality Assurance) and Appendix E (Emergency Planning)

d. 10CFR51, Licensing and Regulatory Policy and Procedures for Environmental Protection

e. 10CFR60, Disposal of High Level Radioactive Waste in Geologic Repositories

f. 10CFR71, Packaging of Radioactive Materials for Transport

g. 10CFR72, Licensing Requirements for the Storage of Spent Fuel in an Independent Spent Fuel Storage Installation

h. 10CFR73, Physical Protection of Plants and Materials

i. 40CFR191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes

Regulatory Guides

The following Regulatory Guides shall be used as applicable in the design:

a. 1.25, Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors

b. 3.48, Standard Format and Content for the Safety Analysis Report for an Independent Spent Fuel Installation (Dry Storage)

c. 8.8, Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations will be as Low as is Reasonably Achievable (ALARA)

d. 8.10, Operating Philosophy for Maintaining Occupational Radiation Exposures as Low as is Reasonably Achievable

DOE Orders

The applicable portions of the following DOE Orders shall be applied to the design of this facility; copies of these DOE orders will be avail able at the preproposal conference.

a. DOE 5480.1A, Environmental Protection, Safety, and Health Protection Program for DOE Operations

b. DOE 5630.2, Control and Accountability of Nuclear Materials, Basic Principles

c. DOE 5632.2, Physical Protection of Special Nuclear Materials

d. DOE 5700.6, Quality Assurance

e. DOE 6430.1, General Design Criteria

Codes

a. AEC-ERDA RDT Standards for F8-6T--Hoisting and Rigging of Critical Components and Related Equipment

b. American National Standards Institute (ANSI)

c. ANSI C2--National Institute of Electrical and Electronic Engineers (IEEE), Motor Control Centers and Transformers

d. ANSI N13.1--Sampling Airborne Radioactive Materials in Nuclear Facilities

e. ANSI N13.3--Dosimetry for Criticality Accidents

f. ANSI N16.1--Safety Standards for Operations with Fissionable Material Outside Reactors

g. ANSI/NFPA No. 70--National Electrical Code (NEC)

h. ANSI/ASME NQA-1--Quality Assurance Requirements for Nuclear Facilities, with all revisions.

i. American Society of Mechanical Engineers (ASME)--Boiler and Pressure Vessel Code, Sections III and VIII

j. National Electrical Manufacturer's Association (NEMA) Standards

k. Occupational Safety and Health Administration (OSHA) Standards

l. Uniform Building Code (UBC)

m. Uniform Plumbing Code (UPC)

Specifications

a. American Petroleum Institute (API) "Recommended Rules for Design and Construction for Large Welded Low-Pressure Storage Tanks"--API 620

b. American Society for Testing Materials (ASTM)

c. American Welding Society (AWS)

d. Crane Manufacturers Association of American (CMAA), Spec. No. 70

e. Illuminating Engineering Society (IES) "The Standard Lighting Guide"

Functional and operational requirements (F&ORs)

The following are the Functional and Operational Requirements provided by DOE.

General Functional Requirements

FOR 1. The system shall consolidate 750 metric tons of heavy metal (MTHM) per year of spent nuclear fuel. This throughput rate is based on an availability of 75% for operation two shifts/day and five days/week over a 30-year lifetime. As a basis of design, 60% of the spent fuel, on a metric ton heavy metal basis, 60% will be PWR, and 40% will be BWR.

FOR 2. The system shall package all rods from two PWR fuel assemblies or from four BWR bundles in one canister. The system shall be capable of consolidating most configurations of PWR and BWR fuel used in the United States LWR industry.

FOR 3. The system shall be capable of being modified to utilize canisters of one of the following cross sections: square, round, triangular, hexagonal or trapezoidal.

FOR 4. The system shall operate on a continuous basis.

FOR 5. The system shall operate remotely during normal and off-normal operations. The system shall be semi-automatic or fully automatic.

FOR 6. The system shall provide for remote monitoring of operations from the consolidation process equipment control panels. Monitoring shall include audio monitoring of the equipment operation and monitoring of the system operation by instrumentation and alarm.

FOR 7. The system shall minimize the generation of radioactive crud, fines, and cuttings, as well as the potential for breaching fuel cladding.

FOR 8. The system shall provide for collection/control of such radioactive crud, fines, cuttings, and fuel pellets and/or dust as may be generated.

FOR 9. The system shall provide for remote tooling changes, remote maintenance, remote component replacement, and remote decontamination of all consolidation and supporting equipment.

FOR 10. The system shall permit and facilitate accountability for all special nuclear material during the rod consolidation process. Accountability shall be provided for intact fuel rods, broken fuel rods, and fuel pellets.

FOR 11. For criticality control the system shall maintain K_{eff} less than 0.95 for all normal and off-normal conditions.

FOR 12. The system shall minimize the potential for the pyrophoric ignition of zirconium or any other material(s) capable of pyrophoric ignition.

FOR 13. The system shall minimize the occurrence of and demonstrate the ability to recover from off-normal events occurring in the consolidation of spent fuel rods. Such events, which shall be identified by the contractor, should include: handling and packaging of a fuel assembly that has been partially disassembled when inspection criteria dictate that the specific fuel assembly cannot continue to be consolidated; rod rupture; rod sticking during disassembly; recovery of dropped fuel pellets; recovery of fissile material in the form of fines as the result of fuel rod rupture; fire; equipment breakdown and repair; loss of electrical power or other utilities and loss of ventilation.

FOR 14. The system shall meet the requirements of quality assurance standards established in ASME/ANSI-NQA-1 (1986) with all revisions.

FOR 15. The system shall include all equipment for the handling of materials, components and containers.

FOR 16. The system shall minimize the external contamination of the consolidated canisters during all operations involved in the rod consolidation.

FOR 17. The system shall be capable of being installed in the enclosure described in Section J, Attachment 1 (of the Request for Proposal).

<u>TAN Specific Requirements</u>

DOE has also provided TAN-Specific Requirements which are to be used as a general guide during the Phase 1 generic design effort. DOE has stated that Phase 1 emphasis should be placed on meeting the Generic, rather than the TAN Specific Requirements.

Tan-Specific Functional Requirements

TAN 1. The system shall package all rods from two 15 x 15 PWR fuel assemblies or from four 8 x 8 BWR fuel bundles in one canister.

TAN 2. The system shall include a means to place the consolidated rods into square canisters with inside dimensions of 8.5 inches by 8.5 inches by 15 feet in length.

TAN 3. The system shall provide for closure of the loaded consolidation canisters. The closure system shall provide a closure capable of maintaining the fuel rods within the canister and, if the closure involves the canister lid, the closure shall be of sufficient strength to support the weight of the loaded canister. If welding is used for closure of the loaded canister then the system shall provide for non-destructive examination (NDE) of the seal weld(s) for the loaded consolidation canister.

TAN 4. The system shall operate on a batch basis for the Hot Demonstration.

TAN 5. Due to the limited availability of shielded windows for the Hot Demonstration, the system shall provide for remote operation utilizing CCTV for viewing.

TAN 6. The design shall include a decontamination system which shall decontaminate the exterior surface of the consolidated fuel and canisters and NFBC containers to 2200 dpm/100 cm^2 beta gamma and less than or equal to 200 dpm/100 cm^2 alpha.

TAN 7. The system shall provide for placing the intact fuel assembly skeleton (after fuel rod removal) into a container. The skeleton may or may not have the lower end fitting attached. The container and lid will be provided by DOE and will be approximately 20 inches wide by 20 inches high by 15 feet long. The container will be subdivided into four 10 inch by 10 inch compartments to accommodate four fuel assembly skeletons.

TAN 8. For the Hot Demonstration, the system shall provide the following:

(1) A storage rack for the storage of unconsolidated spent fuel.

(2) Storage capacity for empty and loaded consolidated fuel rod canisters. This storage area shall maintain a "clean" environment for the empty and loaded fuel rod canisters.

(3) Storage capacity for empty and loaded NFBC drums. This storage area shall maintain a "clean" environment for the empty and loaded NFBC drums.

(4) All required instrumentation, controls, alarms and panels necessary for operation, observation, and data collection.

System Architecture

DOE also has provided the following system description:

Contractor Functions (Phase 1 Design)

Consolidate nuclear fuel rods

System Level Design
Transfer Equipment
End Fitting Removal Station
Rod Removal and Transition Equipment
Rod Packaging Station
NFBC Handling Equipment
Storage, Decon. and Waste Support

DOE Interfaces (Phase 1)

Generic Facility

Fuel supply
Canister supply
Canister removal

1.3.2 Requirements Analysis

Requirements analysis was performed to identify the requirements for Phase 1 which would lead to an appropriate preliminary design. The objective was to develop a uniform and comprehensive understanding of DOE requirements by all participating personnel; i.e. the managers, the designers and the performance evaluators. A peer group of experts was assembled and chartered with reviewing, interpreting and allocating the DOE requirements (F&ORs) from each of seven functional viewpoints as appropriate for the preliminary design. These viewpoints are:

- Design
- Operation and Maintenance
- Safety and Licensing
- Quality Assurance
- Availability and Reliability
- Producibility

Each viewpoint reviewed each DOE F&OR from the perspective of meeting specific end objectives, e.g., the design end objective is the preliminary generic equipment design whereas the safety and licensing objective is the supporting analyses and documentation required to license the preliminary equipment design. Yet another example is the reliability objective which is an iterative analysis closely tuned to the design and based on an analytical model and supporting data which verifies throughput expectations.

Functional Analysis

Functional analysis was completed to assure a complete translation of DOE's Functional and Operational Requirements (F&ORs) into Preliminary Design Requirements. The first step was to identify the generic set of actions required to reach DOE's end objectives. These were defined in functional terms by the experts. The PCDP Phase 1 generic functions were identified as follows:

PCDP Generic Functions

- Design equipment
- License equipment design*
- Fabricate and install equipment
- Operate equipment
- Maintain equipment
- Determine equipment capability
- Determine equipment cost

The next step was to identify the activities required to accomplish each generic function consistent with the end objectives.

Design equipment

- Handle process inputs, outputs, and equipment
- Remove PWR top nozzles
- Remove BWR nozzles
- Remove rods
- Package rods
- Close canister
- Handle NFBC
- Store bundles and canisters
- Treat wastes

*License and licensable were defined as interchangeable for purposes of this functional analysis.

- Control system operation
- Maintain equipment
- Handle tooling
- Decontaminate canisters and equipment
- Define facility requirements

Fabricate Equipment

- Establish U.S. compatibility
- Identify critical components
- Identify materials, size and shapes
- Establish tolerance magnitudes
- Identify quantities and QA requirements

License Equipment Design

- Meet codes and regulations
- Prevent radioactive releases
- Contain radioactive releases
- Account SNM
- Shield radiation

Operate Equipment

- Provide continuous operation capability
- Provide automatic controls with manual override
- Minimize manpower requirements
- Anticipate abnormal events
- Engineer clean-up systems

Maintain Equipment

- Provide independent maintenance capability
- Provide mock-up capability
- Provide equipment diagnostic feedback
- Reduce manpower requirements

- Modularize components
- Minimize contact maintenance
- Provide cell access for replacement parts
- Provide engineered cleaning system(s)

Determine Equipment Capability

- Establish bundle acceptance criteria
- Model process parameters and material flows
- Evaluate equipment reliability data
- Identify spare parts and support services
- identify off-normal events
- Detect off-normal events
- Provide visual and audio diagnostics capability
- Prepare recovery plans
- Identify staff requirements
- Iterate reliability analysis

Requirements Allocation

The experts for each functional viewpoint identified the attributes which measure completion of the function then converted each attribute to a requirement by defining a required level of successful performance in as quantitative terms as possible. Care was taken to assure that the lower level functions bounded the upper level function and that the resulting requirements bounded the lower level functions. In this manner, the expert viewpoints establish the requirements which provide uniform guidance for the designers and the design evaluation team. The resulting requirements were applied by the designers and by the reviewers during the final design review to verify the completeness of the design. This check and balance between the designers and the performance evaluators makes an important contribution to the overall confidence in meeting DOE's requirements. The give and take which ensued between the designers and the expert viewpoints and among the various viewpoints represents an informal set of trade studies which occurred spontaneously through using this approach.

Phase 1 Requirements Baseline

The following is the GE/SGN/LIS PCDP-Phase 1 Requirements Baseline which resulted from the process described above. Each requirement is traceable to the F&OR from which it was derived or the F&OR is simply included if further derivation or allocation was unnecessary for Phase 1.

Design

FOR-1 a. The system shall be capable of consolidating spent nuclear fuel at a rate of 750 metric tons of heavy metal (MTHM) per year during the normal operation schedule.

FOR-1 b. The equipment design lifetime shall be 30 years including appropriate features for replacing expendable components.

FOR-1 c. The normal operating schedule shall be two shifts/day and five days/week.

FOR-1 d. Lag storage shall be integral to the process and located as necessary to meet Requirement 1 and to provide for operation of portions of the process during recovery from equipment malfunction.

FOR-1 e. Continuous normal flow through the process shall exclude back-tracking operations.

FOR-1 f. Properly trained, tested and monitored operators shall perform remote maintenance operations.

FOR-1 g. Identification of spare parts and an indication of their need (frequency, quantity) shall be a design consideration producing a recommended spare parts list and a running 12-month inventory.

FOR-1 h. The design shall identify criteria for selecting incoming fuel bundles as regards cooling time, exposure, enrichment, post irradiation characteristics, mechanical design and reactor operating history.

FOR-1 i. Bundles of similar characteristics shall be supplied in batches using the criteria for sound/failed, mechanical design, enrichment, exposure, fuel weight, and thermal condition.

FOR-2 a. The system shall package all rods from two PWR fuel assemblies or from four BWR bundles in one canister.

FOR-2 b. The system shall be capable of consolidating most configurations of PWR and BWR fuel used in the United States LWR industry.

FOR-3 a. The system shall be capable of being modified to utilize canisters of one of the following cross sections: square, round, triangular, hexagonal or trapezoidal.

FOR-4 a. Operation shall be on a continuous basis during the normal operating schedule with provision for startup, shutdown, and off-normal operation.

FOR-5 a. The system shall operate remotely during normal operation and off-normal operation.

FOR-5 b. The system shall be semi-automatic or fully automatic.

FOR-5 c. The man-machine interface shall include a sequence control panel requiring minimal human interaction during normal operation.

FOR-5 d. The man-machine interface shall include meaningful interlocks with provision for manual override under administrative control for off-normal conditions.

FOR-5 e. System performance capability shall permit a minimum size operating staff with defined skill and training requirements.

FOR-6 a. The system shall provide for remote monitoring of operations from the consolidation process equipment control panels.

FOR-6 b. Monitoring shall include audio monitoring of the equipment operation and monitoring of the system operation by instrumentation and alarms backed up by visual feedback capability.

FOR-6 c. A diagnostic program shall be available for system functional checkout.

FOR-7 a. The system shall have provisions to remove loose crud deposited on individual fuel rods at the time the rods are being extracted from the bundle structure.

FOR-7 b. The system shall minimize the generation of radioactive cruds, fines, and cuttings as well as the potential for breaching fuel cladding.

FOR-7 c. Crud removal capability using integral crud collection systems shall permit immediate crud collection where appropriate.

FOR-8 a. The system shall provide for collection/control of such radioactive cruds, fines, cuttings and fuel pellets and/or dust as may be generated.

FOR-9 a. The system shall provide for remote tooling changes, remote maintenance, remote component replacement, and select in-cell storage capability for all in-cell equipment.

FOR-9 b. All equipment with in-cell life expectancy (mean time between failure) and repair times >TBD which could impact the average availability over the plant lifetime greater than TBD% shall be modularized for remote replacement to ensure the desired throughput.

FOR-9 c. Modularized components shall have features for in-cell identification, and ease of replacement, ease of handling, transport and storage.

FOR-9 d. Contact maintenance requirements shall be minimized through provision of simple, accessible and standard design features.

FOR-9 e. The design shall specify the requirements for an independent maintenance station including work space, viewing facilities, manipulation features, decontamination tool storage and tool inventory and provisions for disposal of contaminated tools and equipment.

FOR-9 f. The design shall specify the service requirements for maintenance of the crane and modules removed from the cell.

FOR-9 g. The in-cell crane(s) shall be specified as part of the preliminary design.

FOR-10 a. The system shall permit and facilitate accountability for all special nuclear material during the rod consolidation process. Accountability shall be provided for intact fuel rods, broken fuel rods, and fuel pellets using item control as bundles or fractions thereof.

FOR-10 b. All solid fuel bearing material shall exit the cell within fuel rod canisters under item control including rods, pellets and powder materials.

FOR-10 c. All liquid waste systems shall possess the capability to representatively sample SNM as input to the facility MBA accountability system.

FOR-10 d. Fuel inventory control (location, identification, quantity) shall be an integral part of the design of all lag storage features.

FOR-11 a. The system shall maintain criticality control by maintaining k_{eff} less than 0.95 for all normal and off-normal conditions assuming optimum moderation and peak bundle average enrichments.

FOR-12 a. The system shall minimize the potential for the pyrophoric ignition of zirconium or any other material(s) capable of pyrophoric ignition.

FOR-12 b. Process methods and operations shall minimize the formation and accumulation of zirconium metal fines.

FOR-12 c. The design shall include features to collect, package and dispose of metal fines in a safe manner.

FOR-13 a. Fuel handling processes shall include safety devices to prevent bundle and rod drops and other impacting incidences.

FOR-13 b. The system shall minimize the occurrence of and demonstrate the ability to recover from off-normal events occurring in the consolidation of spent fuel rods. Such events, which shall be identified by the contractor, should include: handling and packaging of a fuel assembly that has been partially disassembled when inspection criteria dictate that the specific fuel assembly cannot continue to be consolidated; rod rupture; rod sticking during disassembly; recovery of dropped fuel pellets; recovery of fissile material in the form of fines as the result of fuel rod rupture; fire; equipment breakdown and repair; loss of electrical power or other utilities and loss of ventilation.

FOR-13 c. The design shall provide built-in features for recovery from predicted off-normal events.

FOR-13 d. Expected off-normal events shall be listed and a recovery plan included with the preliminary design featuring remote tool requirements, and built-in features to collect and package extraneous pieces of hardware and fuel.

FOR-14 a. The system shall meet the requirements of quality assurance standards established in ASME/ANSI-NQA-1 (1986) with all revisions.

FOR-14 b. Preliminary design drawings and parts lists shall use English units/tolerances and shall identify material types, general part shapes and sizes.

FOR-14 c. Preliminary design drawings and parts lists shall identify components critical to performance and those parts which will require unusual tolerance and inspection levels in final design and fabrication.

FOR-15 The system shall include all equipment for the handling of materials, components containers, and tooling.

FOR-16 The system shall minimize the external contamination of the consolidated canisters during all operations involved in the rod consolidation.

FOR-17 a. The system shall be capable of being arranged so that the essential features can be fit into an envelope defined by the TAN Facility enclosure.

FOR-17 b. The generic design shall provide minimal NFBC size reduction prior to packaging for removal from the rod consolidation cell. Final size reduction shall be completed in an independent facility.

Facility Interface

a. The design shall specify the following process cell requirements:

- cell floor space
- cell shield walls
- cell windows/manipulators

- cell penetrations/access/egress
- cell lighting
- cell cranes
- cell and equipment decontamination system(s)

b. The design shall specify the following support service requirements:

- utilities
- ALARA program
- heating and ventilation
- analytical
- waste disposal
- fire protection
- emergency power

TAN-Specific Requirements

The TAN-Specific Requirements were reviewed and no further development of these requirements was necessary for this phase of the work.

1.3.3 Evaluation Bases

A systematic design evaluation was conducted for each step of the design process. The design process adapted the SGN concept to the DOE Functional and Operational Requirements then evolved the DOE concept through system requirements definition, system trade off studies, system design, and system definition. The design evaluation process integrated performance, cost, and schedule aspects of the design into each design step.

Performance evaluation emphasis in Phase 1 was placed on input/output capability and early and consistent application of operability, maintainability, safety, reliability and producibility constraints to assure system performance.

Input/output capability was evaluated using a process simulation model designed to determine the throughput capability of the system in a 260 day working year at two 8 hour shifts/day. The model includes all key operations and is flexible to allow increasing sophistication as the design detail matures.

The basis for evaluating the operational aspects of the design was to assemble a peer group with over 120 years of applicable experience and apply this group to a, constrain the design with operational requirements, review the design against these requirements, analyze special aspects against prior experience and report results.

Thus, a solid basis for the Preliminary Design was established and a methodology executed which provided a high level of confidence that the DOE requirements are met. DOE established that the Phase 1 design should accomplish this verification at the 75 percent confidence level. The GE/SGN/LSI approach to evaluating the total Phase 1 effort for meeting the DOE requirements was to build the confidence using credit for the quality and completeness of the work in the areas of:

	Credit Range
Requirements definition	7-10%
Performance evaluation	10-15%
Test data and reports	0-15%
Design analysis, trade studies and drawings	15-25%
Design reviews	20-35%

The credit range was established using judgement. The results of the confidence evaluation are given in Section 4.

1.4 SAFETY AND QUALITY ASSURANCE

Safety and quality assurance were treated as important considerations and were given the same considerations as system performance. Representatives of the safety and licensing viewpoint and of the QA viewpoint participated as members of the peer group which developed the requirements baseline and which evaluated the design and contributed to the design reviews.

The Rod Consolidation Quality Assurance Program Plan is documented and has been issued as a controlled and approved document. The requirements of ASME/ANSI NQA-1 have been addressed and the implementing General Electric Policies and Procedures have been identified.

The implementation of the quality requirements have been accomplished during Phase I of the Prototype Spent Nuclear Fuel Rod Consolidation Equipment Project by the following activities:

1. Pass through to all subcontractors of the ASME/ANSI NQA-1 requirements.

2. Review of the subcontractor system descriptions of how the requirements were implemented.

3. Performance of formal audits of internal project activities.

4. Establishment of records requirements and implementation of requirements.

5. Surveillance of supplier activities.

6. Review of design activities by formal Design Review including both independent and peer review. Documented review results.

2. PROCESS AND EQUIPMENT DESCRIPTION

The purpose of this section is to describe the process system and the equipment necessary to perform fuel rod consolidation operations. The process system and the equipment will be described for the generic facility.

The first subsection (subsection 2.1) describes the process system, and consequently it is a description of functions from the beginning of the process to the end. The subsection ends with considerations on in-cell support systems necessary to perform the operations and on process safety and licensability.

After the description of the functions, subsection 2.2 will describe the equipment necessary to perform the corresponding operations. The description will follow the same order as subsection 2.1, and will also end with considerations on in-cell support systems, and on equipment safety and licensability.

The topic of subsection 2.3 is facility support requirements. Information and requirements will be given on the process cell system, on cell support systems and on facility safety and licenseability.

At the end of the section (subsection 2.4), a paragraph will describe the differences between equipment for the generic facility and for the TAN facility, and will explain the reasons for these differences and why they do not affect the validity of the operation and equipment tests.

2.1 PROCESS SYSTEM DESCRIPTION

The process system is described in terms of a functional flow diagram and material balances for both PWR and BWR fuel elements, unit process descriptions, support requirements and safety and licenseability.

2.1.1 Functional Flow Diagram

The functional flow of normal and off-normal, PWR and BWR elements through the rod consolidation process is given on Drawing SH-1886-20-001. This drawing illustrates the functional flow of separate PWR and BWR elements through end fitting removal, common flow through rod removal, and separate reconfiguration for hexagonal or circular canisters and all other canister shapes.

A material balance is provided for the generic facility in Figure 2-1. This figure illustrates the throughput of BWR (top portion) and PWR (lower portion) elements which are equivalent to 750 metric tons of heavy metal (MTHM) per year of spent nuclear fuel. The throughput is based on 75 per cent availability, operation two shifts per day and five days per week, and a 60%/40% split of PWR/BWR (heavy metal basis). The production rate given is equivalent to 14 PWR or 14 BWR elements per day.

System Functions and Sequence

The whole sequence for the mechanical process includes three main phases:

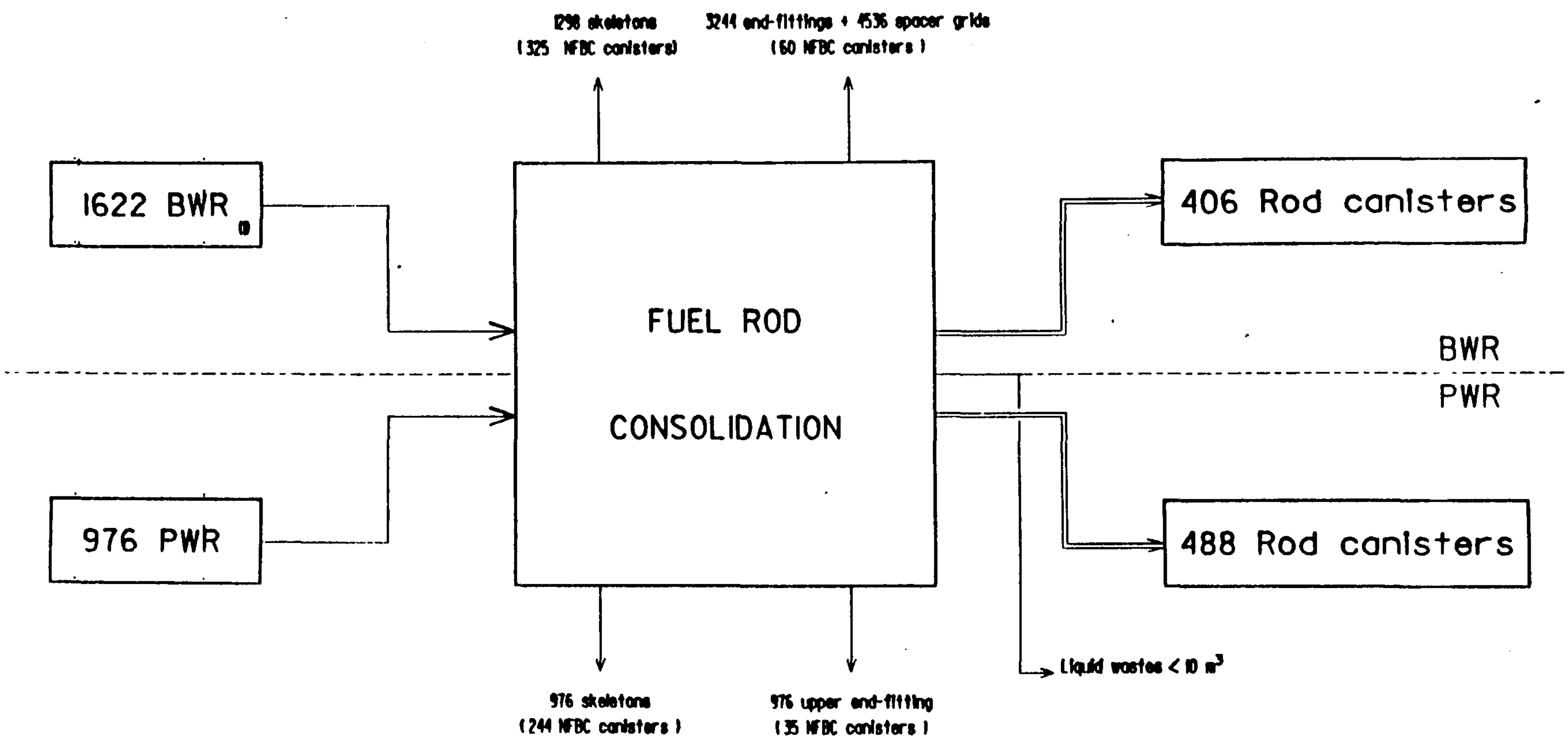
- end fitting removal
- fuel rod removal
- fuel rod packaging

End-Fitting Removal

The first step in the end-fitting removal operation is transfer of a fuel element by the in-cell crane from lag storage to a vertically positioned tilting device that has been configured for the specific type of fuel to be consolidated. Once clamped to the fuel tilting device, the element can be rotated for drilling out the central instrument tube plug in PWR elements and for positioning on a transfer table for end-fitting removal.

Figure 2-1 Material Balance

MATERIAL BALANCE GENERIC APPLICATION



(1)- with the following distribution : 20 % BWR 7 x 7 - 80 % BWR 8 x 8

For PWR fuels, the guide and instrument tubes at the top of the element are cut from the inside out with a multiple blade cutting head and the top-end scrap hardware is removed to a container for non-fuel bearing components (NFBC). The remainder of the PWR element is ready for transfer to the rod removal station.

For BWR fuels, two cutting heads are used simultaneously to cut the tie rods at the upper and lower end-fitting locations and the scrap hardware from both ends is removed to a NFBC container.

Fuel Rod Removal

The first steps in the fuel rod removal operation are lateral movement of the transfer table for positioning in line with the rod gripping head, and enclosure of the partially disassembled fuel such that particulates released from the surface of the fuel are contained. The gripping head contains gripper jaws for each rod in a module that are unique for each type of fuel.

Fuel Rod Packaging

The first step in the fuel rod packaging operation is to arrange the fuel rods from each element into a configuration compatible with the cross section of the consolidated rod storage canister. The horizontal combs are removed from the array of rods and the vertical combs are retained in position so that the rods can be transferred one horizontal row at at time into a carriage that shuttles back and forth between the comb array position and the rod reconfiguration receiver. The geometry of the receiver is configured to complement that of the storage canister. The receiver is loaded with rods one horizontal row at a time until it is filled with the rods from 2 PWR or 4 BWR fuel elements at which point the rods are ready for transfer into the storage canister. The reconfiguration system can accommodate square, round, triangular, hexagonal and trapezoidal canisters. Square, triangular and trapezoidal canisters can be loaded in one operation, while the round and hexagonal configurations require two loadings into a compartmented canister.

The canister loading operation consists of sealing a clean, empty canister against a contamination barrier wall and pushing the rods from the reconfiguration receiver through the wall into the canister. An interim seal is placed over the canister opening.

NFBC Handling

In addition to the main operations described above, there is an auxiliary phase (which does not concern the fuel rods), i.e., handling of the non-fuel bearing components, which occurs twice during the rod consolidation process, once before the rods are pulled from the element and once after. The end-fittings from both the PWR and BWR fuels fall through a chute into an NFBC canister that is connected to floor hatch opening. After loading, the hatch is closed, the NFBC canister lid is replaced, and the canister is removed.

The skeleton from a PWR element or the water rod component from an 8 x 8 BWR bundle remains on the transfer table after the rods are pulled and is returned to the end-fitting removal station. The fuel tilting device is then used to grip the long NFBC skeleton and raises it to the vertical position. The cell crane grapples the NFBC skeleton and lowers it into one of the four compartments in the NFBC canister that is connected to a hatch opening.

When the fuel rods and the capture rod are removed from a 7 x 7 BWR element, the spacer grids remain clamped on the working table. After the clamps are removed, the spacer grids are pushed into an NFBC container through a chute.

Process Flowsheet

The process flowsheet (see drawing SH 1886 20 001) shows the main normal and off-normal operations for the consolidation of either PWR fuel elements or BWR fuel elements, as well as the differences in the processes for the different families of elements, which are the result of differences between fuel elements themselves, namely :

- differences in the design of PWR and BWR elements which affect end-fitting removal
- difference between BWR 7X7 and BWR 8X8 elements (the spacer connector rod is or is not fueled), which affects the fuel rod removal and NFBC recovery.

The case of rods that are broken or released during rod removal operations is also shown as part of off-normal operations. The three main functions described by the process flowsheet, already discussed above, are :

- end-fitting removal
- fuel rod removal
- fuel rod packaging

Material Balance

The purpose of the material balance sheet is to account for materials that enter the generic cell (the fuel elements) and those that exit the cell, i.e. the consolidated rod canisters and the waste generated by rod consolidation operations.

The number of NFBC canisters is calculated on the basis of TAN-specific requirements, which do not call for processing of the NFBC (see details in subsection 2.3.3). However, NFBC packaging could easily be optimized and therefore the number of canisters could easily be reduced by using simple devices in the cell such as shearing devices for fuel element skeletons, or compaction devices.

Generic Facility Layout (see drawing PI 1886 20 001)

The facility is composed of two main cells :

- one rod consolidation cell where all necessary rod consolidation operations as well as fuel element handling operations are performed.

- one canister cell where rod canister contamination monitoring and lid closure are performed. Contrary to the rod consolidation cell, the canister cell is considered not to be contaminated.

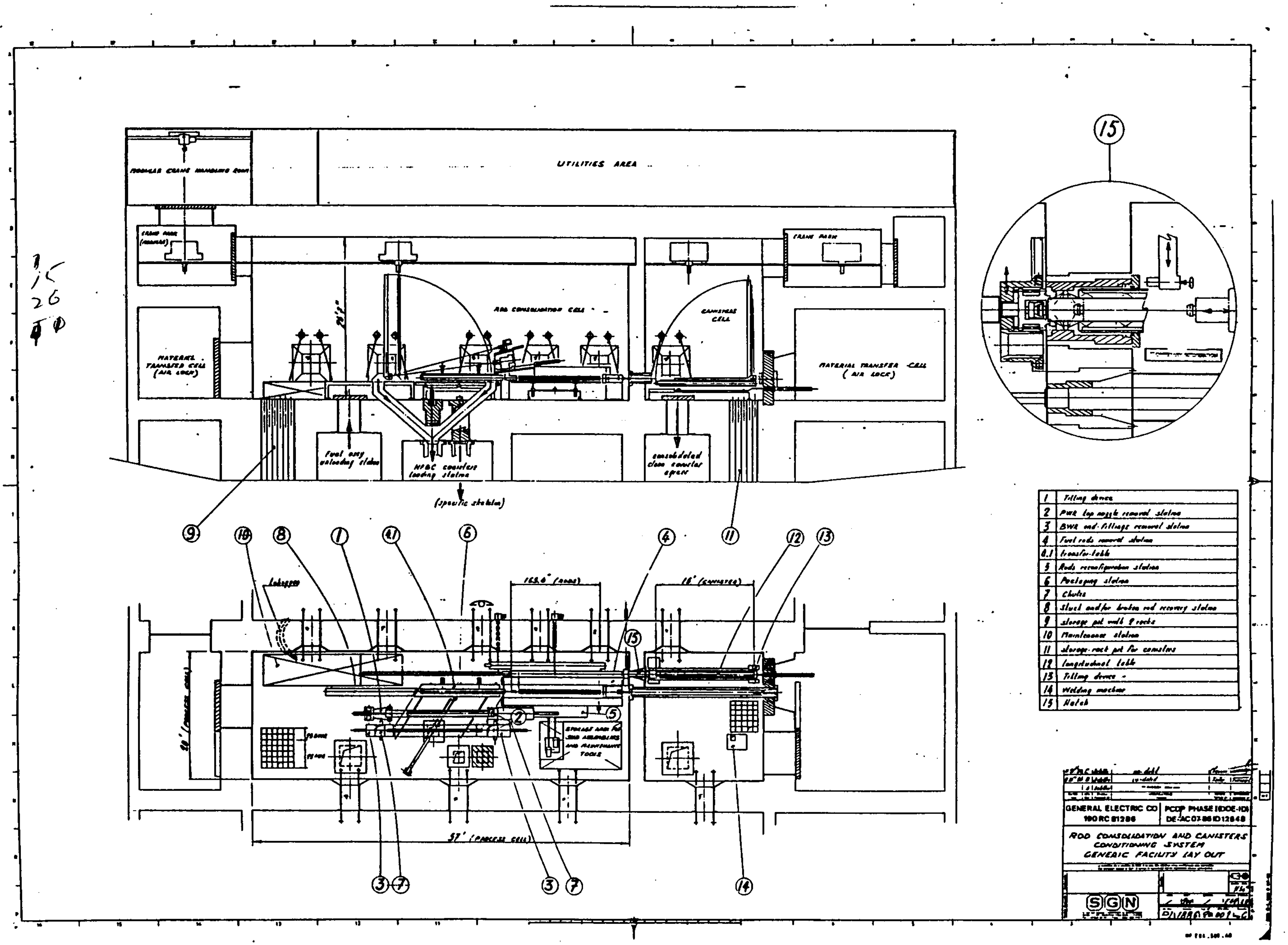
The two cells communicate by a hatch through the separation wall. This hatch is closed by a shield door in the rod consolidation cell to prevent the spread of contamination to the canister cell. In addition, each cell communicates with its own materials transfer cell via an air lock. The materials, such as new modules, new tools, etc, are introduced through these cells.

Beneath the rod consolidation cell, two parallel corridors allow:

- access for fuel elements to be consolidated
- access for NFBC canisters

The fuel element corridor communicates with the rod consolidation cell by a square opening providing for vertical unloading of fuel elements. This opening is closed by a floor hatch operated by the crane.

The NFBC corridor communicates with the rod consolidation cell by two openings : one for the fuel skeleton canisters and the other for canisters for end-fittings, spacer grids and other NFBC. Each opening is closed by a shield-plug. When an NFBC canister is presented, its lid is gripped and pulled into the plug so that it can be protected against contamination. In the same way, the top head of the canister is tightly connected to the lower part of the opening. In this way, the outside surface of the canister is kept clean.



Generic Lay-out PI-1986-20-001

The rod consolidation cell is serviced by a modular handling crane. Its maintenance is performed in a crane park separated from the cell by a shielded door and serviced itself by a small crane which allows crane modules to be changed.

The canister cell communicates with the empty canisters access and the consolidated canisters corridor by a common opening kept closed by a floor-hatch. It is serviced by a handling crane. The crane park room is separated from the canister cell by a shielded door.

Along the length of the rod consolidation and the canister cells, corridors ensure the operators access to the windows and to the local control panels. The upper-level is devoted to the facilities areas.

2.1.2 Fuel Element Handling

Prior to consolidation operations, the fuel element is in a vertical position in a storage rack close to the consolidation equipment. This uses less floor space for lag storage inside the rod consolidation cell. The consolidated rack can accommodate 28 elements, or the equivalent of two day's production.

The fuel element in storage is picked up by a grapple connected to the in-cell overhead crane and transferred to a vertically-positioned tilting device, to which it is clamped. Visual inspection is completed as the element is lifted. The grapple is released and the tilting device with the fuel element is lowered toward a horizontal transfer table. After end-fitting removal, described in paragraph 2.1.3 below, the fuel element is unclamped from the tilting device onto the transfer table. The tilting device returns to the vertical position, and the transfer table with the fuel element moves laterally to the rod removal station described in paragraph 2.1.4. There, the partially disassembled fuel element is enclosed so that particulates released from the surface of the fuel are contained. Following rod removal, the transfer table with the fuel element skeleton returns to the end-fitting removal station. The tilting device is then lowered to the horizontal position, clamped onto the fuel element skeleton, and raised to the vertical position.

At this point the NFBC are removed with grippers attached to the crane grapple and transferred to the NFBC storage canisters, as described in paragraph 2.1.6.

2.1.3 End-Fitting Removal

PWR Fuel Element

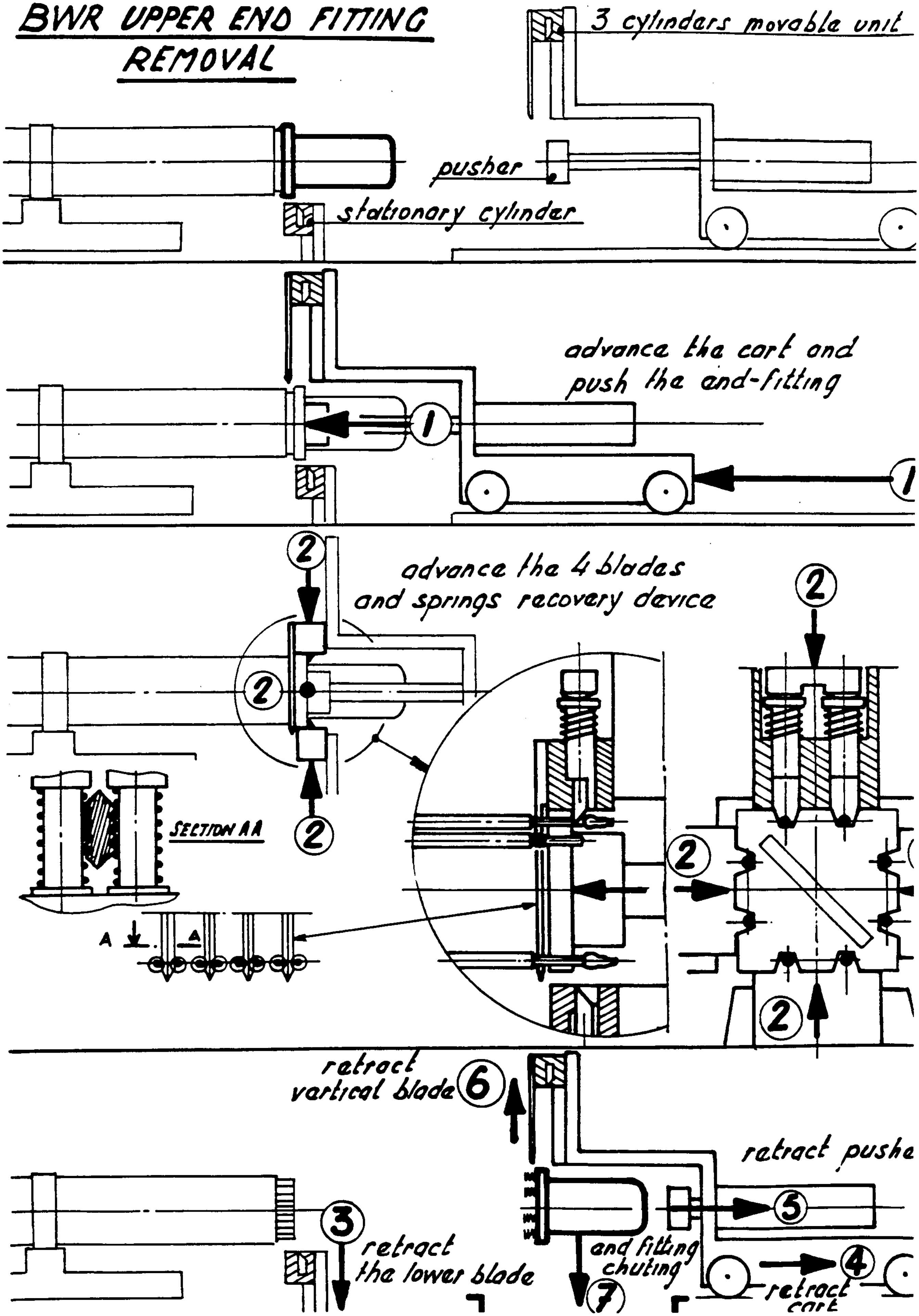
The process consists of separating the upper end-fitting from the fuel element in two consecutive steps, each of which is performed while the fuel element is clamped to the tilting device (refer to Figure 2-2).

- Drilling the instrument tube at the interface with the upper end-fitting base plate, to enable the penetration of the multiple blade cutter.

- Cutting all the guide tubes and instrument tubes simultaneously by inserting a multiple blade cutter far enough to clear the upper spacer grid. In this way the grid remains attached to the upper end-fitting with the portions of cut tubes, and is removed together with the end-fitting. This provides greater access to the fuel rods for the grippers (see trade-off study B, Appendix II). A continuous nitrogen flow rate is supplied while the cutting operation is performed.

The drilling machine and multiple blade cutter are positioned one above the other and the operations are performed in two different sloped positions of the tilting device, close to the horizontal. This approach presents two advantages:

o the cuttings can be preferentially directed into the inside of


BWR UPPER END FITTING REMOVAL
3 cylinders movable unit
pusher
stationary cylinder
advance the cart and push the end-fitting
1
advance the 4 blades and springs recovery device
2
SECTION AA
A
retract vertical blade
6
retract pusher
5
3
retract the lower blade
end fitting chuting
7
4
retract cart

the guide tubes

- o the operations can be conducted in the same reference alignment without having to translate the machines. It must be noted that this equipment layout saves floor space by reducing the distance across the cell.

BWR Fuel Element

By tilting down to a horizontal position, the tilting device can lay the fuel element down on a transfer table. After the tilting device has been moved up to its initial vertical position, the transfer table is moved laterally to the BWR end-fitting removal station. The upper and lower end-fittings are removed separately with the upper end-fitting first, (refer to Figures 2-3 and 2-4).

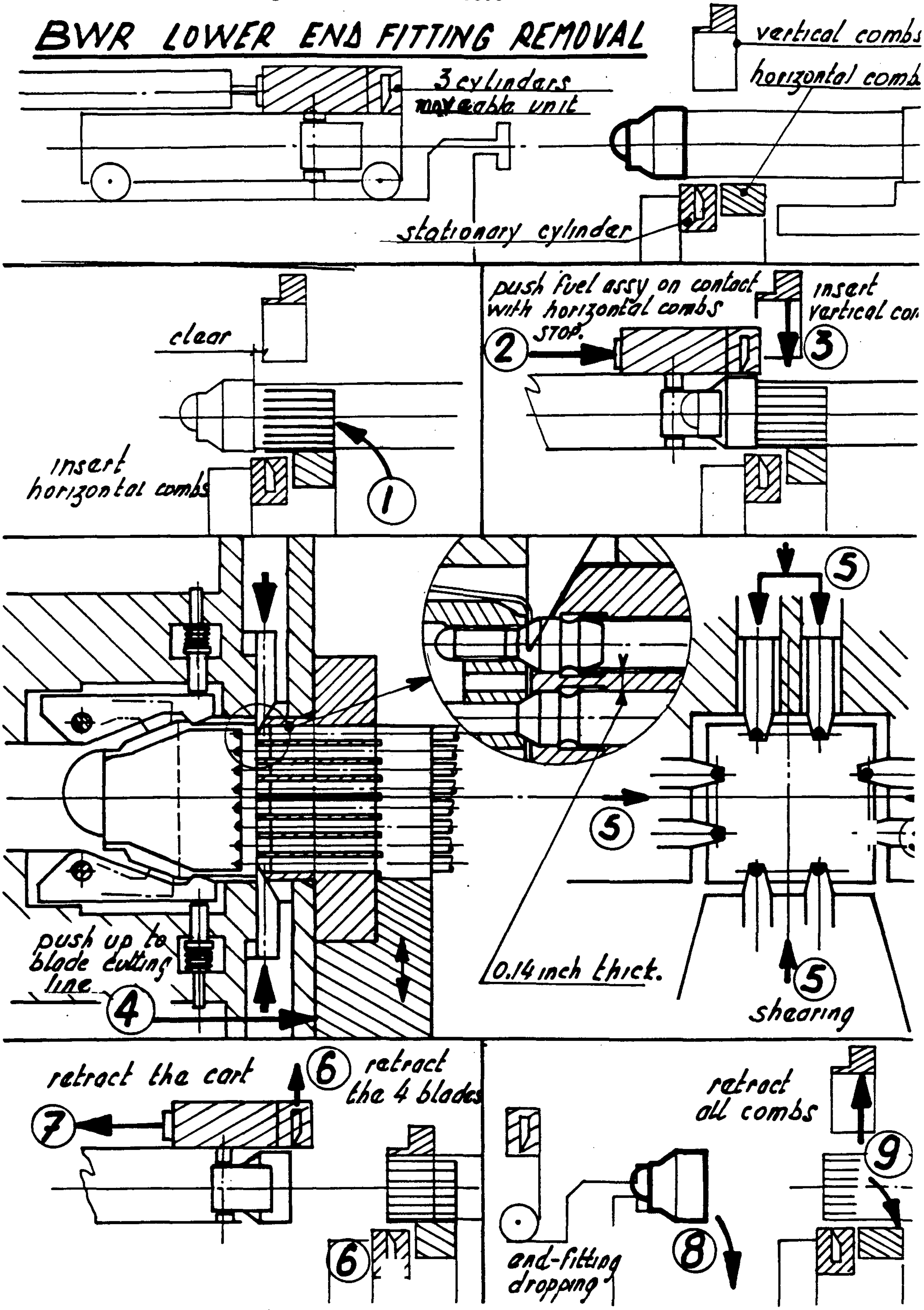
The BWR upper end-fitting is removed by simultaneously shearing the eight tie-rods at the interface with the upper end-fitting after pushing on the end-fitting to provide a clear space between the nuts and the end-fitting. During the shearing operation, the springs are maintained to avoid ejecting them.

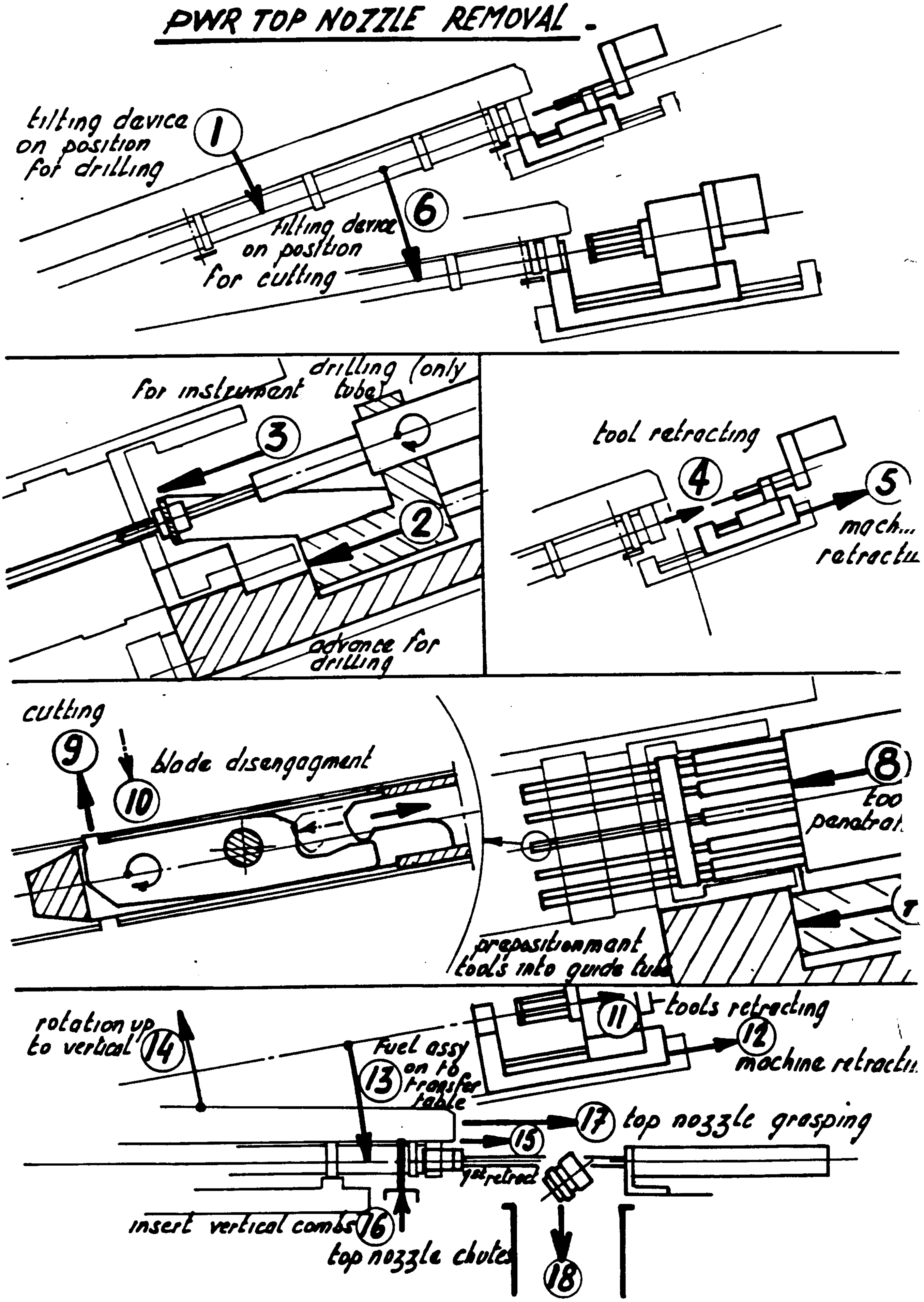
The BWR lower end-fitting is removed by simultaneously shearing the eight tie-rods at the inner face of the lower end-fitting after inserting combs between the rods to avoid any deformations during shearing.

2.1.4 Fuel Rod Removal

After the end-fittings have been removed, the fuel element lays on the transfer table. The table is transferred laterally to the fuel rod removal station and positioned in line with the rod gripping head.

Prior to fuel rod removal, a heavy plate is placed over the fuel element. The plate serves to clamp the fuel element to the table and to contain any particulates released from the fuel inside a channel which is open at each end.


BWR LOWER END FITTING REMOVAL
vertical combs
horizontal combs
3 cylinders
moveable unit
stationary cylinder
clear
insert horizontal combs
1
push fuel assy on contact with horizontal combs
STOP.
2
insert vertical combs
3
5
push up to blade cutting line
4
0.14 inch thick.
5
shearing
retract the cart
7
6
retract the 4 blades
6
retract all combs
9
end-fitting dropping
8


PWR TOP NOZZLE REMOVAL
tilting device on position for drilling
1
6
tilting device on position for cutting
drilling (only for instrument tube)
3
2
advance for drilling
tool retracting
4
5
mach... retractu
cutting
9
10
blade disengagment
8
too penetrat
prepositionmant tool's into guide tube
rotation up to vertical
14
Fuel assy on to transfer table
13
11
tools retracting
12
machine retractu
17
top nozzle grasping
15
insert vertical combs
16
top nozzle chute
18

Fuel rod removal includes the two main operations (see Figure 2-5) of rod pulling and rod counting.

Rod Pulling

Each fuel rod is gripped by means of a gripping jaw that is part of the gripping head and all the fuel rods are pulled simultaneously by retraction of the gripping head. See Figure 2-6.

While the fuel element is clamped to the transfer table, the gripping head is retracted and stops at an intermediate position, where clearance of about 8 inches is provided between the upper end of the fuel element structure and the bottom end of the removed fuel rods, enabling rod counting to be performed.

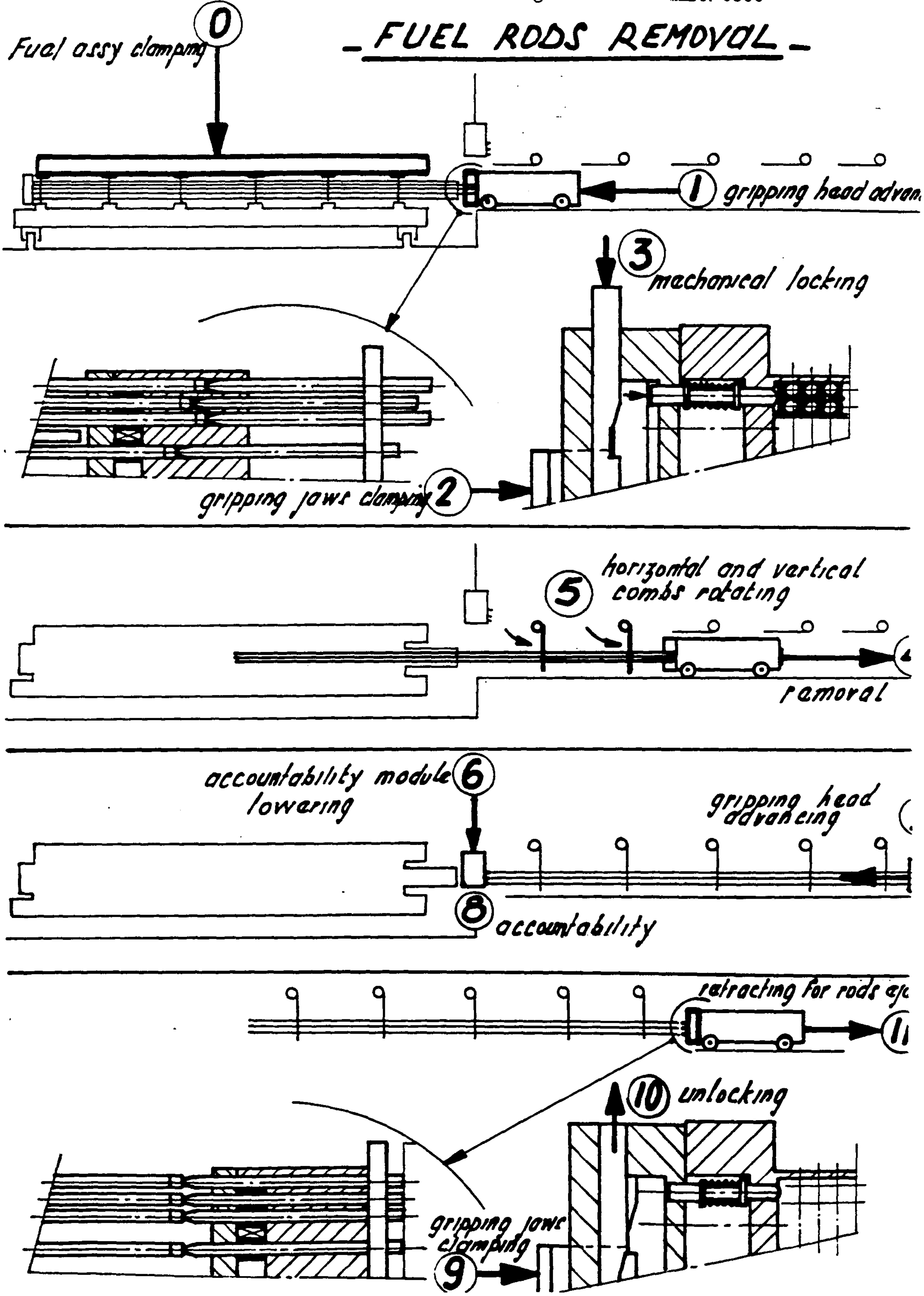
As the gripping head is retracted, vertical and horizontal combs are placed throughout the fuel bundle in order to keep the fuel rods in an array identical to the array they constituted in the fuel element.

Rod Counting

The fuel rod counting system checks that all rods have been removed (no stuck rod), checks that no rod has been broken during removal and counts the rods for accountability. The system is illustrated in Figure 2-7.

The system consists of a module with sensors in quantity and position identical to the quantity and configuration of fuel rods in the fuel element. The sequence of operations is as follows:

- The module is moved down through the 8 inch clearance. Passing through the clear space means that all rods have been removed and transferred from the fuel element structure to the removal station.



FUEL RODS REMOVAL
0
Fuel assy clamping
1
gripping head advan
3
mechanical locking
gripping jaws clamping
2
5
horizontal and vertical
combs rotating
removal
accountability module
lowering
6
gripping head
advancing
8
accountability
retracting for rods ej
10
unlocking
gripping jaws
clamping
9

Figure 2-6

Gripper Head Detail

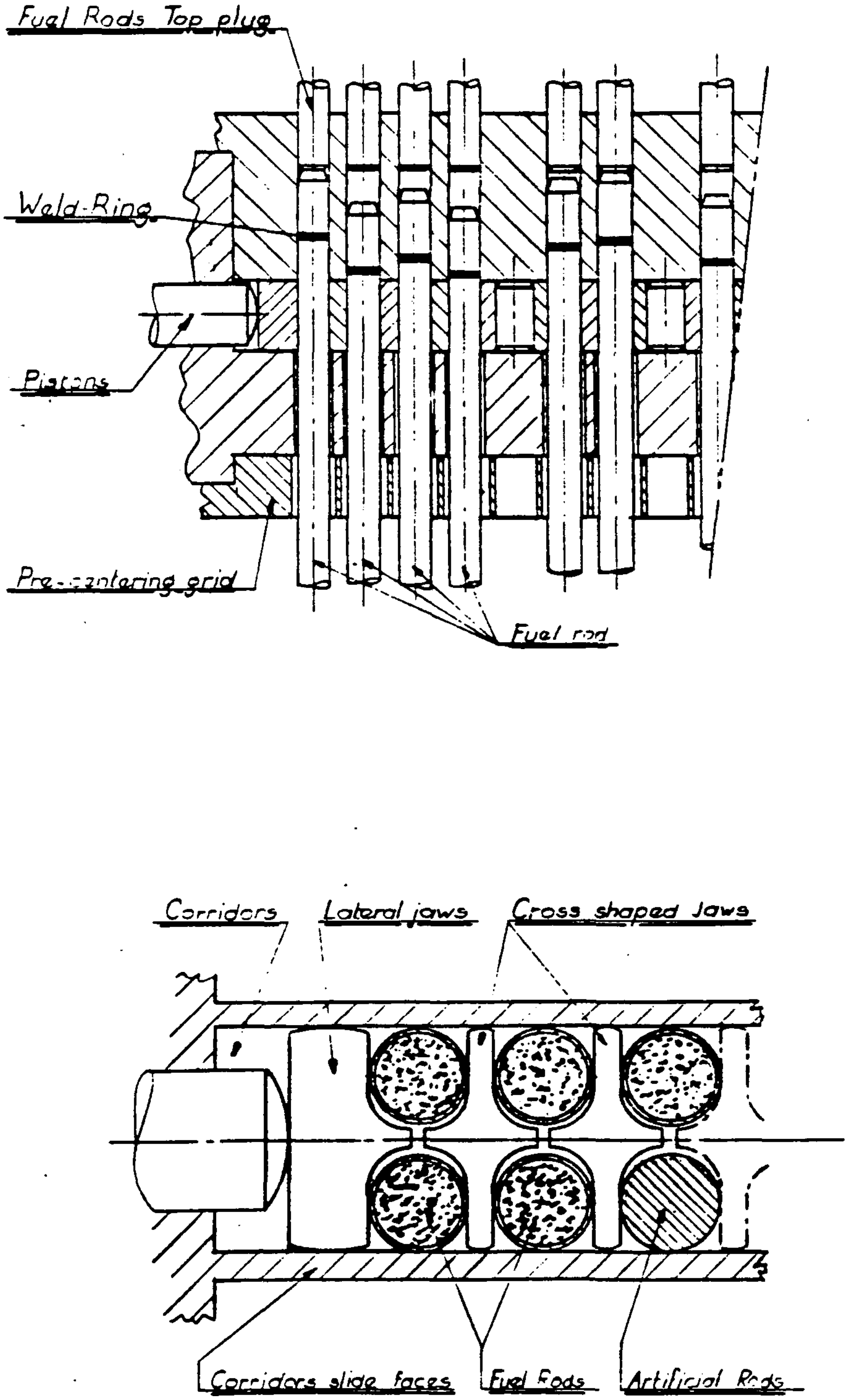
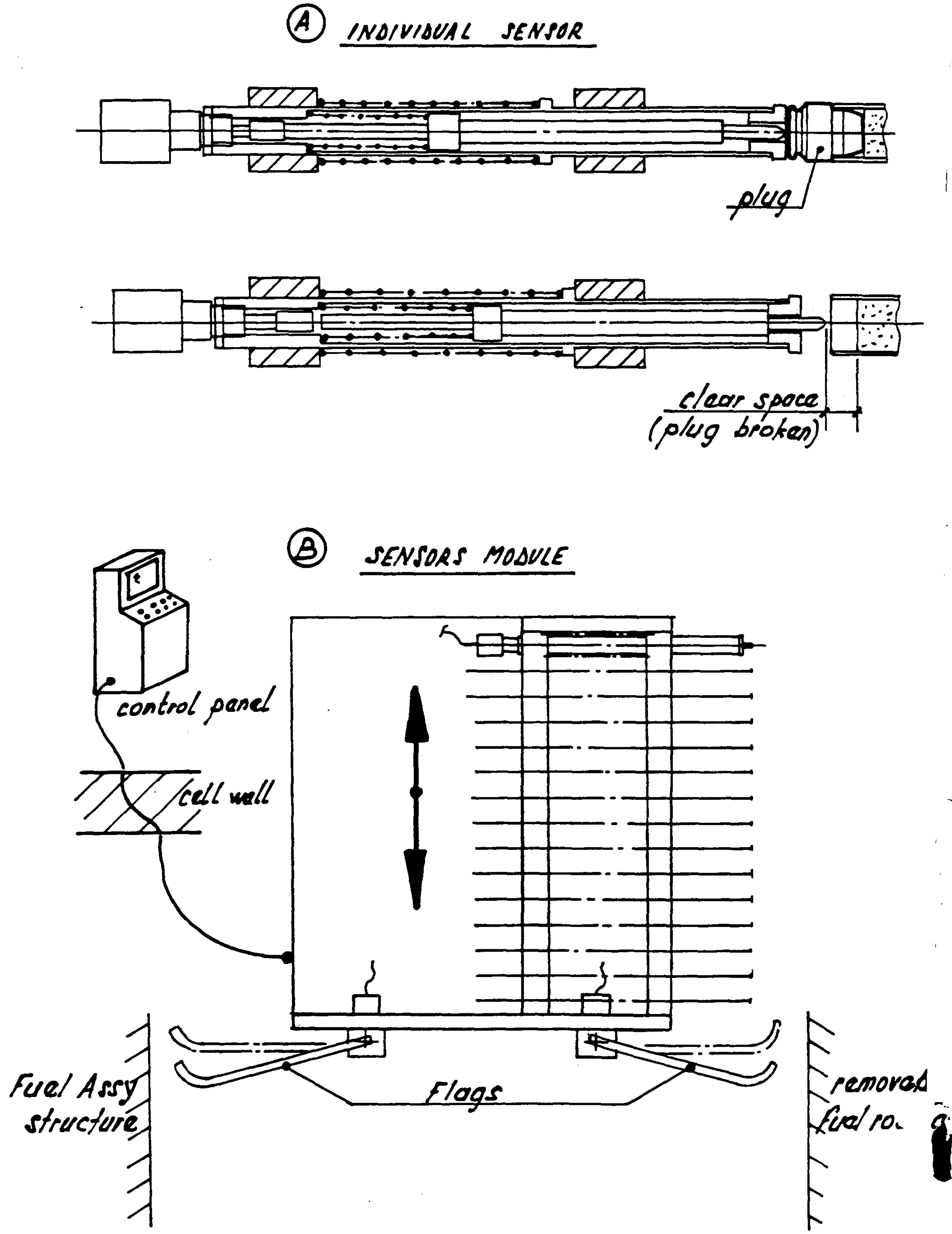


Figure 2-7

FUEL ROD ACCOUNTABILITY SYSTEM



- If all rods have cleared then the gripping head is moved forward so that the extremity of the fuel rod compresses a sensor. The sensor pushes a button, which indicates to the computer whether the rod is present. The fuel rod array of each typical fuel element is entered into the computerized process control system. The computer indicates that all the rods are present in the removal station, and that no rod is broken.

- If a rod is broken, its position is detected both in the removed rod array and in the remaining fuel element structural frame on the transfer table. These positions are memorized to facilitate the recovery operations.

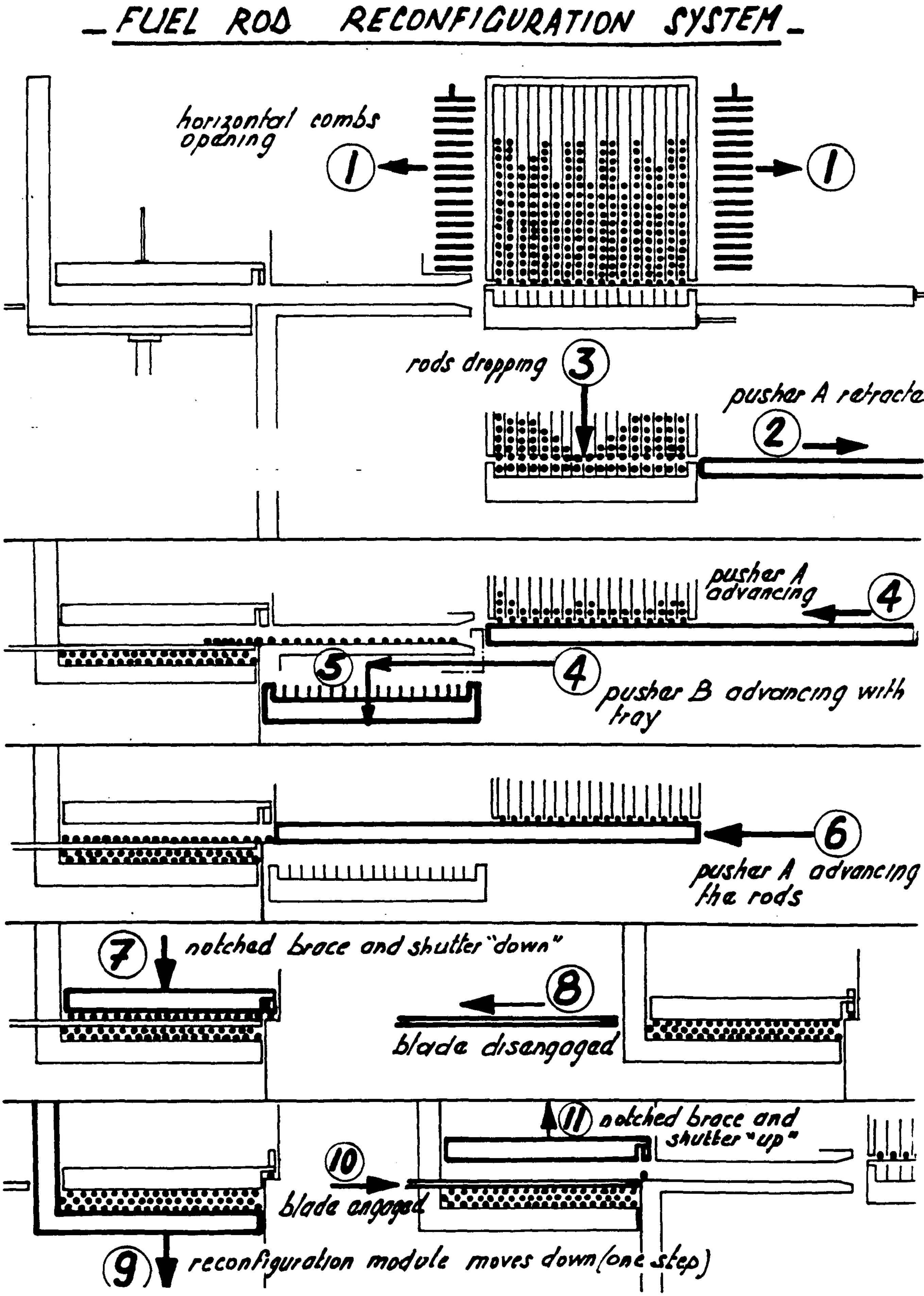
After all counting operations have been completed, the gripping head can continue the sequence of operations, i.e., release the gripping jaws, put a back-position stop plate into place, and retract the gripping head to the full back position, causing the fuel rods to be released from the gripping jaws.

2.1.5 Fuel Rod Packaging

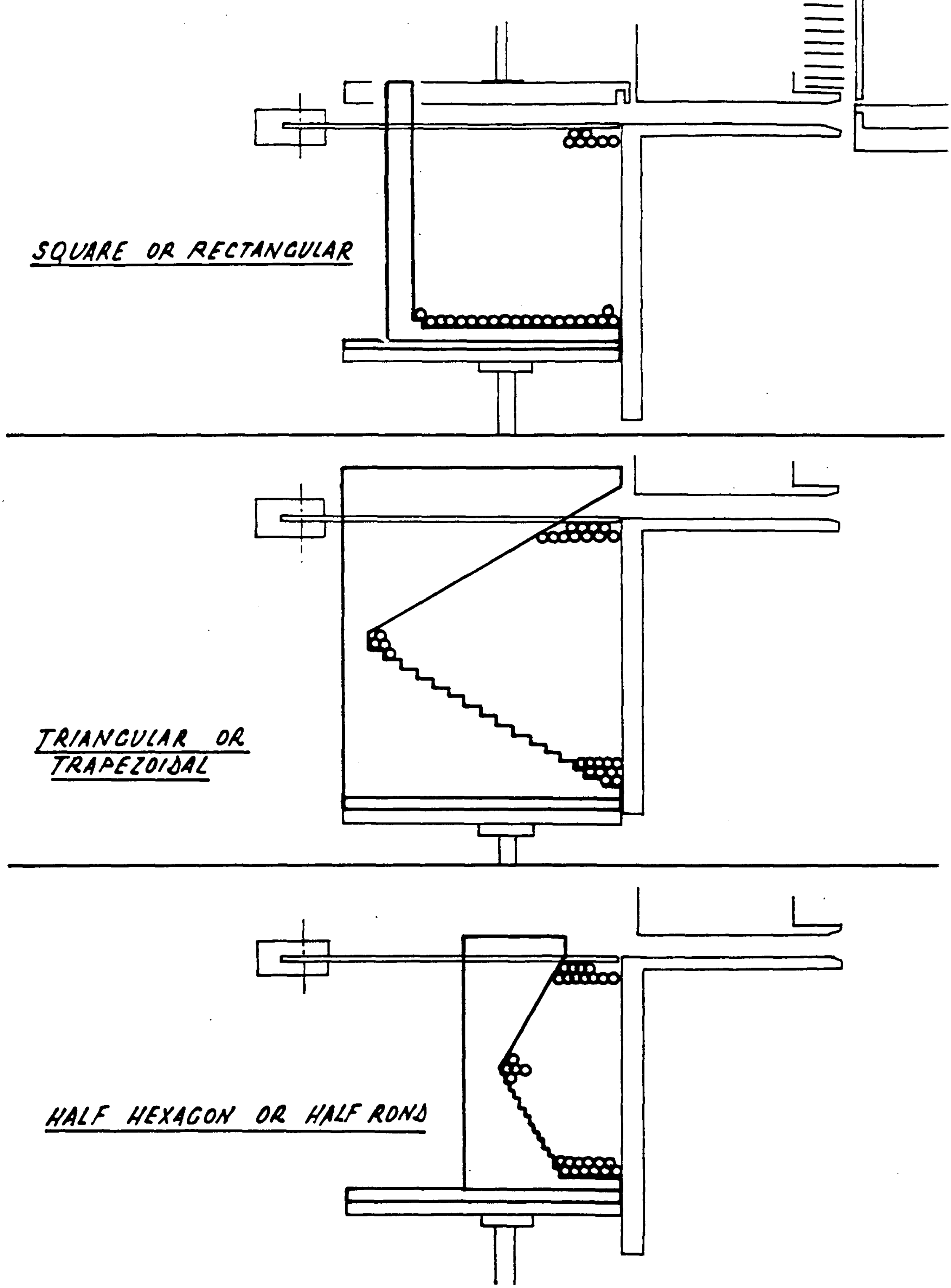
This part of the process includes fuel rod reconfiguration and canister packaging.

Fuel Rod Reconfiguration

The rod reconfiguration system consists of rearranging the fuel rods from two PWR or four BWR elements from their original array to a closely packed array compatible with the cross section of the consolidation rod storage canister, which may be square, rectangular, triangular, hexagonal, round or trapezoidal. The system includes three main components (see also Figures 2-8 and 2-9) which receive, transfer and reconfigure the rods.


FUEL ROD RECONFIGURATION SYSTEM
horizontal combs opening
1
1
rods dropping
3
pusher A retracted
2
pusher A advancing
4
5
4
pusher B advancing with tray
6
pusher A advancing the rods
7
notched brace and shutter "down"
8
blade disengaged
11
notched brace and shutter "up"
10
blade engaged
9
reconfiguration module moves down (one step)

FUEL ROD CANISTERS PACKAGING



When the rods are pulled from the fuel element structure by the gripping head horizontal and vertical "combs" or artificial spacer grids, are swung into place throughout the fuel bundle in order to maintain the original spacing of the rods. Once rod removal and counting have been completed, the horizontal combs are rotated out of the fuel bundle while the vertical combs remain stationary, such that the rods form vertical rows that drop down into a tray beneath the fuel rod array. The tray, which is composed of five longitudinal sections, sits below a table with lateral slots that extends from the fuel bundle to the rod reconfiguration module. The tray sections fit between the slots. One horizontal row of rods fills the tray as the rods drop down.

The loaded tray is transferred laterally along the table toward the rod reconfiguration module by a pusher that is connected to the tray, while a second pusher advances into the tray's original position under the fuel bundle and acts as a trap to hold the vertical rows of rods in place. When the forward stroke of the tray pusher has been completed, the tray is automatically dropped, leaving the row of fuel rods on the slotted table.

The lowering of the tray activates the second pusher, which pushes the rods through the entrance to the rod reconfiguration module. The rear section of the pusher continues to trap the remaining rods in the rod array. The rod reconfiguration module is a sectional mold that has the same cross section as the consolidated rod storage canister. Horizontal blades inside the mold at the level of the rod entrance support the row of rods as it is pushed into the mold. When the first rod reaches the wall of the mold the row stops advancing, and a shutter at the mold extrance falls into place.

The horizontal blades are then rotated out of the mold and at the same time, a notched brace is lowered through the open sections at the top of the mold and comes to rest on the row of rods to maintain their correct position. The entire mold, which sits on retractable cylinders, is then lowered one rows width. The notched brace is then lifted while the horizontal blades are swung back into the mold. At that point, either the rod pusher pushes the remaining rods into the mold, or, if there are no remaining rods, the tray is returned to its original position beneath the fuel bundle and the rod pusher is retracted. The next horizontal row of rods drops into the tray, and the sequence described above is repeated, until the mold is filled with rods.

Canister Packaging

Once the reconfiguration module is loaded with fuel rods from 2 PWR or 4 PWR elements, the consolidated rods are packaged in a clean canister and transferred to lag storage. This involves canister loading, canister monitoring and decontamination (if necessary), and canister closure.

The canisters to be loaded are located in a canister cell that is adjacent to the rod consolidation cell. The cells are connected by a hatch that serves as both a canister loading station and for canister decontamination. The hatch has a shield plug on the consolidation cell side and an inflatable seal on the canister cell side which act as contamination barriers.

Canister Loading

The canister to be loaded is lifted by the overhead crane in the canister cell and placed on a vertical tilting device which clamps around it. The crane grapple is released from the canister and the tilting device is lowered to a horizontal transfer table. The tilting device is linked to the transfer table.

The through wall hatch seals are deflated and the transfer table is advanced toward the hatch such that the upper end of the canisters and of the tilting device penetrate the hatch and that the upper end of the canister abuts the shield plug of the rod consolidation cell. The canister head locks onto the outside of the shield plug, and the seals are inflated around the canister and the tilting device at both ends of the hatch to ensure radioactive containment. The seal is shown on Drawing P1-1886-20-001.

A gripper inside the plug pulls the canister lid into the plug, and the entire plug element slides laterally, giving free access to the rod consolidation cell. The cell opening is aligned with the rod reconfiguration module.

In the rod consolidation cell, a pusher at the far end of the rod reconfiguration module pushes all the rods simultaneously through the module toward the open hatch, through a guide tube, and into the canister in one movement, and is then retracted. The shield plug element is returned to its initial position, the gripper replaces the canister lid, the hatch seals are deflated and the transfer table is retracted inside the canister cell, thus retracting the loaded canister.

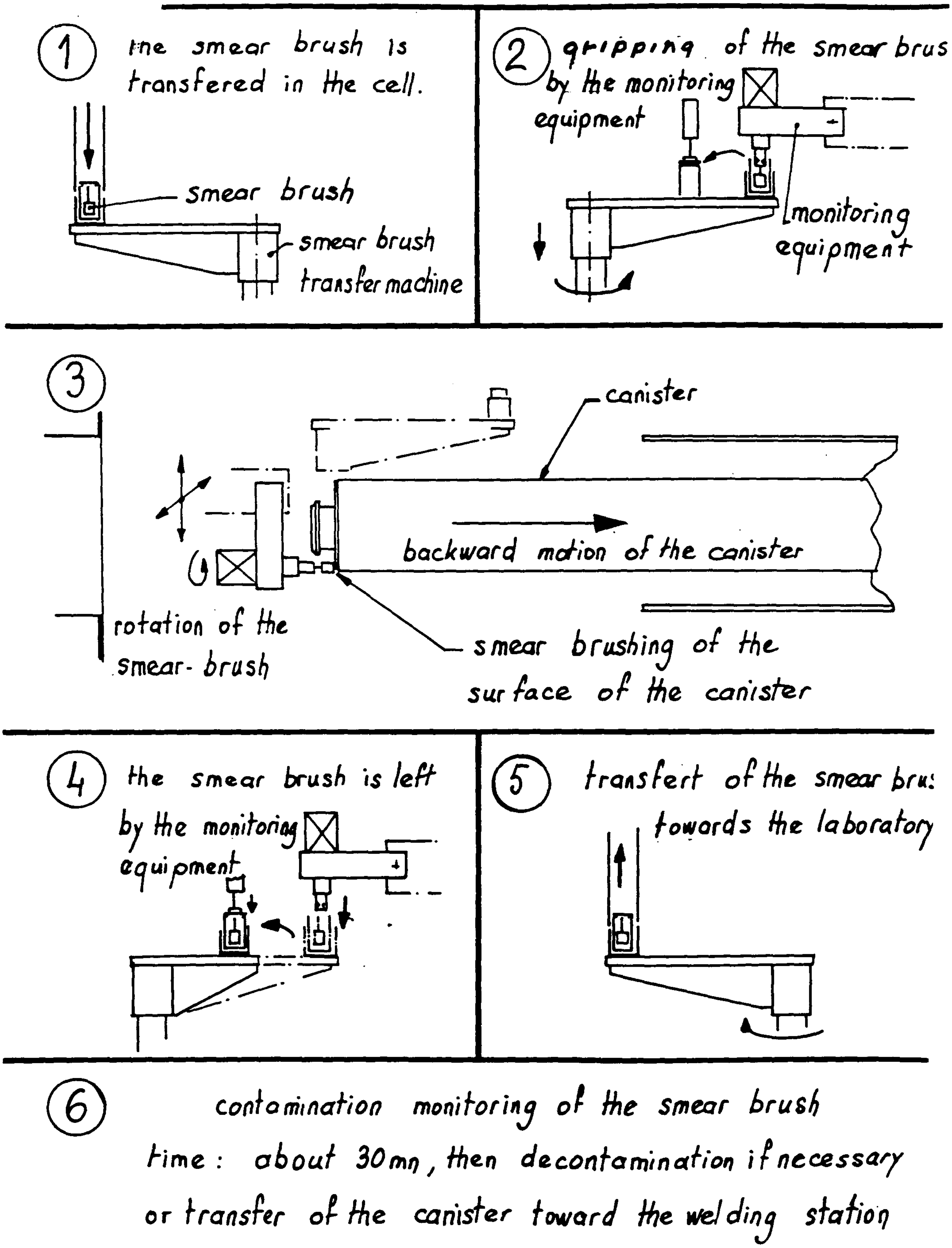
If the canister is square, rectangular, triangular or trapezoidal, this completes the canister loading operation. If the canister is round or hexagonal, it will have a central divider and will be loaded in two steps. After one loading but prior to retraction of the canister, the canister is turned 180 degrees so that a second loading operation may be performed. The remainder of the sequence described above remains the same.

Canister Monitoring and Decontamination

Canister monitoring and decontamination are illustrated in Figure 2-10. Upon retraction from the canister loading hatch, the canisters are monitored for contamination, even though the use of contamination barriers at both ends of the hatch to separate the contaminated rod consolidation cell from the clean hatch and canister cell reduces the probability of such an occurrence. Systematic decontamination of the canister is avoided, and thus the generation of liquid effluents reduced.

Figure 2-10

CONTAMINATION MONITORING



Monitoring is performed with a smear brush that is moved along the upper part of the canister with a robotic arm, thus ensuring that the upper part of the canister surface is brushed. The robotic arm releases the smear brush into a transfer line that sends the brush to the analytical laboratory. If the brush test detects no contamination, the canister can be tranferred to the welding station. If contamination is detected, the canister is returned to the hatch by a forward movement of the transfer table.

The hatch seals are inflated around both the canister and the tilting device. Seals are also inflated between the tilting device and the transfer table. Spray nozzles located inside the hatch spray high pressure water onto the canister as they revolve around the canister, while spray nozzles located inside the tilting device spray low-pressure water onto the canister. Decontamination effluents are drained to an effluent collection tank below the hatch. The hatch seals are deflated, the canister is retracted, the hatch seals are inflated and the canister is again smeared tested as above prior to transfer to the welding station.

<u>Canister Closure</u>

The tilting device returns to the vertical position with the canister. The overhead crane grips the canister, the tilting device is unclamped, and the crane transfers the canister to the welding station located in a pit inside the canister cell.

Welding is performed automatically using a plasma arc. The canister is positioned on a turntable. The welding head is advanced toward the canister and seals the lid to the canister in one continuous movement of the canister. Once the canister is sealed the welding head is retracted, and the crane lifts the canister out of the pit and transfers it to lag storage.

2.1.6 NFBC Handling

The NFBC canister to be loaded is lifted so that the upper-end of the canister penetrates one of the two floor hatch openings. One floor hatch is for the canisters filled with skeletons and one is for the canisters filled with end-fittings and grids. The canister enters the shield plug, the canister head locks onto the outside of the shield plug and seals are inflated to ensure radioactive containment.

A gripper inside the plug pulls the canister lid into the plug and the entire plug is moved to make free access to the consolidation cell.

The end-fittings from both BWR and PWR fuels fall through a chute into a non compartmented NFBC canister that is connected to a floor hatch opening. After loading, the hatch is closed, the NFBC canister lid is replaced and the canister is removed. No special NFBC handling device is necessary.

The skeleton from a PWR element or the water rod from an 8 x 8 BWR bundle remains on the transfer table after the rods are pulled and is returned to the PWR end-fitting removal station. The fuel tilting device is then rotated to the horizontal position and clamps onto the skeleton, raising it to the vertical position. The cell crane grapples the NFBC skeleton and lowers it into one of the four compartments in the NFBC canister that is connected to a hatch opening.

When the fuel rods and the capture rod are removed from a 7 x 7 BWR element, the spacer grids remain clamped on the transfer table. The transfer table return them the BWR end-fitting removal station. A rake pulls the grids toward the chute corresponding to the lower end-fitting removal machine. No handling machine is necessary.

Once the canister is filled, the shield plug is returned to its initial position, the gripper replaces the canister lid, the hatch seals are deflated and the canister can be removed.

2.1.7 In-Cell Support Requirements

Lag Storage

Lag-storage is integral to the rod consolidation process, and is provided where necessary to ensure that the throughput capacity of the system can be maintained, as well as to enable operations to continue for portions of the system while others are undergoing maintenance.

A basic requirement utilized in determining lag-storage capacity was that storage should be sufficient for one production campaign, i.e., 30 MTHM of the same fuel element type from the same vendor. From that starting point, lag-storage is divided into 2 parts: in-cell and out-of-cell.

In-cell lag-storage is the equivalent of 2 days production capacity or 28 elements whether for PWR or for BWR fuels. Stocking of in-cell lag storage must be performed during non-production periods, i.e., during nights or week-ends.

The lag storage capacity for empty consolidation rod canisters is linked to the consolidated rod production capacity of the system. Therefore, lag storage is equal to two days of production, or 14 canisters. It will be stocked with fresh canisters at the same time as fuel element lag-storage is stocked. In the case of full consolidated rod canisters, lag-storage is required only in the event of an equipment failure so that production is not interrupted for maintenance. Lag-storage is provided for the equivalent of one day's production, i.e., 7 canisters.

Lag-storage of empty NFBC canisters is provided for 2 days production, i.e. 7 four compartment canisters for skeletons and one uncompartmented canister for end-fittings and spacer grids.

Lag-storage for filled NFBC canisters should be sufficient for one day production. Consequently, lag-storage has space enough for four NFBC canisters.

Canister Decontamination

The possibility of fuel rod canisters being contaminated is low; however it must be ensured that the fuel rod canisters are not contaminated. The packaging of the rods is performed through the wall separating the cells and containment is ensured by the design of the hatch. Consequently, to avoid systematic decontamination which produces liquid waste, a non-contamination monitoring of the upper part of the canister (the only one which could be contaminated since the canister cell is clean) is performed.

If monitoring proves the upper-part of the canister is contaminated, decontamination is performed prior to welding to avoid the inclusion of contaminated particles in the welding seal.

The contamination monitoring is performed after having replaced the shield plug and retracted the transfer table supporting the canister with its lid and consists of a smear-brushing of the upper-part of the canister. The smear-brush is transferred to an analytical laboratory for analysis. The result of the analysis determines whether the canister should be decontaminated or not.

In case decontamination should be necessary, the canister is returned to the hatch, the seals are inflated and high pressure decontamination is performed, which also decontaminates the hatch. The canister is monitored again after decontamination to confirm the decontamination.

NFBC Canisters

NFBC canisters are located on the uncontaminated side of a hatch similar to the rod canisters. Containment is ensured using a similar hatch and consequently contamination is minimized. Furthermore, the NFBC canisters are closed in a way which enables them to be re-opened later. Depending on their ultimate disposition, contamination monitoring and decontamination could be performed in the evacuation corridor.

2.2 EQUIPMENT SYSTEM DESCRIPTION

This section describes the system and each piece of equipment which is designed to meet the process requirements outlined in Section 2.1. These descriptions are done in terms of layout drawings, equipment lists, equipment drawings, equipment specifications and descriptive text. Equipment trade studies and safety and licensing evaluations are included.

2.2.1 Equipment Drawings and Specifications

The equipment arrangement, equipment list, drawing list (all drawings are included as Appendix III), equipment classification, trade-off study list (trade-off studies are included as Appendix I). Any discussion of the types of equipment which will be purchased using specifications are included here.

Equipment Arrangement

The facility layout is shown on Drawing PI 1886 20 001. This section briefly describes the important features of the layout. A reduced version of the layout drawing is included in this section for easy reference.

The equipment arrangement is based on a horizontal mechanical process (see trade-off study A: Horizontal versus Vertical - Appendix I). The main pieces of equipment are arranged along four parallel lines :

1) BWR end-fittings removal (station 2 on the drawing)
2) PWR end-fitting removal (station 3
3) Fuel rod removal station (station 4)
4) Fuel rod reconfiguration and packaging (station 5 and 6)

The fuel element is transferred between these lines with a transfer-table identified as item 4.1 on the drawing. The fuel rod removal station and the fuel reconfiguration station are very close to each other. Rows of fuel rods are moved from the removal station to the rod reconfiguration station by means of pushers. A stuck or broken rod recovery area (item 8) is aligned with the rod removal station.

The rod packaging station is in line with a port (Item 15) in the wall separating the Rod Consolidation Cell and the Canister Cell. A plug in this port ensures the confinement of contamination to the consolidation cell. A longitudinal table for canisters (item 12) provides for ensures translation of the canisters to mate with the port.

The fuel element tilting device (Item 1) is located in alignment with the PWR end-fitting removal station. Similarly, a canister tilting device (Item 13) is located in alignment with the rod packaging station.

In the Canisters Cell, the canister contamination monitoring station is located just behind the inter-cells port. The canister lid welding station (Item 14) is located near the canister storage area.

As far as possible, driving equipment is located outside the cell (see trade-off study E: In-cell repair versus replacement - Appendix II). For example, the rod removal hydraulic cylinder is located in the canisters cell which is maintained free of contamination. The piston rod extends through a seal in a second port in the inter-cell wall. This arrangement allows for easy maintenance and the use of hydraulic fluid which would be prohibited in the consolidation cell.

On the lower level, the fuel element corridor communicates with the rod consolidation cell cell through a square hatch which provides for vertical unloading of fuel elements. The hatch is closed by a shield plug handled by the crane.

The NFBC corridor communicates with the rod consolidation cell through two ports. A compartmented canister for element skeletons mates with one, while a standard canister for end-fittings, spacer grids and other NFBC mates with the other. Each part is tightly closed by a shield plug. When a NFBC canister is presented, its lid is locked to the plug to protect against contamination. The canister opening is then sealed to the lower part of the hatch, to maintain the canister outside surface clean.

The rod consolidation cell is serviced by a modular process crane. Maintenance is performed in a crane bay separated from the main cell by a shielded door. This bay connects to a crane maintenance room with a small hoist for crane module handling. Similarly, the canister cell is serviced by a handling crane which, when not in use, is moved to a bay separated from the process cell by a shielded door. This bay also has access from a maintenance room.

List Of Equipment

Table 2-1 is an equipment list which includes the following for each item:

- An item number
- The reference number in the lay-out drawing (Table 2-2) (PI 1886 120 0014)
- Description (Table 2-1)
- Number of items (or sets) required for all types of fuel elements (Column A)
- Number of items per type of fuel element (column B)

Table 2-2 is a list of the equipment drawings that are included as Appendix III. Following these lists, the equipment is categorized by its state of development.

TABLE 2-1
EQUIPMENT LIST

ITEM	Reference on Drawing PI 1886 20 001	Description	Col A	Col B PWR	Col B BWR
A. PROCESS EQUIPMENT					
1	1	<u>Tilting Device</u>	1		
1.1		Structural frame	1		
1.2		Tilting hydraulic cylinder (demineralized water)	1		
1.3		Driving hydraulic cylinder	1		
1.4		Fuel element clamping device	1	4	3
2	2	<u>PWR top end-fitting removal station</u>	1		
2.1		Support structure with one actuator	1		
2.2		instrument tube drill	1	4	
2.3		Multiple blade cutting machine	1	4	
2.4		Top nozzle removal device	1	1	
3	3	<u>BWR end-fitting removal station</u>	1		
3.1		Upper end-fitting shearing machine	1		
3.1.1		support structure with one actuator	1		
3.1.2		Shearing machine with 4 hydraulic cylinders	1		2
3.2		Lower end-fitting shearing machine	1		

ITEM	Reference on Drawing PI 1886 20 001	Description	Col A	Col B PWR	BWR
3.2.1		support structure with actuator	1		
3.2.2		shearing machine with 4 hydraulic cylinders	1		2
4	4	<u>Fuel rod removal station</u>	1		
4.1	4.1	transfer table, rails and one actuator	1		
4.1.1		clamping devices	1	4	3
4.1.2		2.5 tons clamping plate and one actuator	1		
4.1.2.1		Set of friction plates	1	1	1
4.1.3		Fuel element restraint device	1	1	1
4.1.4		Suction device	1		
4.1.5		Rake to collect BWR grids	1		1
4.2		tool to rotate 7 x 7 BWR capture rod by 90	1		1
4.3		Bench	1		
4.3.1		bench frame with rails	1		
4.3.2		combs modules	1	4	3
4.3.3		drive actuator to rotate horizontal combs	1		
4.3.4		Three cylinder unit to clamp gripping head	1		
4.3.5		Three cylinder unit to unclamping gripping head	1		
4.3.6		Gripping head support cart with rollers	1		
4.3.7		Rod-pulling hydraulic cylinder (10 ton capacity)	1		

ITEM	Reference on Drawing PI 1886 20 001	Description	Col A	Col B PWR	Col B BWR
4.4		Gripping head	1	4	3
4.5		Accountability module	1		
4.5.1		Support with one acutator	1		
4.5.2		Counter	1	4	3
5	5	<u>Rod reconfiguration station</u>	1		
5.1		Longitudinal fuel rods sliding table	1		
5.2		Trays			
5.2.1		Five arm tray support	1		
5.2.2		Pusher B	1		
5.2.3		Trays	5	4	3
5.3		Five arm pusher (pusher A)	1		
5.4		Support table with cover plate	1		
5.5		Mold	1		
5.5.1		Reconfiguration module	6 (one per canister type)		
5.5.2		Alignment positioner	5	4	3
5.5.3		Reconfiguration module incremental drive unit	1		
5.6		Blades and notched braces			
5.6.1		Five rod support blades	1	4	3
5.6.2		Three notched braces	1	4	3
5.6.3		Driving bar and actuator	1		
6	6	<u>Packaging station</u>	1		
6.1		Pusher-heeds	6 (one per canister type)		
6.2		Electric actuator	1		

ITEM	Reference on Drawing PI 1886 20 001	Description	Col A	Col B PWR	BWR
B.	SUPPORT EQUIPMENT				
B.1	ROD CONSOLIDATION CELL				
1		<u>Fuel Handling Equipment</u>	1		
1.1		modular process crane (2 ton capacity)	1		
1.2		Grapple, fuel assy and skeleton	1	1	1
2		<u>Plugs</u>			
2.1		Plug with integrated NFBC compartmented canister lid grasping system	1		
2.2		Plug with integrated NFBC canister lid grasping system	1		
2.3		Plug with integrated fuel canister lid grasping system	1		
3	7	<u>Chutes</u>			
4		<u>Cell floor hatch w/actuator</u>	1		
5	8	<u>Stuck and/or broken rod recovery station</u>	1		
6	9	<u>Storage pit for 2 racks</u> 1 for 28 BWR fuel elements 1 for 28 PWR fuel elements	1		
7		<u>Maintenance Equipment</u>			
7.1	10	Maintenance station with working table	1		
7.2		Module removal lifting beam	1		
7.3		Set of maintenance tools	1		
8		<u>TV Cameras</u>	3		
9		<u>Microphones</u>	2		

ITEM	Reference on Drawing PI 1886 20 001	Description	Col A	Col B PWR	BWR
B.2	CANISTER CELL				
1	1	Handling Equipment			
1.1		Redundant handling crane (2 ton capacity)	1		
1.2		Cannister grapple	depends on types		
2	11	Storage pit for canisters	1		
3		Tilting device and longitudinal table	1		
3.1	12	Longitudinal tabel with one actuator	1		
3.2	13	Tilting device	1		
3.2.1		Clamping device	6 (one per type)		
3.2.2		ramp of spray nozzles	1		
3.2.3		Cylinder for tilting motion	1		
3.2.4		cylinder for clamping device	1		
4		Contamination monitoring Device	1		
5	14	Welding Machine	1		
6		Hatches	2		
6.1	15	Inter-cell port with bank of spray nozzles and actuator to rotate hexagonal and circular canisters	1		
6.2		Cell floor hatch - canister access and egress station with drive actuator	1		

ITEM	Reference on Drawing PI 1886 20 001	Description	Col A	Col B PWR	Col B BWR
7		TV Cameras	4		
B.3	OUTSIDE THE PROCESS CELL				
1		Control Equipment	1		

TABLE 2-2
LIST OF DRAWINGS

The following drawings are included in Appendix III.

SYSTEM DESIGN	Drawing No.
Process flowsheet	SH 1886 20 001
Time line diagram for PWR fuel element	SH 1886 20 002
Time line diagram for BWR fuel element	SH 1886 20 003
Operations signal-System and safety interlocks	SH 1886 20 005
Generic Facility lay-out	PI 1886 20 001
TAN Facility lay-out	PI 1886 20 002
TRANSFER EQUIPMENT	
Crane outline drawing for TAN enclosure	PE 1886 20 001
Tilting and clamping device	PE 1886 20 002
Handling grapple for PWR fuel	PE 1886 20 003
END-FITTING REMOVAL STATION	
PWR top-nozzle removal machine	PE 1886 20 004
Detail of individual cutter	PE 1886 20 005
BWR removal machine	PE 1886 20 006
PWR top-nozzle removal device	PE 1886 20 017

ROD REMOVAL STATION	Drawing No.
Fuel rods gripping head sized for 17 x 17 PWR fuel assy	PE 1886 20 010
Removal reconfiguration packaging lay-out in TAN inclosure	PE 1886 20 007
Fuel rod reconfiguration station	PE 1886 20 008
Transfer table with tightening modules for PWR or BWR fuel assy	PE 1886 20 011
Removal, reconfiguration packaging layout	PE 1886 20 009

ROD PACKAGING

Typical square reconfiguration	PE 1886 20 012
Typical triangular and hexagon reconfiguration	PE 1886 20 013
Welding machine	PE 1886 20 014

NFBC HANDLING

PWR fuel assy. Skeletons and canister handling system (typical for TAN)	PE 1886 20 016

List of Equipment Categories

a). Specialized Equipment Under Development:

Items in this category will be designed specifically for this project (such as end-fitting removal devices, or rod reconfiguration system) or which have already been designed and built for other rod consolidation systems but which can be easily adapted to this project (PWR top-nozzle removal equipment, rod removal equipment, canister packaging station).

b). Equipment Currently in Nuclear Service:

Items in this category have already been tested and used in nuclear plants. Only minor modifications will be necessary for use in TAN or generic facilities. Examples are cranes, servo and master-slave manipulators, windows, decontamination equipment, and contamination control equipment. Such equipment would be purchased using procurement specifications rather than fabrication drawings.

c). Standard equipment commercially available:

In this category are items such as lights, filters, reducers, motors, jacks, etc.which may need preparation for use in radioactive cells. These items would all be purchased with consideration given to such preparation.

List of Design Trade-off Studies

The design trade-off studies reflect the logic for design choices, indicating why one process or one layout has been preferred to another. They thus form the basis of the design.

Appendix I includes descriptions of the following studies:

a)-Fuel element handling

- Vertical vs horizontal

b) End-fitting removal

- Sawing vs cutting

c) Fuel rod removal

- All rods vs row of rods

d) Fuel rod packaging

- Reconfiguration funnel vs stacker
- Mechanical closure vs welding

e)- In cell support system

-Water versus ultrasonic water decontamination

-In-cell repair versus replacement

Specified Equipment

Many equipment items can be purchased using procurement specifications in place of drawings. These are off-the-shelf equipment which will require only specifications for "nuclearization" or for the specific requirements of the rod consolidation application or equipment already designed for other shops, which have been successfully tested and require only minor modifications to be adapted to the rod consolidation process.

The main equipment in the off-the-shelf category is the following:

- lighting, cameras, motors, moto-reducers, jacks, filters, sensors, windows, bearings, etc.

For this equipment, the main specifications will be:

- the most radiation resistance possible, for example use resistant electronics, use "good" polymerics (for example ethylene propylene) which have the best resistance, etc. If not possible, they will need to be protected, i.e. be located as far from the radiation sources as possible or, alternatively, be shielded.

- provide with the required performance : pulling or pushing forces, lightness, etc.

The equipment in the second category mainly consists of:

- Master-slave manipulators (many have been successfully used, see appendix II)

2.2.2. Fuel Element Handling

Process crane

The process crane is made of stainless steel, including its bridges, rollers and rails. The crane drive mechanisms are redundant and independent, and are connected to an emergency power source to allow continuing operation in the event of failure of one drive mechanism. The drive mechanisms are remotely removable modules to facilite crane maintenance operations (see also discussion in Appendix II)

The travel of the crane's trolley on the bridge is driven by two independent drives, each consisting of a direct current electric motor coupled to an electric clutch and a gear reducer. Each drive is electrically supplied by its own independent multiconductor cable reel. The cable is automatically connected to the drive module through female plugs on the bridge.

The crane's chain hoist is driven by two independent gear motors, each 2 ton capacity, placed side by side. The chain is pulled from its removable storage box to the first drive pulley, then to a common hoist block, from there to the second reducer pulley, and finally to a second chain storage box. In this way, if one of the drive units should fail, the other can complete the operation in progress at half speed sincee the first gear motor cannot freewheel. The gear motor modules are electrically supplied by two independant cable reels. The lifting chain was chosen over a wire rope and drum in order to minimize the spread of contamination.

Tilting and Clamping Device

a) Description

The tilting device (shown on drawing PE 1886 20 002) consists of a strong back large enough for any type of fuel elements and adapted to a specific fuel element by means of interchangeable clamps. The clamping activator is an integral part of the tilting device. The clamps are located in pairs on either side of the beam, along the length of the fuel element at the spacer grid locations so as to secure the fuel element to the strong back when the tilting device is lowered. These clamps rotate on transverse axes, driven by a geared rack running the length of the strongback. The rack is actuated by a gearmotor with a drive nut running on a threaded portion of the rack.

The tilting device is in vertical position and the clamps are open when being loaded with a fuel element. After the fuel element is correctly located on the strongback,, the clamps are rotated shut simultaneously. The entire mechanism is rotated to the horizontal position by a hydraulic cylinder.

b) PWR Fuel Element

The tilting device performs several functions for the PWR elements. First it must receive and clamp the fuel element,then rotate down by 75 degrees to place the fuel element in line with the instrument tube drill, then rotate down a further 7 degrees to place the fuel in line with the guide tube cutting machine, then rotate down from 82 to the horizontal position to lay the fuel element down on the transfer table, and finally return to the initial vertical position.

After the fuel rods are pulled from the element, the tilting device rotates down to the horizontal position, clamps the fuel element skeleton, and rotates back to the initial vertical position to enable the skeleton to be grappled by the crane.

c) BWR Fuel Element

The tilting device performs similar operations for BWR fuel elements. First, it receives and clamps a fuel element transferred by the process crane, then it rotates to the horizontal position to lay the fuel element down on the transfer table, and it returns from the horizontal to the vertical position.

After the fuel rods have been removed from the element, the tilting device rotates down to the horizontal position to recover the skelton (for 8 x 8 BWR fuels only)_, and rotates back to the vertical position to enable the skelton to be grappled by the crane.

d) Interlocks

The tilting device is electrically interlocked to other process equipment to ensure the safety of operations. The following examples illustrate the design philosophy. When a fuel element is loaded on the tilting device, sensors detect its correct positioning and automatically activate the clamps. The hoist grapples can then release the element only if the clamps are properly closed.

The rotation of the tilting device from 0 degrees to 75 degrees can occur only if three conditions are met: the fuel element grapple has been raised high enough to give free passage; the clamps are closed around the fuel element; and the support for the instrument tube drilling machine has been advanced to receive the upper end-fitting of the fuel element.

Similarly, rotation from 75 degrees to 82 degrees can occur only if the drilling machineis retracted and the guide tube cutting machine has been advanced to receive the upper end-fitting. Further rotation from 82 degrees to the horizontal position can occur only when the cutting machine with the upper end-fitting and the upper spacer grid havebeen retracted, and the transfer table is positioned to receive the fuel element.

For BWR elements the intermediate interlocks are by-passed. When the tilting device reaches the horizontal position the clamps automatically unlock and remain in that position until a signal is received to recover the element skeleton.

Fuel Element Grapples

The PWR grapples are shown on drawings PE 1886 20 003 and PE 1886 20 016). As a rule, the concept for the fuel element gripping system is identical for all fuel types whether PWR or BWR, but the dimensions and the shapes of their gripping hooks are different. For a given type of fuel the same grapple can be used to handle fuel elements with similar charateristics and dimensions.

With respect to the rod consolidation process system, the placing of a fuel element on the tilting device, and the subsequent recovery of the fuel element skeleton, are closely connected in the operating sequences. Thus, it was decided to integrate mechanical devices in the grapple to recover the skeleton in order to eliminate the need for special equipment to recover the skeleton.

The grapple consists of three main parts :

- a jacket covering the grapple
- the grapple itself with its mechanical devices and electrical connectors
- the skeleton handling device that slides down over the jacket

a) Jacket Description

The jacket consists of a tube that is closed at the top with the inside diameter matching the outside diameter of the grapple. The jacket is connected to the grapple and to the crane hoistblock. The outside diameter of the jacket matches the inside diameter of the skeleton handling device and is keyed to guide the skeleton handling device into place.

b) Grapple Description

The grapple includes geared rotary hooks (4 for PWR, 2 for BWR) shaped to mate with the fuel element's top nozzle or lifting bail. Mating with the gears on the hooks is a central drive gear. TRhe gear is connected to a cylindical cam which is turned through 35 degrees by the vertical motion of a drive activator.

Once the hooks are engagead, a mechanical interlock prevents the hooks from releasing the fuel element during transfer. The interlock consists of a sliding vertical rod with lobes mating with recesses in the drive gear hub, preventing the hooks from rotating out of the fuel element's top nozzle or lifting bail. The lower end of the rod bears against the top of the fuel element, and is spring-loaded into the locking position when the hooks are engaged and the lifting motion begins.

When the interlock is engaged, rotation of the hooks is not possible, even in the event of such operator error as a command from the control room for drive gear rotation. The grapple therefore will not release the fuel element unless it is in a stable position. To release the element, it must be lowered into a receiving surface. When the fuel element has been stabilized, the lowering motion continues until the rod comes to rest on the top end fitting and the interlock is disengaged. An electrical actuator automatically stops the lowering motion while actuating the drive gear to rotate and disengage the hooks.

c) Skeleton Handling Device

The skeleton handling device consists of a sleeve that fits around the outside of the grapple jacket. Two hooks are attached to the sleeve and are also connected to the grapple's drive gear. When the grapple is lowered to grasp an intact fuel element, the sleeve comes to rest on the top of the fuel element and slides up over the jacket while the grapple continues to move down. When the grapple comes to rest on the fuel element, the locking operation described in the previous section occurs with no effect from the sleeve hooks. When the grapple is lowered to grasp a skeleton, on the other hand, the sleeve continues to move down and envelop the skeleton's upper section. The interlock rod of the grapple comes to rest on the central part of the skeleton (i.e., instrument tube for PWR or water or spacer rod for 8 x 8 BWR) and stops automatically. The grapple's drive gear is thus unlocked and rotates. This motion is transmitted to the sleeve which closes the hooks to grasp the skeleton from beneath the spacer grid. For installation in the TAN, the skeleton handling device has a second position which allows the waste canister to be grasped.

Off-Normal Operations

Tilting Device

The tilting device's rotating motion is driven by a hydraulic cylinder. In the event of cylinder failure, the process crane can rotate the strongback using a bail provided for this purpose at the upper end. The tilt cylinder rod would be disconnected from the rotary drive lever, and the strongback lowered to a horizontal position so that the cylinder could then be removed.

Clamping Device

Failure of the clamps would have no safety consequences. If the clamps fail to close, the grapple continues to secure the fuel element due to the electrical safety interlock, if the clamps fail to open, the tilting device would be rotated to the horizontal position if necessary where the clamping device could be removed remotely.

Fuel Element Grapple

Three off-normal conditions were taken into account :

- failure of the actuator push rod,
- failure of the driven gear for one or more fuel element gripping hooks,
- loss of electric power to drive the actuator

If any of these failures occurs while a fuel element is grappled, the element cannot be released as described earlier. To release the fuel element, it is necessary to transfer the fuel element to a special maintenance stand, disconnect the grapple from the crane hoist block, attach a special maintenance tool crane and pull up the jacket of the grapple. This action pulls up the actuator rod connected to the jacket and forces the drive gear to rotate, disengaging the hooks from the fuel element. Since the loads on the grapple's mechanical parts are low, failure is unlikely and thus maintenance would be exceptional.

2.2.3 End-Fitting Removal

PWR Fuel Element

The work station and tools for PWR end-fitting removal are shown on drawings PE 1886 20 004 PE 1886 20 005 and PLE 188620 017. The PWR work station is disposed in line with the tilting device. It includes tools for drilling, guide tube cutting, and end-fitting removal. These are described in the following sections.

a) Drilling Machine

The drilling machine includes a support, an intermediate base plate, the drill bed plate, and the drill itself.

The intermediate base plate is mounted to the support by clamps. The machine bed plate slides along the base plate on machine ways. The advance or retract motion is controlled from an electrical cylinder. The drill machine is aligned to receive the upper end-fitting of the PWR fuel element at an angle 75 degrees from vertical. Before the tilting device can be lowered, the machine must be advanced as described earlier. The front of the bed plate includes guide flanges accurately machined to match the upper end-fitting of the fuel element to ensure drill alignment with the instrument tube.

b) Guide Tube Cutting Machine

The guide tubes cutting machine is beneath the drill in a position to receive the fuel element at about 82 degrees from vertical. The cutting machine is mounted like the drilling machine with a base plate and a bed plate, enabling the machine to advance or to retract.

The machine includes up to 25 cutting tools arranged to correspond to the individual fuel elements number and location of guide tubes and instrument tube, and a gear box driving all the tools simulanteously. One cutting tool (illustrated in Figure 2-11) includes a blade holder tube with an outside diameter matching the guide tube inside diameter. The front of the tube includes a yoke with a pivoting cutting blade. The blade's cutting edge is designed for efficient cutting and to retain chips inside the tube. The rear of the blade has a ramp-shaped tang. Inside the blade holder tube is a blade driving rod which is shaped to match the ramp and tilt the blade. In the rear of the machine head the rods are fixed to a common plate. Moving the plate backward causes the blades to tilt, advancing the cutting edges into the guide tubes. Moving the plate forward tilts the blades to disengage from the tube walls.

To improve the cutting performance the machine includes a guide nozzle which mates with the inside of the fuel element upper end-fitting. This nozzel adds support to the blade holder element to minimize bending.

Before the tilting device can be lowered, the drilling machine must be retracted and the cutting machine advanced as described earlier. While cutting the zircaloy tubes, nitrogen is blown from the rear part of the machine and enters into the blade holder, passing around the blade driving rod to minimize zirconium oxidation.

c) End-Fitting Removal Device

When the cutting is complete, the fuel element is lowered to the horizontal position to the end-fitting removal device. This device includes a cart which rolls on side rails, and carries a grapple with two jaws. The cart is advanced with jaws open until it contacts the end-fitting. The actuator then retracts, which first locks the grapple onto the end-fitting, then pulls it. When the end-fitting is pulled about 3/4 in., a set of vertical combs is introduced into the array at the location where the guide tubes were cut. The teeth of the combs are about 3 millimeters thickness. The comb verifies that all the guide tubes are cut since the clear space between a guide tube and the surrounding rods is only one millimeter. Now when clamped by an an electric actuator, the comb locks the fuel rods and prevents them from being pulled with the end-fitting. The cart continues to retract pulling the end-fitting free. At its limit of travel, the activator reverses, first unlocking the jaws and ejecting the end-fitting, then the cart is translated forward again to reset fuel rods which may have been pulled before being locked in place.

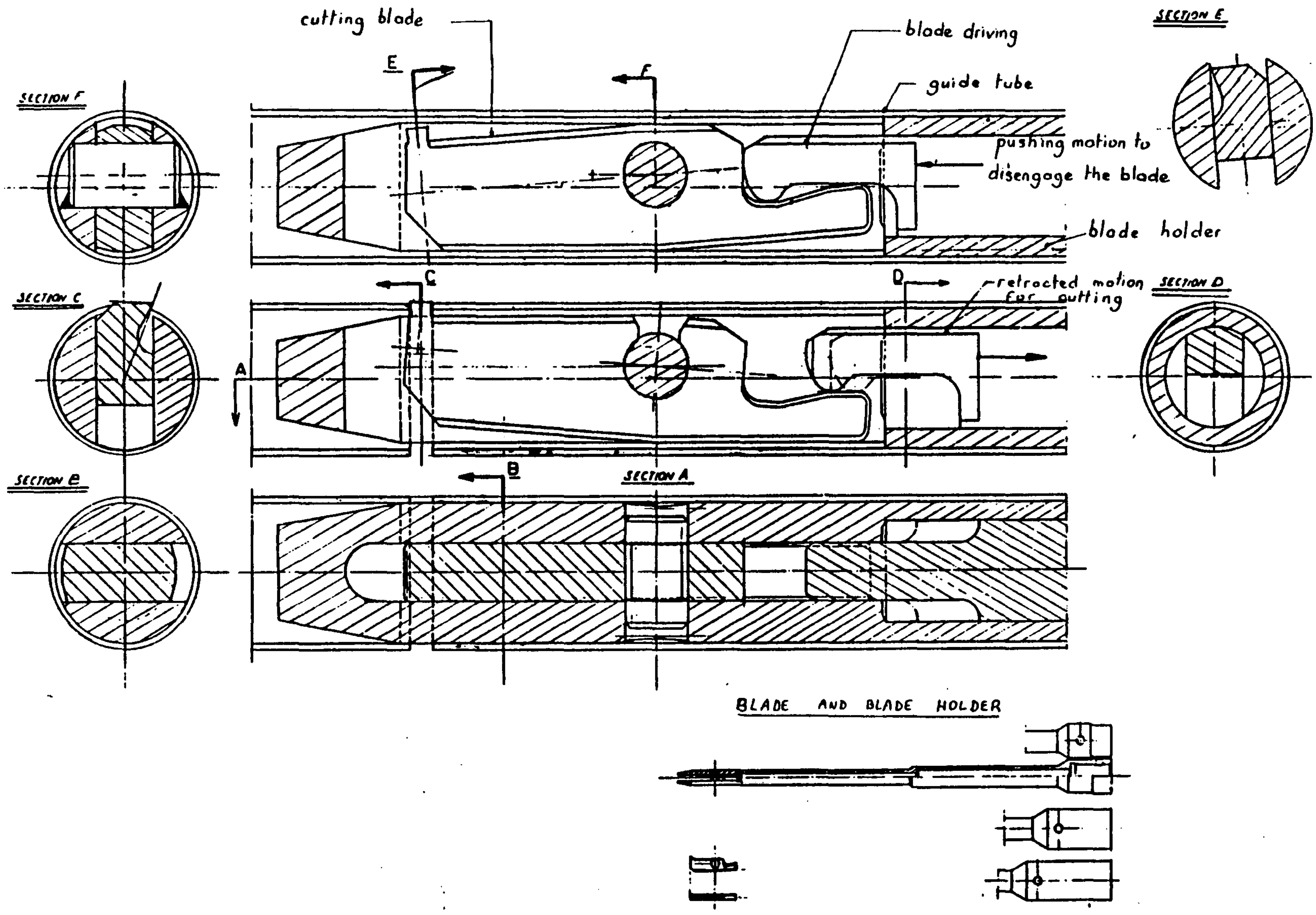
d) Off-Normal Conditions

The bed plates and activators of the drilling and cutting machines are designed to be remotely removed in case of failure. A broken drill is considered highly unlikely because of the design of the tool and its cutting edge; however, the drill can be replaced remotely in this exceptional situation.

While the guide tube cutting blade has been designed for long service by selection of specific materials and machining parameters, and while the cutting tools will be replaced routinely, the risk of

Figure 2-11

Cutting Tool Detail



breaking a blade has been taken into account. The end-fitting pulling force is limited to a maximum value sufficient to separate the nozzle with the attached upper grid and tube segments but low enough to stop the operation if a tube has not been cut. If this occurs, it is difficult to detect which tube is uncut, because some tubes are hidden by the surrounding fuel rods. array, it is problematic to detect which tube remains uncut. In such a situation the cutting machine would be removed and placed on a maintenance stand with a fixture simulating the upper part of the fuel element, minus the top nozzle and the fuel rods. A cutting operation shall be performed on this fixture jig to detect which tool is not working. The affected tool would then be replaced with a shorter tool and the operation repeated on fuel element.

<u>BWR Fuel Element</u>

The BWR end-fitting work station (drawing 1886 20 006) is adjacent to and parallel to the PWR end fitting station just discussed. It is comprosed of two shearing stations to cut the eight tie rods near each end of the element.

a) <u>Upper End-Fitting Removal Machine</u>

The BWR upper end-fitting removal machine includes three mobile shearing blocks and a fixed shearing block located just beneath the end-fitting. The mobile shearing blocks are mounted on a cart fitted with rollers. The cart moves (about 31.5 in) to allow passage of the transfer table with the fuel element and to allow the disposal of the end-fitting after shearing. The cart also carries a pusher which moves the end-fitting against the expansion springs, providing a clear space between the plate and the tie-rods.

Each shearing block, either mobile or fixed, has a clamping device which contacts the end-fitting plate and locks it in position during shearing. The block also has a pair of shearing blades which are spring-loading to retract into a sheath in the clamping device. When the shearing block is move toward the fuel element, the clamping device first contacts the end-fitting plates, then the blades continue to move inward for shearing.

A set of four combs are carried by the upper shearing block, and inserted into the element to capture the expansion springs during shearing. After shearing, the springs and the end-fitting are held between the pusher and the combs while the cart is translated to the disposal chute. When the pusher and the combs are retracted, the end-fitting is ejected. The shearing-blocks will be interchangeable so that each set will match closely the fuel elements to be consolidated.

b) BWR Lower End-Fitting Removal Machine

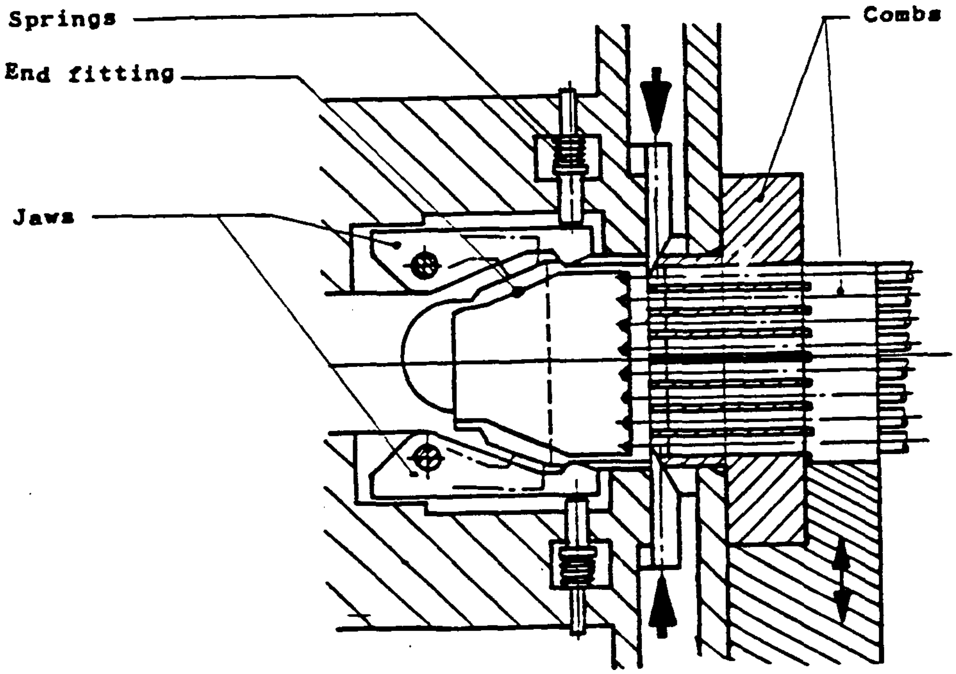
The lower end-fitting removal machine is similar to the one just described. Three mobile shearing blocks mounted on a cart and one stationary shearing block is located under the end-fitting. Each shearing block holds two blades actuated by a hydraulic cylinder.

At the lower end, however, the tie-rods are sheared along the inside of the end-fitting, and a different clamping device with horizontal and vertical combs is needed to avoid any deformation of the fuel rods during shearing. Figure 2-12 is a sketch of the mechanism.

The clamping device consists of two jaws which lock onto the end-fittings. The jaws are automatically engaged when pushed over the fitting and are locked in place by two small spring-loaded plungers. After shearing, the jaws remain locked while the cart is retracted because the load on the plungers is enough to overcome the force of pulling the lower-end-fitting from the fuel rods. Near the end of the retracting motion, the end-fitting bottoms on a stop overcoming the springs load on the jaws. The lower end-fitting is disengaged and drops in the disposal chute.

Figure 2-12

Lower End Fitting Removal Device



Previous testing has shown that the vertical and horizontal combs are necessary to avoid deformation of the BWR rods during shearing. Each comb, either vertical or horizontal, is 1.4 inch. thick. The horizontal combs are first engaged in the fuel element, to provide a reference surface against which the lower end-fitting bears when being pushed by the cart. This provides thus good precision in the positioning of the shearing blocks so that the blades shear the tie-rods flush with the end-fitting.

The vertical combs are then inserted in the fuel element to complete the protection for the fuel rods. It is not desired to lock the rods in the combs, but only to support them during the shearing operation. The combs hold the rods just tight enough to also retain them when the cart is retracted with the end fitting.

c) Safety Interlocks

The upper and lower end-fittings removal machines are in-interlocked so that the transfer table cannot be moved to the BWR end-fittings removal station unless the machine is retracted. They are also interlocked so that both cannot be advanced at the same time.

d) Off-Normal Events

The simplicity of the shearing equipment leaves little to be considered. Any failure of the translation or activation mechanism would require removal of the machine to a maintenance stand. In the unlikely event of either blade breaking, switches would indicate the end-fitting has not been removed.

2.2.4 Fuel Rods Removal

After removing one or both end-fittings, the fuel element is layed on the transfer table for movement to the rod removal work station where the rods will be removed from the fuel element structure.

Transfer Table And Fuel Element Camping Device

The transfer table is and clamping device is shown on Drawing PE 1886 20 011. The table receives the fuel element from the tilting device, and can translate either to the BWR end-fitting removal station, or to the fuel rod removal work station. The transfer table is an open channel stsructure which has interchangeable positioning devices set up at the spacer grid location for each typical fuel element. Each positioning station includes tapered spring-loaded pads at either side of the fuel element spacer grid, and a bed plate with polyurethane blocks having a coefficient of friction of about 0.6 to avoid sliding of the fuel element.

The transfer table slides on a set of three rails and is positioned by a hydraulic cylinder. The rail and bushings are designed to resist the pulling force exerted when removing the fuel rods.

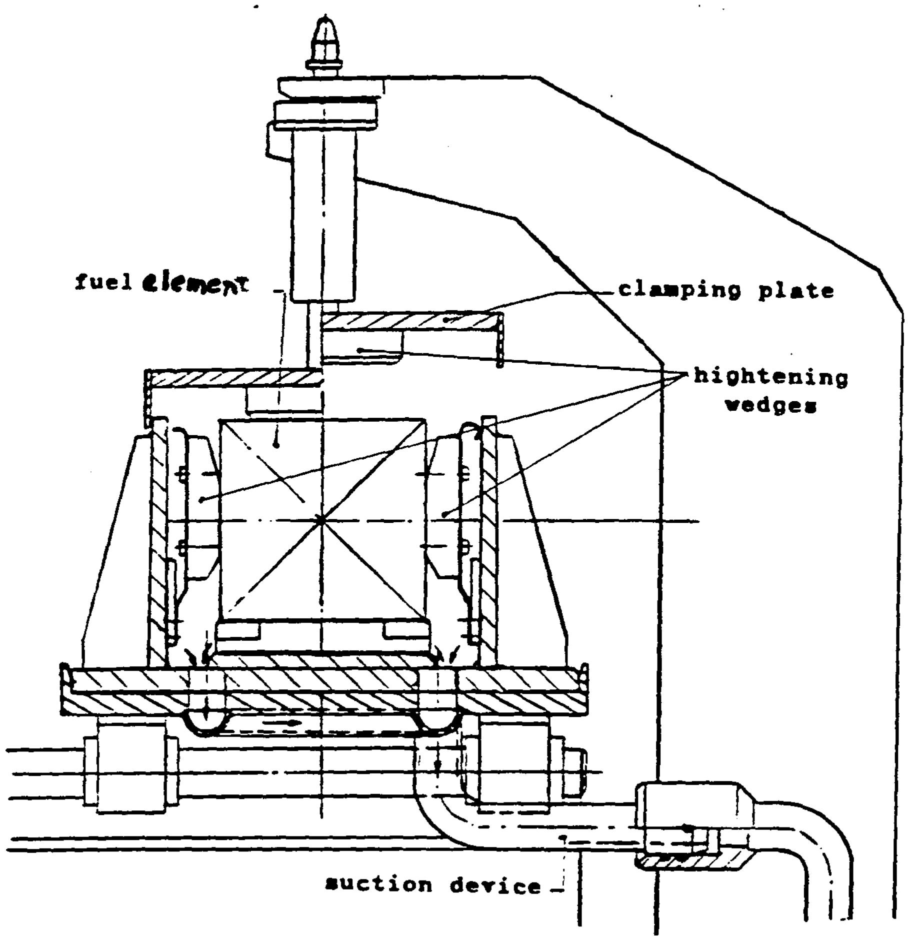
At the fuel rod removal station, the transfer table stops under an element clamping device illustrated in Figure 2-13. The clamping device consists of a heavy reinforced plate fitted with polyurethane blocks set to the location of the fuel element spacer grids. When the transfer table moves into position the clamp is in the raised position. When properly aligned, the clamp is closed by a pair of 2.5 ton hydraulic cylinders. In addition, for PWR elements an additional clamp locks onto the lower end-fitting so that the fuel element structure restrains the pulling force. This additional restraint is not needed for BWR elements.

For BWR 7 x 7 fuel elements, the PWR bottom-end fitting clampling device is remotely removed and replaced by a tool for removal of the capture rod prior to fuel rod removal. This tool grips the capture rod, turns it by 90 degrees and holds it in place during pulling of the PWR rods.

A ventilation device is provided in the transfer-table to collect crud loosened by pulling the fuel rods through the spacer

Figure 2-13

Fuel Assembly Clamping Device



grids. The ventilation suction openings are placed beneath the spacer grids where cruds and fines are generated, and are routed to two quick-connect fittings on the transfer table. When in position, these fittings mate with remotely removable filters which lead to the hot cell ventilation system. Sufficient flow is maintained in this suction system to collect most of the loose contamination generated.

The transfer-table, the fuel element tilting device,and the clamping device interlocked to prevent movement of the table to or from the fuel rods removal station unless the tilting device has been raised, the clamping plate is retracted, and the rod pulling head is retracted.

Fuel Rods Removal Bench

The fuel rod removal bench is in line with and adjacent to the clamping device just discussed. It includes a support structure, a traversing cart, and a gripping head. Drawing PE 1886 20 009 illustrates these components.

A - Support structure

The support structure is a bench about 19 feet long mounted to the cell floor on base plates. It includes supports for 4 series of vertical and horizontal comb modules, a set of rails guiding the traversing cart, and a set of three hydraulic cylinders located at each end of the bench.

b) Traversing

This cart has a support for inter-changeable fuel rod gripping heads, and traverses the length of the bench supported on the rails by rollers and guidead by counter rollers. The cart is driven from outside the cell by a 10 ton capacity 15 foot stroke hydraulic cylinder through a sealed wall penetration. From forward to back, the cart has four designated stopping positions:

(1) fuel rod gripping position
(2) fuel rod gripping jaws unlocking position
(3) fuel rod accountability position
(4) fuel rod ejecting position

c) <u>Gripping Head Fuel Rods.</u>

The gripping operation locks all the fuel rods at their upper extremity into the gripping head. The head is mounted in the traversing cart and pulls the rods when the cart is retracted. The head contains an array of mobile cross pieces (jaws) located so that each rod is locked between two of them and a fixed wall. Hydraulic pressure is applied to the periphery of the element so that each rod is gripped, then the head is mechanically locked for pulling the rods.

Interchangeable gripping heads are designed for each element to be processed to match the rod pitch and diameter in appropriate ranges to minimize the number of different heads. While the functions and main features are the same for PWR or BWR fuel, the following description assumes a 17 x 17 PWR fuel element.

The gripping head is illustrated in Figure 2-14 and Figure 2-15, and consists of a box including horizontal and vertical channels. One horizontal channel corresponds to two horizontal rows of fuel rods. As the 17 x 17 PWR fuel element has an odd number of rows, an eighteenth artifical row made of 17 tube segments has been incorporated in the gripping head in order to maintain the balance of the clamping system. There are consequently 9 channels of two horizontal rows each.

Fourteen cross shaped gripping jaws and two half cross jaws are located in each horizontal channel. The half cross jaws bear on the peripheral fuel rods. When withdrawn from a fuel element the crosses are kept in position by ejector rods the diameter of a fuel rod plug weld in each fuel rod position in the fuel element. For each empty location in the fuel element an artifical fuel rod (tube segment) is located in the gripping head. Thus the array of ejector rods and tube segments corresponds to the array of fuel rods and guide tubes in the fuel element.

Nine pushrods are located in a vertical channel on each side of the fuel array . Each pushrod includes a piston, a set of Belville spring washers and a piston cap. The spring washers are located between the piston top-head and the cap. The pistons go through the vertical inner wall, contacting the lateral half crosses and maintaining a light pressure on the array of crosses and ejectors. This pressure is applied by a vertical beam between the piston caps and the outside wall of the gripping head, forced inward by a movable vertical key. The two keys corresponding to the two channels are connected by an arm, constituting the mechanical locking stirrup.

When the head is advanced to the gripping position, it stops inline with the 3 hydraulic cylinders located at the front of the fuel rod removal bench.

When the gripping head is advanced to this position, each ejector rod in the gripping head is displaced by the correspooding fuel rod in the array. Thus the fuel rods' different length after irradiation is accommodated automatically. The fuel rods finally are inserted into the gripping jaws beyond the top end plug weld as illustrated in the upper portion of Figure 2-16. When the signal is given to grip the fuel rods, the two horizontal hydraulic cylinders apply force to the outer walls of the head which is transmitted to the piston heads by the vertical beams. The pushing force exerted on the piston heads is then transmitted to the gripping jaws horizontal line. After the Belville spring washers have been crushed with the necessary force, the cross-shaped gripping jaws squeeze each pair of fuel rods until all the jaws contact solidly. At this point the vertical hydraulic cylinder pushes down the mechanical locking stir-rup. The entire element of fuel rods is now tightly locked into the

Figu1 2-14

Fuel Rod Gripping Head

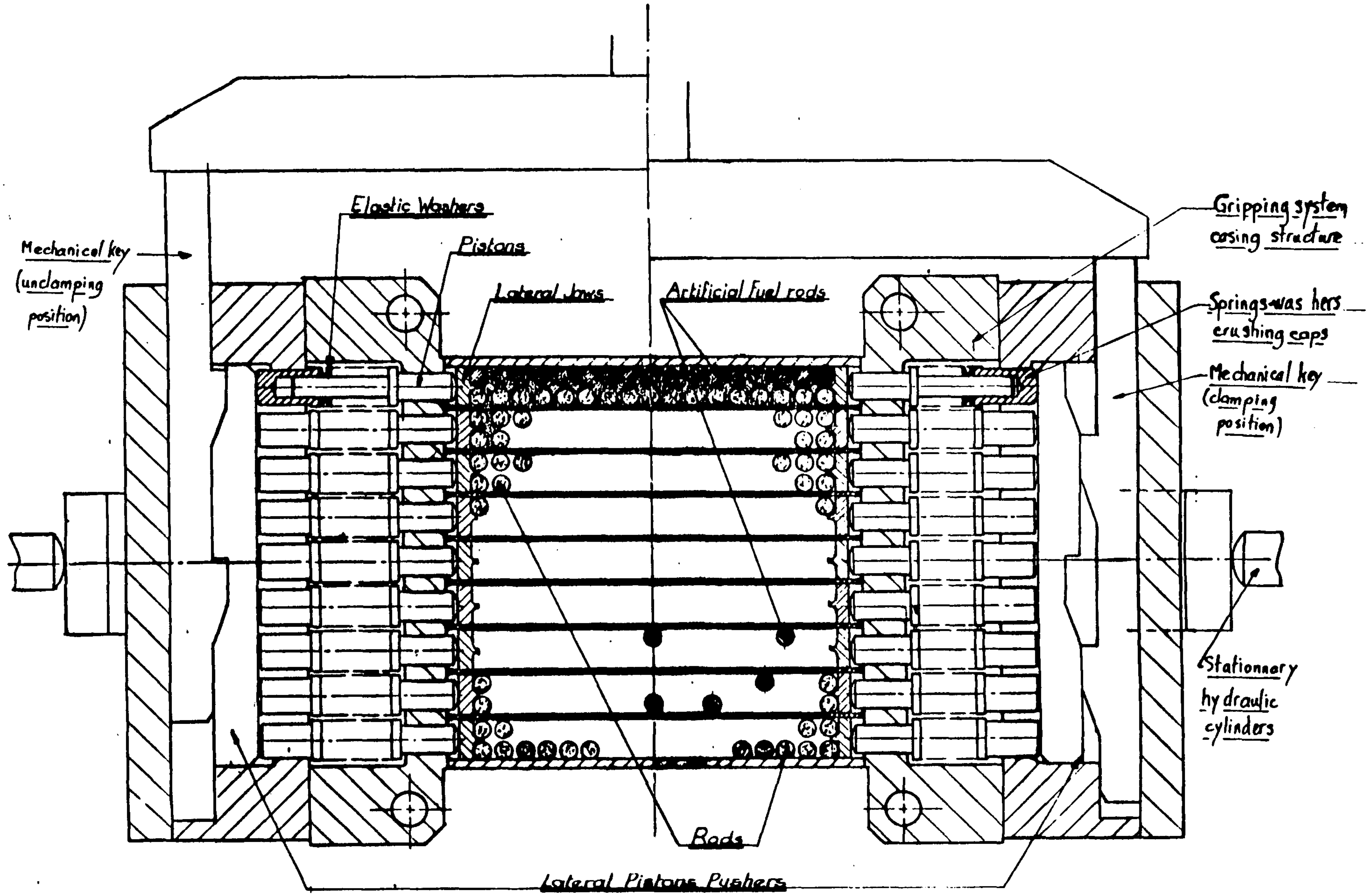


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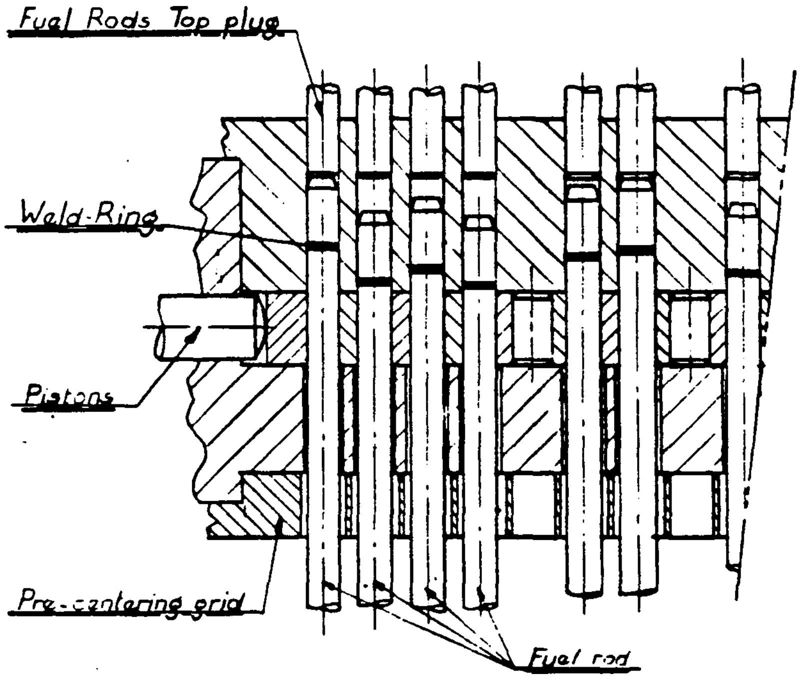
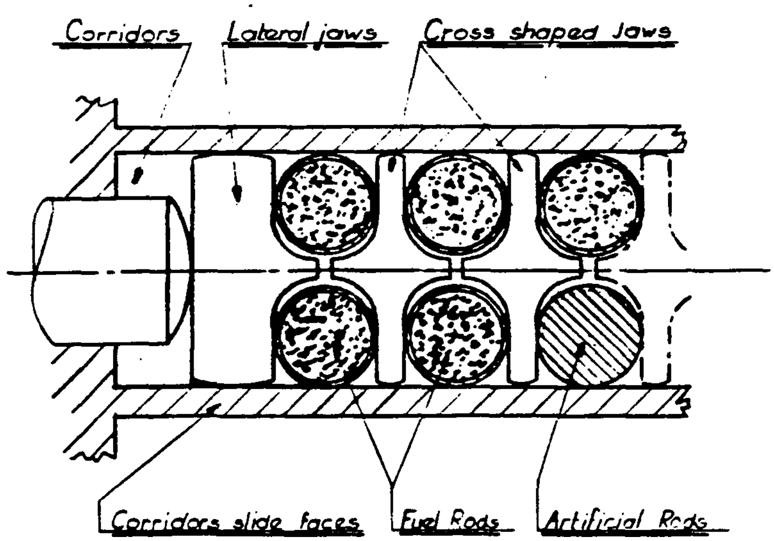
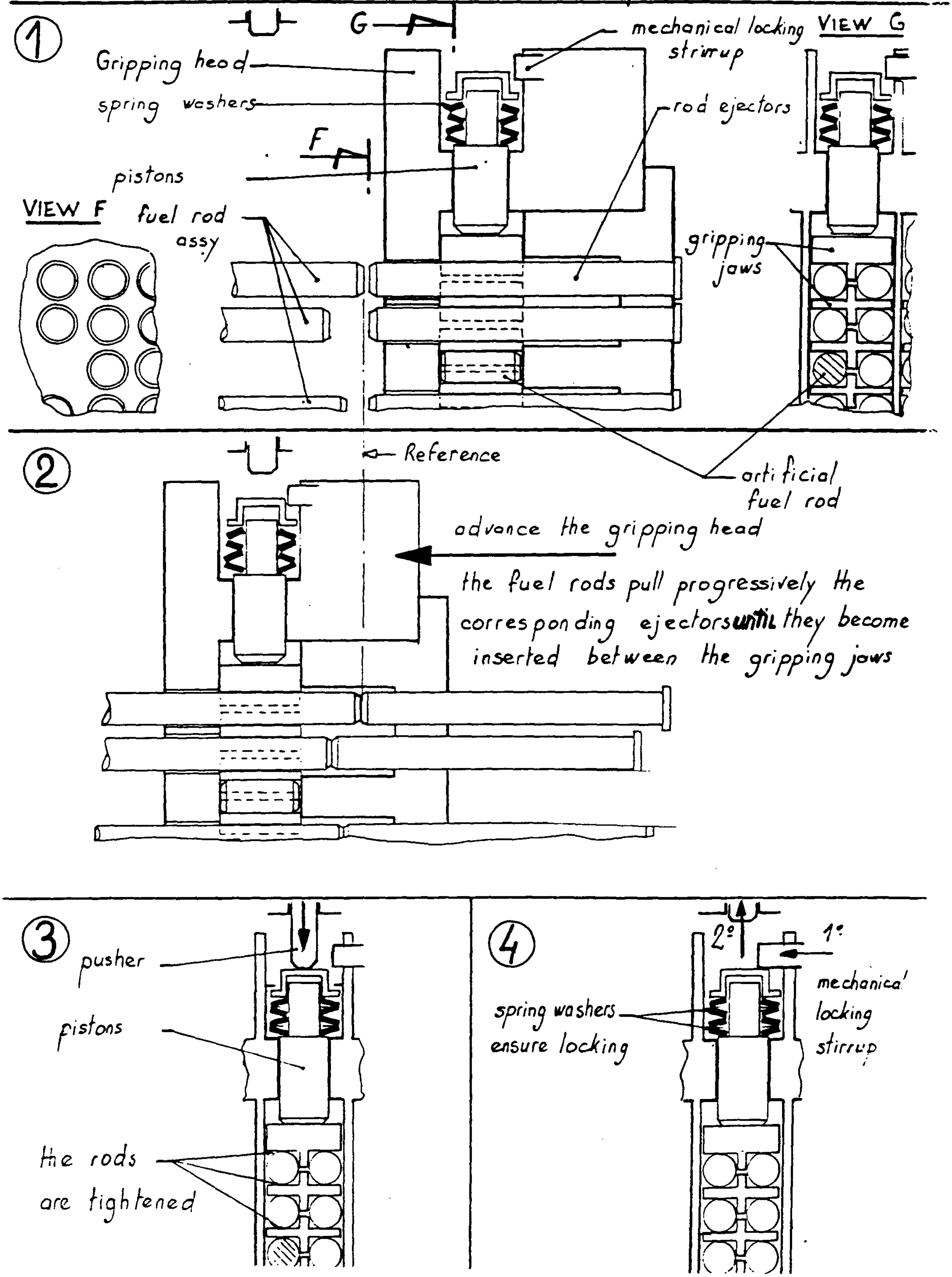
Figure 2-15

Gripping Head Details





GRIPPING HEAD sketch of operations 1/2



gripping head and mechanically secured. The hydraulic cylinders then retract and no further pressure is required to keep the rods locked into the head through the fuel rod removal sequence.

The traversing cart with the gripping head is retracted by the hydraulic system, pulling the fuel rods from the element until the head is in the accountability position, near the rear of the bench. During the withdrawal the support combs described in the next section are activated

d) Vertical and Horizontal Comb Modules

A vertical and horizontal comb module consists of a common support on which are located the vertical combs and one section of horizontal combs. Each vertical comb is a little longer than the fuel element width. Each horizontal comb is composed of two parts, the width of each part being half the width of the fuel element. The vertical combs rotate on a horizontal axis rotating inside support bearings. Each horizontal comb is assembled on a vertical shaft rotating inside the same bearing housing. In normal resting position the vertical combs are raised by a counter weight and the horizontal combs are moved aside for passage of the gripping head. Retracting the gripping head causes each vertical comb in turn to rotate into the rod array driven by a cam linked to the puller. After each vertical comb has been rotated to the vertical position, the corresponding horizontal combs are rotated by two driving bars located at the side of the fuel rod removal bench.

When consolidating BWR 7 x 7 fuel elements, the combs will have a gap to allow the passage of the capture rod with its licking tabs. The position of this gap will be determined for the exact position of the capture rod.

e) Fuel Rod Accountability Module

When the gripping head reaches the accountability position in line near the rear of the bench, it stops and the accountability module is lowered into place between the bundle hardware and the bottom of the fuel rod array. The role of the accountability module is to check that all fuel rods have been removed from the fuel element (check C1) and that all the rods are intact (check C2). When not engaged, the module will be positioned behind a shield to avoid deterioration of the sensors.

Check C1

The device moves into the clearance between the bundle skeleton and the end of the fuel rod array, as shown in Figure 2-17. The module is fitted with two sensors connected to an electric switch. If either sensor contacts a fuel rod in this zone which should be clear, the lowering motion is stopped and the module is retracted to allow for inspection and intervention. If the module crosses the zone freely, check C2 can be performed.

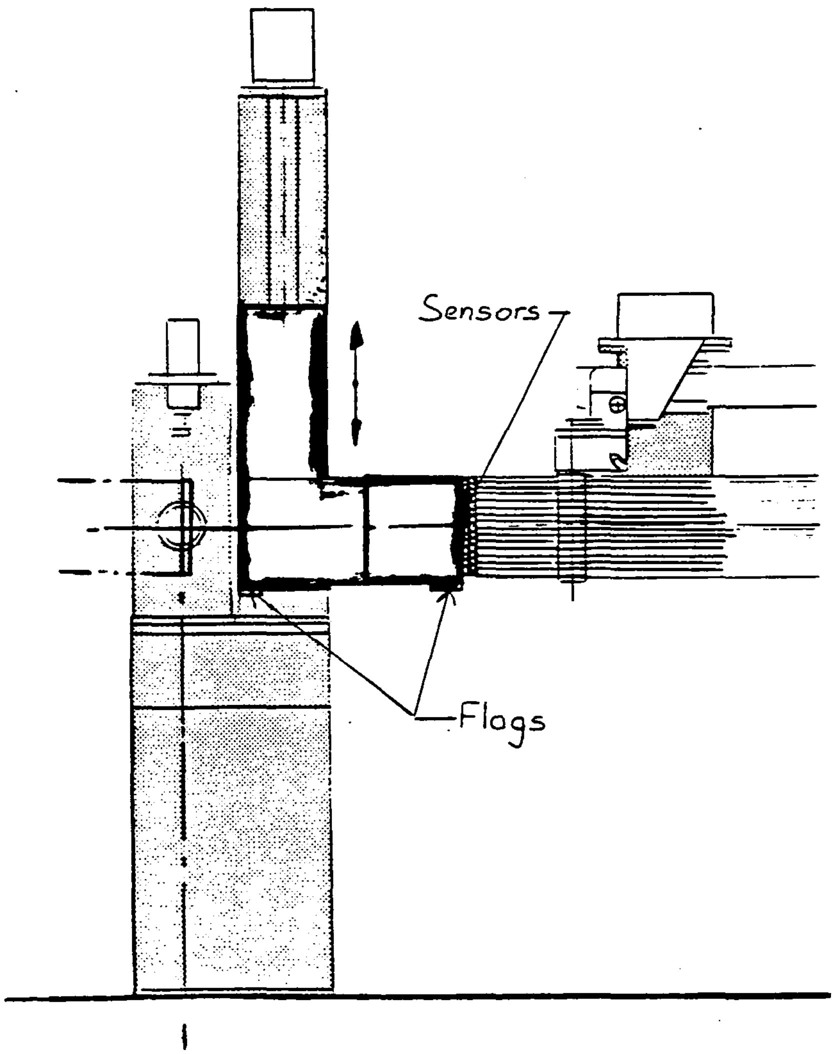
Check 2

The module is fitted with an array of sensors corresponding to the array of fuel rods to be checked. When fully lowered, each sensor is in line with a fuel rod held in the proper array by the combs. Each individual sensor includes a tube sliding into a hole in a support plate on the module. A helical spring between the tube and the support allows for individual positioning of each sensor since the fuel rods may be of different lengths. A microswitch is attached to the rear part of the tube, behind the support plate. Inside each

tube an inner spring-loaded rod slides in normal position, the outer end of the rod extends 0.2 in beyond the tube, while the inner end is nearly in contact with the switch.

When the accountability module is in position, the gripping head moves back toward the bundle hardware so that each fuel rod contacts the corresponding inner rod, tripping the switch and indicating the

Figure 2-17 Accountability Check



presence of the fuel rod on the control panel. The advancing fuel rods continue until the tubes are pushed up to a positive stop and the motion of gripping head halts. If a rod has been broken the switch is not contacted and the absence of the fuel rod appears on the control panel. In the most difficult situation, where the bottom plug of one rod is missing, there would be a gap corresponding to the length of the plug inside the fuel rod cladding (about 0.4 in). As a consequence, since the sensor inner rod extends outside the tube by just 0.2, the tube itself is pushed by the fuel rod cladding without contacting the inner rod.

The accountability must be set up to correspond to each fuel element array including empty locations. Likewise, the microprocessor in the control panel must be programmed to properly indicate and check each array.

f) Fuel Rods Ejection From The Gipping Head

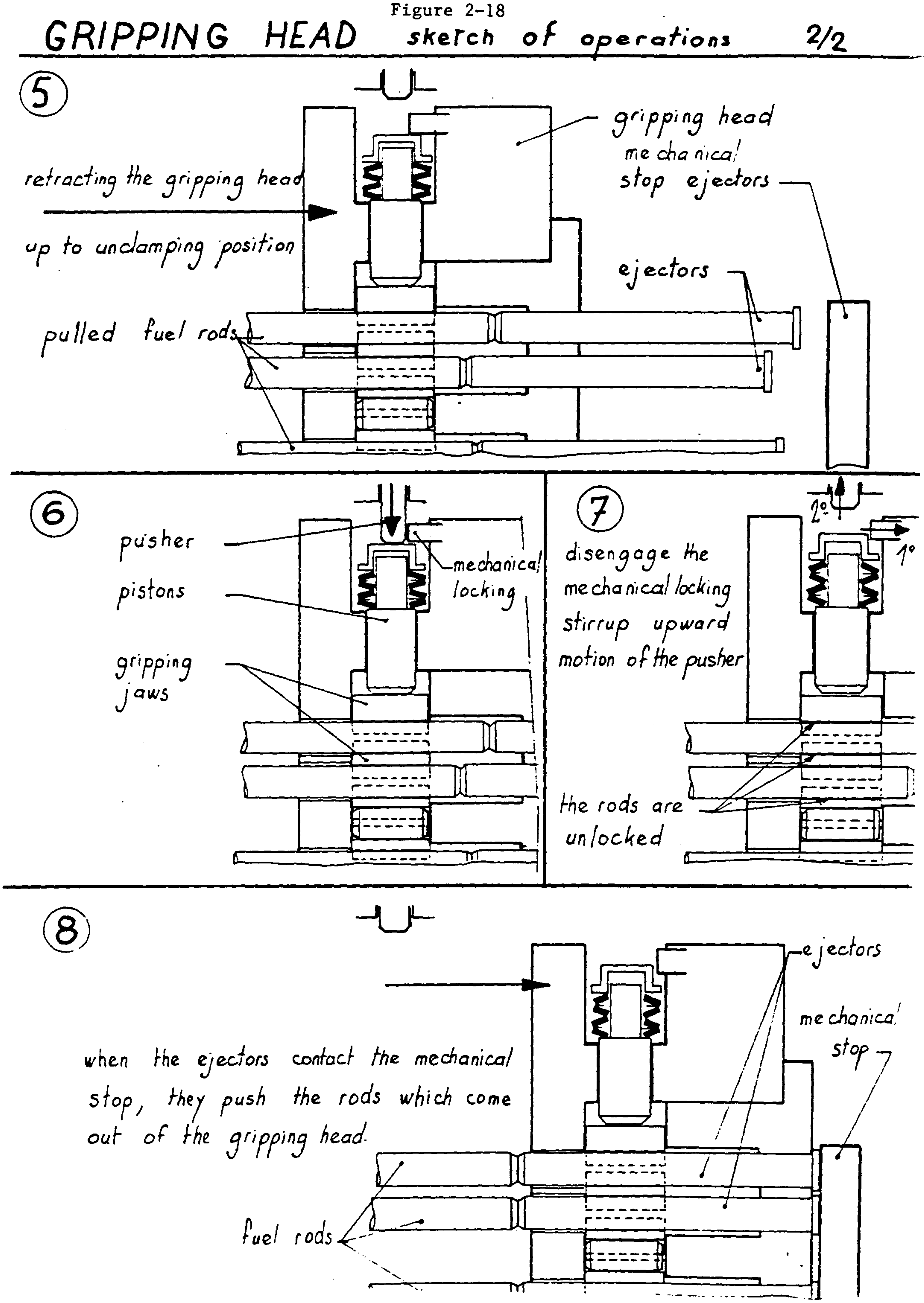
After the accountability check is successful, the gripping head is again retracted and stops in alighment with the three hydraulic cylinders located at the rear of the bench. As shown in Figure 2-18 both horizontal hydraulic cylinders are then moved to compress the spring washers, providing a clearance which allows the mechanical lock stirrup to be lifted by the vertical cylinder. The locking process is thus reversed and the fuel rods are unclamped.

When the unlocking process is complete the gripping head moves to extreme rear position. When the ejector rods reach a mechanical stop, they are forced into the gripping jaws array, pushing the fuel rods out of the jaws, and readying the gripping head for the next cycle.

g) Safety Interlocks

Fuel rod removal starts after the transfer-table has been moved in line with the removal bench and the fuel element is clamped in

Figure 2-18


GRIPPING HEAD sketch of operations 2/2
5
retracting the gripping head
up to unclamping position
gripping head
mechanical stop ejectors
ejectors
pulled fuel rods
6
pusher
pistons
gripping jaws
mechanical locking
7
2°
1°
disengage the mechanical locking stirrup upward motion of the pusher
the rods are unlocked
8
ejectors
mechanical stop
when the ejectors contact the mechanical stop, they push the rods which come out of the gripping head.
fuel rods

place. In the first step of the sequence the gripping head moves forward to enter the fuel rod array. From this step to the final ejection of fuel rods the whole sequence is automatic as long as both accountability checks are successful.

To control this automatic operation many interlocks have been provided to assure safety of the operation. For example, the gripping head advance motion to the fuel element is prevented unless the transfer table has been aligned with the removal bench and the clamping plate is holding down the fuel element. Next, the vertical cylinder driving the mechanical lock stirrup operates only when both horizontal cylinders have reached shutoff pressure condition. this allows the mechanical lock stirrup to be pushed into place. This the gripping head may retract when the mechanical lock stirrup is in place and all hydraulic pressure is relieved. The acccountability module moves down when the gripping head reaches the predetermined position defining the checking zone. The gripping head then advances to contract the sensors when the accountability module is in line with the fuel array. In this position, the module support constitutes a positive stop for the gripping head, tripping the over-pressure shutoff.

When the presence of all fuel rods is indicated, the gripping head is allowed to retract into the unclamped position. In this position, the vertical cylinder is prevented from actuation until both horizontal cylinders have reached overpressure shutoff to provide clearance for raising the mechanical lock stirrup. The hydraulic pressure must be relieved before the gripping head may retract to the extreme rear position for ejection of the fuel rods.

h) Off Normal Conditions

See Section 3.3

2.2.5 Fuel Rod Packaging

The Fuel Rod Packaging station involves four main functions :

- rod reconfiguration,
- canister loading,
- canister closure,
- canister handling.

Details of these operations are discussed in the following sections.

Rod Reconfiguration System

The rod reconfiguration system performs the transfer of rods row by row into the rod reconfiguration module, the shape of which is the same as the section of the fuel canister to be loaded. Any regular geometry can be accommodated.

a) General Description

The rod reconfiguration system includes the following sub-systems:

- a tray which receives and transfers rows of rods
- a pusher (pusher B) which moves the tray
- a reconfiguration frame with a cross-section the same as the consolidated rod storage canister.
- a rod support table which extends from the fuel array to the rod consolidation module
- a pusher (pusher A) which advances under the fuel array and holds the vertical rows of rods in place.
- horizontal blades inside the frame which support each row of rods as it is pushed into the frame.

- notched braces which are lowered through the open section of the top of the frame to maintain the correct arrangement of the rods.

b) Detailed description (see drawings PE 1886 20 007, 008, 009, 012 and 013)

Tray: The tray is an interchangeable carrier for one row of fuel rods. It is segmented into five sections distributed along the length of the rods. Each segment of the tray is divided by walls, the pitch of which is the same as the fuel element to be processed. The tray and other components are shown in Figures 2-19 and 2-20. The tray is mounted on a cart which moves from the fuel element toward the reconfiguration frame which is adjacent and parallel to the array of rods. The cart is supported by rollers and is the same for all types of fuel elements. When the reconfiguration begins, the horizontal combs in the fuel array are simultaneously opened, allowing the rods to drop into columns between the vertical combs, and the lowest row of rods falls onto the tray.

Pusher B: Pusher B is driven by an electric actuator self-connected to the tray mobile support cart and pivoted at its other end to allow vertical movement of the tray.

Reconfiguration Module: This module is a box common to all fuel elements which receives different frames having the same cross-section as the consolidated rod storage canister.

The reconfiguration module can be incrementally lowered, step by step, corresponding to one row of rods. The reconfiguration module is aligned with the axis of the canister to be loaded.

Rod Support Table: The rod support table extends from the reconfiguration module toward the fuel rod element. It is

Figure 2-19 Reconfiguration System Plan View

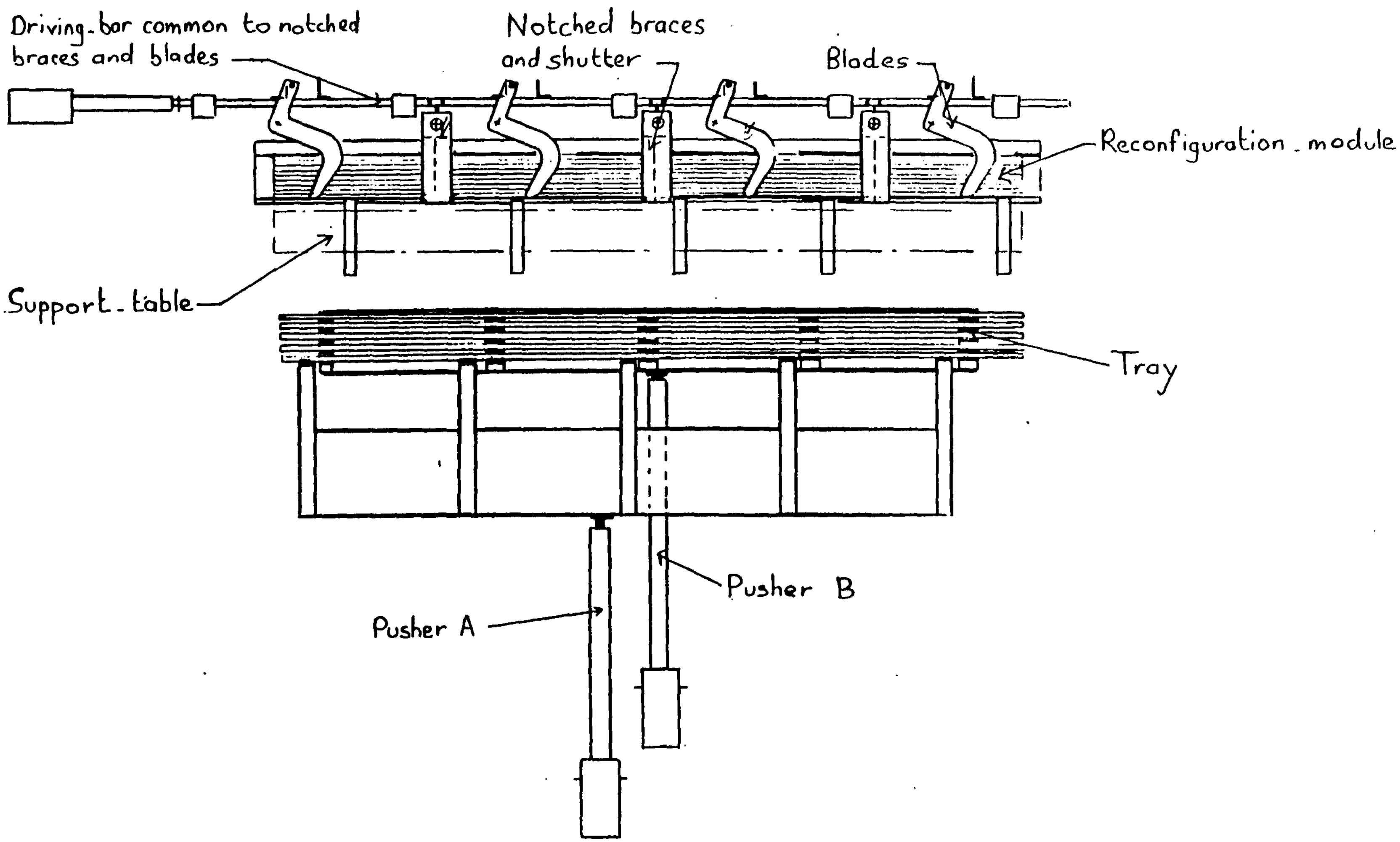
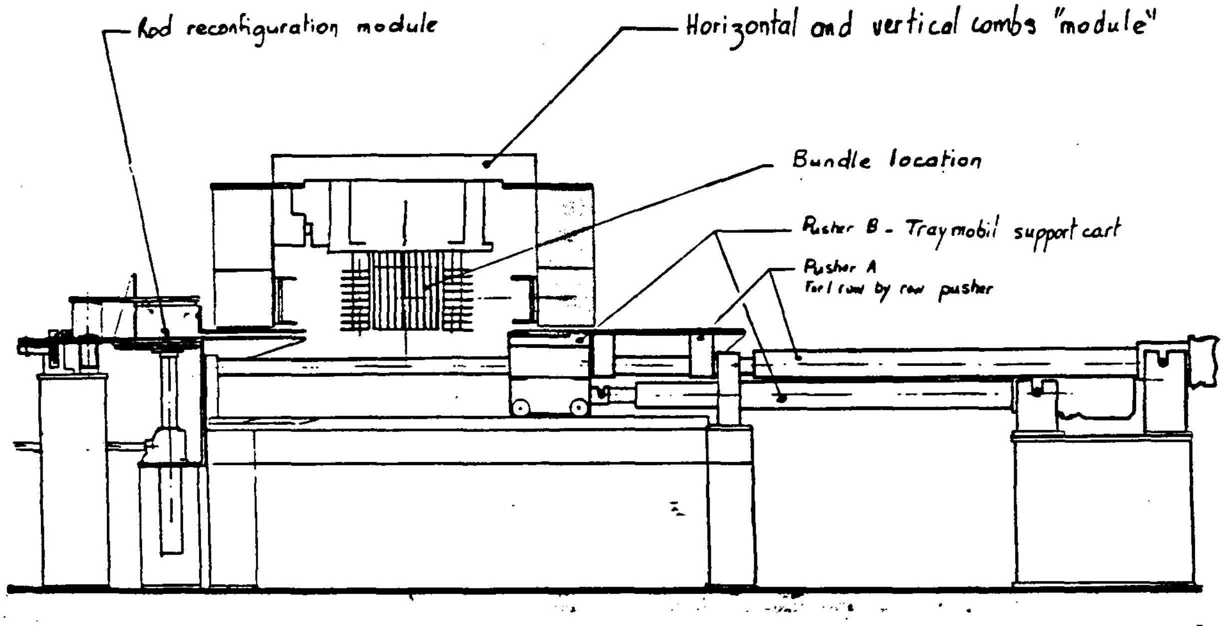


Figure 2-20 Reconfiguration System Elevation



segmented into fingers which fit between the segments of the tray when the latter advances. The tray support cart rails are depressed under the table, so that when the tray reaches this position the rods are deposited on the table. A cover plate over the table prevents the rods from overlapping when being pushed onto the table.

Pusher A: This pusher, driven by another electric actuator, has five arms which push the row of rods from the rod support table into the reconfiguration module. It also continuously supports the vertical columns of rods and prevents their falling when the tray is translated.

Horizontal Blades: There are four retracting horizontal blades aligned with the rod support table which constitute a sliding surface for the row of fuel rods when being pushed into the reconfiguration module. The blades are connected to a driving bar common to the blades and to the notched braces. The driving bar is actuated by a gearmotor. The "S" shape of the blades is designed to minimize the friction with the rods when being withdrawn. When they are inserted, the blades cross the reconfiguration module through gaps in its wall and reach to the suport table.

Notched Braces: The notched braces consist of remotely removable plates with notches corresponding to the fuel rod diameter. The notches of one plate are offset from the other so as to arrange the rods in a triangular close-packed array. There are three pairs of notched braces which are freely hinged on one arm. Each arm is moved by a driving bar common to the blades. When the arms are moved down, the notched brace corresponding to the row to be maintained moves down due to its own weight to hold each rod in place while the other brace stops when it contacts the rods with the tips of the notches resting on the middle of the rods.

Shutter: The shutter is an integral part of the notched braces, but its travel is longer than the notched braces so that it stops the advance of the rods when needed.

c) Sequences and Safety Interlocks

Prior to starting the reconfiguration sequence, the configuration of the fuel element is entered on the control panel to account for the empty locations due to guide tubes or water rods.

The gripping head is prevented from moving in either direction unless both pushers A and B are retracted. After the fuel rods have been ejected, the gripping head reaches the extreme back position, allowing pusher B to move the tray from its retracted position to the fuel rod array. Pusher A is prevented from moving at this time. When the tray is in position, an interlock allows the horizontal combs to open so that one horizontal row falls down into the tray.

Once the tray is loaded with one row of rods, it is pushed from the loading position to the rod support table close to the reconfiguration module. The tray trajectory is lowered as the tray reaches the support table so that the fuel rods are left on the table. Pusher A is allowed to move from its retracted position to the reconfiguration module when three conditions are satisfied:

- the retractable blades are in position in the reconfiguration module
- the notched braces and the shutter are raised
- the reconfiguration module is in the upper position.

The lowering of the tray activates pusher A which pushes the rods though the entrance of the reconfiguration module. The pushing motion is automatically stopped when the fuel rods contact the opposite wall of the reconfiguration module. This is detected by a sensor located in the arms of pusher A. The same signal causes the notched braces to fall onto the row of rods and the shutter to stop any remaining portion of the row on the table.

The actuator for pusher A is also fitted with a sensor adjusted to a slightly higher force. Thus, even if the direct sensor fails, the second stops the advance. As the motion of pusher A is monitored on the control panel, it is possible to detect if jamming occurs before the fuel rod row has contacted the wall of the reconfiguration module.

When the reconfiguration module row is filled, the horizontal blades are retracted causing the single row of rods supported by the blades to drop into the module. The rods are driven by their own weight and the notched braces while any excess rods are kept captive on the table by the shutter. When this step is complete the reconfiguration module is moved one step down and the horizontal blades are again inserted.

There are three cases to consider in filling one row of the reconfiguration module.

(1) If the number of rods placed on the rod support table by the tray is more than enough to fill one row, the system works as described above. Thus, each time the fuel rod row contacts the wall of the reconfiguration module, pusher A stops, controlling automatically the retraction motion of the blades and the lowering of the reconfiguration module.

(2) The number of fuel rods placed on the table is the same as the number of rods necessary to fill one row of the reconfiguration module. In this case the entire row is transfered, no rods are left on the table, and the module lowers by one row.

(3) The number of rods placed on the table is not sufficient to fill one row of the reconfiguration module. In this case, when the row contacts the wall of the reconfiguration module, the stop signal does not activate the blades retracting motion and as a consequence the module is not lowered.

This process requires the microprocessor controlling the operation to keep track of the quantity of fuel rods in each horizontal row of the fuel element and the quantity of fuel horizontal rod rows loaded into the reconfiguration module. For example, for a PWR 15 x 15 element loaded into a square reconfiguration module, there will be 22 rows of 19 fuels rods with the last row including only 17 rods.

D. Off-Normal Conditions

One of the characteristics of the system is to perform the reconfiguration sequence while maintaining the fuel rods on a single level from the rod removal station to the reconfiguration position. This minimizes the risk of loosing fuel rods in inaccessible areas. In case of any failure of the normal operating system, an additional actuator is inserted beneath the support arms to raise the reconfiguration module, thus releasing the driving actuators from any load. Recovery of broken or stuck rods is covered in Section 3.3.

Canister Loading Station

The canister loading station constitutes the interface between the "Rod Consolidation Cell" and the "Canister Cell". A contamination tight plug is provided in the Rod Consolidation Cell to close the transfer hatch from one cell to the other. During normal conditions the hatch is closed. When loading the canister, the hatch is open to enable the passage of the reconfigurated fuel rod bundle from the reconfiguration module to the canister. (See Figure 2-21).

The main equipment in the rod consolidation cell are the following:

. the fuel rods bundle pushing device,
. the tight lid,
. the reconfiguration module, which is the common equipment with the fuel rod reconfiguration station.

The pushing device consists of an electric actuator whose top head can be fitted with different types of pushers which mate with the

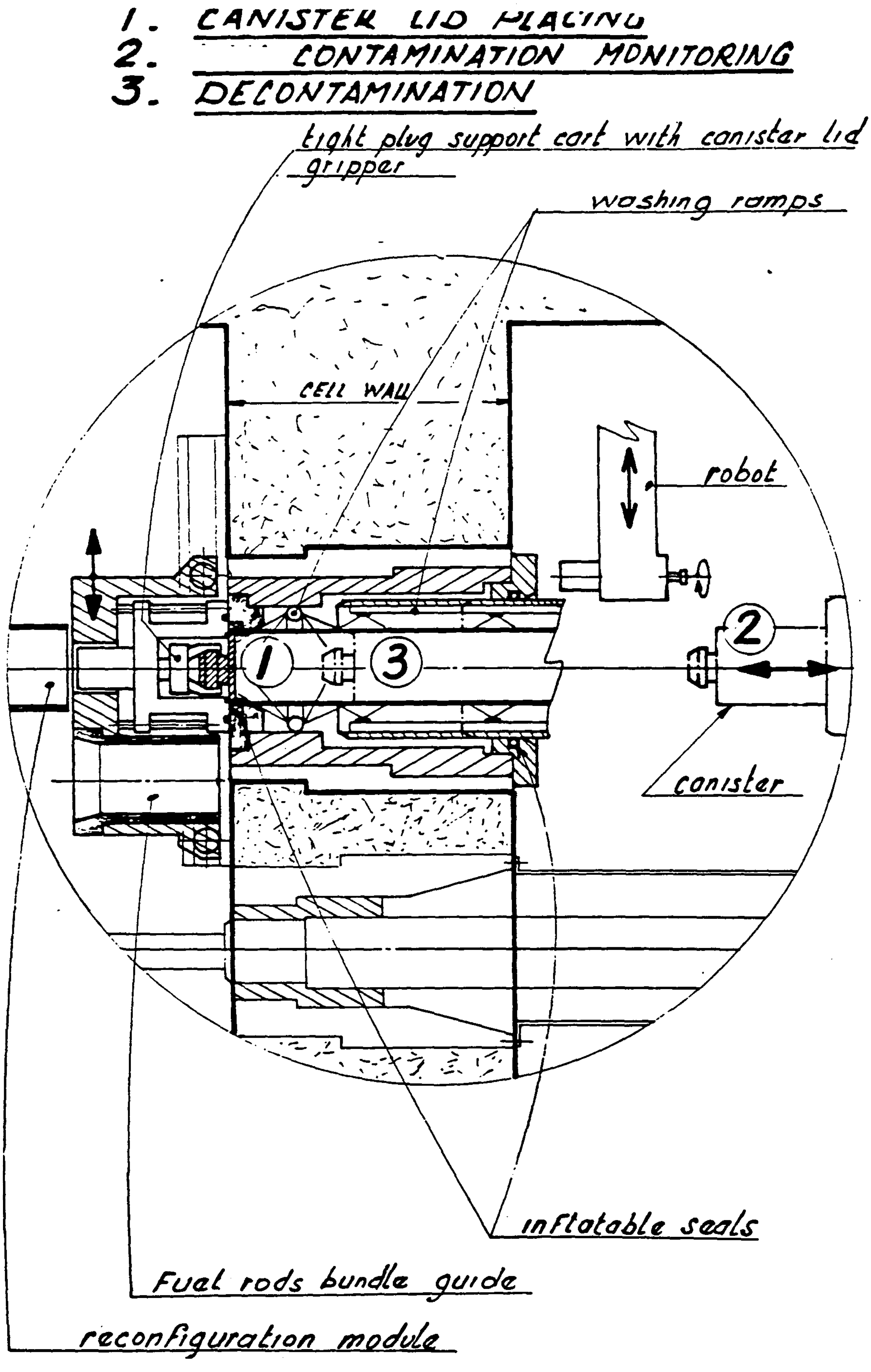


Figure 2-21 Canister Thru Wall Penetration

canister inside section geometry. The actuator lays on line with the reconfiguration module. The bottom part is joined with an open support shaped in such a way to keep the actuator locked in the horizontal position an enable its removal in the vertical position.

The tight lid includes two parts :

- a plug to close the cells communication hatch
- a guide to keep the reconfiguration module and the canister on linewhen the fuel rods bundle goes through the wall.

The plug inner part includes a gripper to grasp the canister lid from the canister top end to pull it inside the plug, and tight against the back wall. This operation is performed in a tight chamber created by the cell wall and the canister in tight contact with the other face of the wall. In that way the lid outside upper face is kept "clean" while the canister loading operation is progressing.

The guide is open on both side. Its inside section is shaped in the same geometry as the canister inside section. It is slightly sloped from outside to inside, to provide clearance sufficient to accept the fuel rods bundle from the Rod Consolidation Cell side. Both the plug and the guide are assembled onto a common cart. Translating the cart brings either the plug in line with the wall hatch or with the canister.

The main equipment in the canister cell are following:

One handling crane provided with two independent lifting drive units. The crane is specific to the handling of canister and can be fitted with different grapples each peculiar to one type of canister with regard to its outside geometry. The grapple connection to the crane pulley block is performed by remote operations.

One longitudinal table fitted with rollers. This table supports one tilting device equipped with clamping devices, each specific to the outside geometry of the canister. The tilting device has a U shaped structure. The inner part of the U is fitted with rows of spray-nozzles to ensure decontamination of the canister. The tilting devices controlled to rotate from the vertical to the horizontal position by a hydraulic cylinder (same as the fuel elements tilting device), laying the empty canister down on the table. After receiving the canister, the canister is pushed forward to make the canister and the upper part of the tilting device penetrate inside the cell wall penetration. The table pushing actuator is installed outside the canister cell.

One tight channel fitted with two inflatable seals (one on the top head and the second on the bottom part). Each channel is specific to one geometry of canister and has to be installed from inside the Canister Cell. The channel includes an inner circular ramp fitted with water spray nozzles. This provides decontamination of the canister.

One robot to check that the canister has not been contaminated during packaging.

One automatic welding machine for sealing the canister lid.

The welding machine is composed of : (see also drawing PE 1886 20 014)

- a frame which supports the torch
- the torch with its motorization
- clamping systems to clamp both the canister and the lid during welding
- cables for utilities

The monitoring of the welding is performed by the monitoring of the following parameters :

- welding intensity
- welding tension
- plasmogene gas flowrate
- protection gas flowrate

- rotation speed of the torch
- cooling water flowrate

Description of Operations and Safety Interlocks

While the reconfiguration operations are progressing inside the Rod Consolidation Cell, one empty canister has to be placed on packaging position inside the Canister Cell. This includes :

. handling of one empty canister from batch storage to the tilting device.
. placing the canister onto the tilting device and clamping it
. rotating the tilting device to horizontal
. pushing the table far enough to make the canister penetrate into the cell wall passage

To perform these operations safely, the following interlocks are provided :

- The tilting device is authorized to rotate on condition that the clamping operation has been performed and the crane disengaged from the tilting device rotation area.

- The canister handling grapple is authorized to ungrasp on condition that the clamping of canister has been performed

- The longitudinal table is authorized to move forward on condition that the presence of the canister has been detected in horizontal position.

- With regard to the cell penetration, the table is authorized to move forward on condition that both inflatable seals are depressurized.

- the seal plug is authorized to be translated on condition that the longitudinal table has been moved forward making the canister top head penetrate into the cells wall penetration and both inflatable seals are under pressure contact with the seal plug inner wall.

- the fuel rod pushing device is authorized to advance on condition that the plug has been translated to bring the intermediate guide in line with the reconfiguration module inside the rod consolidation cell and with the canister.

After the fuel bundle has been pushed far enough inside the canister, the pusher is returned to the initial position. During this phase the following interlocks are provided :

- the seal plug is authorized to be translated on condition that the pusher is in the retracted position,

- simultaneous controls of the pusher and the seal plug are inter locked,

- the longitudinal table is authorized to move on condition that the tight plug has been translated into position to close the cells wall gap and the canister lid has been repushed and ungrasped, closing the canister and both the inflatable seals are depressurized.

At this phase of operations, the table is retracted about 5 feet to disengage the canister top-head from the hatch and to put it in line with the robot for contamination monitoring. After the checking has been performed, the canister is removed from the table using the tilting device and rotated to the vertical position. When the cannister is removed from the tilting device, it has to be unclamped to enable the cell crane to transfer it into the canister closure welding pit. The unclamping operation is authorized on condition that the cell crane grapple hooks are in position grasping the canister. The canister top head emerges from the pit to enable the canister lid to be welded using an automatic welding machine. The welding operation is programmed and all welding parameters checked and recorded by the computer.

With regard to hexagonal or round shaped canisters the same procedure to be performed in except that loading requires two identical steps. Since the canister must be compartmented, it has to be rotated by 180 degrees using the cell crane. The canister is placed onto the tilting device and rotated down to horizontal position on the table for loading the second compartment. The cask lid welding is performed at the end of the second step after the two compartments have been filled.

Simple stress calculations have been completed which show that 0.125 inch canister wall thicknesses are more than adequate to lift the loaded canister and to prevent bending.

2.2.6 NFBC Handling

As already given in Subsection 2.1.6, no specific handling equipment is provided to handle the NFBC or the NFBC canisters. NFBC is completed by using the rod consolidation cell crane. The hatches and associated plugs are simpler than the hatch and plug of the rod packaging station, because they do not contain decontamination systems. Concerning the canisters themselves, the process requires two types of NFBC canisters :

* four compartmented canisters which will receive four skeletons,

* non-compartmented canisters, which will contain a shock absorption grid made of welded cross-pieces. Deformation of these grids absorbs the shock energy without risking a perforation of the bottom of the canister. This type of absorption grid was sucessfully tested by CEA for a 30 feet high chute for end-fittings in 1985.

Each canister will be about 15 ft high, square section dimensions 20 in x 20 in and about 0.125 inch width.

2.2.7 In-Cell Support Requirements

Lag Storage

The in-cell lag storage is located in a pit in the cell. Advantages are good earthquake protection and less equipment weight. It is divided in 2 parts : one PWR lag storage and one BWR lag storage. It is constituted of cavities,containing one fuel element. Consequently, there will be 28 cavities for PWR elements and 28 cavities for BWR elements. Each cavity is perforated to allow air circulation provided by the in-cell ventilation. The cell area of the lag-storage is about 9 ft x 4,5 ft.Fuel rod canister lag storage is a pit constituted of perforated cavities about 8 ft high. The cell area of the rod canister lag storage is about 4,5 ft x 5 ft, and is divided in two parts: one part for the empty canisters, and one for the filled canisters.

The NFBC canisters lag-storage is located under the cell in a corridor.

Canister Decontamination Section

Contamination detection equipment is made up of:

- a frame which supports the different components of the equipment.

- a tool holder made of articulated arms with electrical motors. Coders measure the positions of the arms and allow the definition of the smear brush trajectory. An over pressure is maintained in the arms by blowing air to avoid contamination of the equipment.

- a smear brush is fixed to a remote manipulated device on the extremity of the last arm of the tool holder.

It ensures:

- the smear brush is held tightly
- the smear-brush is rotating
- the smear-brush is applying constant pressure on the canister
- a controller (out of the cell) that ensures the control of all the smear-brushing operations
- a power unit (out of the cell)

Decontamination of the rod canisters is performed by high pressure water in the channel and by low-pressure water in the tilting device. Water is projected through spray-nozzles placed along a circular ramp inside the channel and along the tilting device. Liquid waste is collected and directed towards the water treatment cell of the facility.

As only the upper-part is decontaminated the liquid waste generation is minimized.

2.2.8 Equipment Safety and Licenseability

Equipment protection in the rod consolidation facility is largely an investment protection concern rather than a safety concern. The risks are those of minimizing down time and expensive equipment replacements rather than personnel or public safety. Major considerations for equipment protection are the control of crud and contamination, safety interlocks, accidental drop protection, and seismic/structural assurance.

Contamination Control

Contamination control will be accomplished by process selections, equipment design and good housekeeping practices, structural configuration and ventilation confinement zones.

Processes selected for crud and contamination control include shearing (rather than cutting), collecting cuttings inside the tubing and build-in collection capacity.

The transfer table is designed with an arrangement that forms a channel around each element as it is handled. Cruds fall into the channel and are swept into a vacuum system which exhausts into a filter. Also a tray is positioned below the rod transition station so loose crud and contamination are collected there.

To reduce and control the level of contamination in the process cell where rod consolidation is being performed, remote light housekeeping will be done during slack periods or when dust or particulate accumulation is observed. This will be accomplished by a manipulator operated in-cell vacuum cleaner. A complete remote manipulator cleanup of the cell and consolidation equipment will be performed at the end of each campaign. Major decontamination of the cell will only be performed when or if manned entry of the cell is required.

In the event of a broken rod during the consolidation process, the broken pieces of rod and any large pieces of fuel pellets will be recovered and placed in the special broken rod fuel canister. The area below the position of the broken rod will be vacuumed with a clean vacuum filter and the filter and its contents placed in the broken rod fuel canister.

To prevent the spread of contamination from the process cells to surrounding areas, the ventilation system is designed to maintain air flow within the facility from less hazardous areas to more hazardous areas and to preclude dead air spaces within the facility. Higher hazard areas are maintained at a negative pressure relative to lower hazard areas.

Safety Interlocks

Safety interlocks have been provided which protect the equipment from operating out of sequence. Drawing SH 1886 20 005A lists the limit switches, safety interlocks, hydraulic pressure switches, automatic programs, and memorized visualizations that protect the equipment. There are 123 applications which use limit switches to signal positions and conditions, safety interlocks to authorize automatic actions, and hydraulic pressure switches to limit forces.

Accidental Drops

Accidental drops of fuel elements and equipment is avoided by specifying standard redundant systems for all lifting applications.

Seismic

Seismic/structural concerns as regards the equipment are easily covered by the inherent massive shapes and structures provided to support the normal loads.

2.3 FACILITY SUPPORT REQUIREMENTS

Facility supporting requirements are described to provide an understanding of the interfacing that will be required when the MRS or repository is defined. These requirements include a description of the process cells and their major features and systems, a description of facility features required to support the process cells, then a description of required supporting services.

2.3.1 Process Cell Systems

Process cell systems are illustrated in layout drawing PI-1886-20-001. The cell features adequate space, shielded walls and windows, manipulators, wall penetrations, lighting, monitoring (sensors, viewing and audio) and decontamination features to perform all cell process and institutional functions.

Cell Floor Space

The inside dimensions of the process cells are:

- rod consolidation cell: 57' x 19' height: 24'
- canister cell: 18' x 19' height: 24'

The layout provides the necessary zones for access to the equipment, for maintenance and for initial installation as well as for final decommissioning.

Cell Shield Walls

When the exact position of the equipment in the cell has been determined and therefore the distance from the radioactive sources to the walls, calculations will be performed to determine the minimum thicknesses of the cell walls and any required additional shielding (lead, etc.). Scoping calculations indicate that about 5.4 foot walls of 156 pounds per cubic foot concrete are required.

Cell Windows/Manipulators

Windows and master-slave manipulators are necessary for remote maintenance and remote intervention in the process cells (for example, recovery from off-normal conditions).

The shielded windows have the following functions:

- o allow direct visual observation of equipment and activities in the process cells and enable visual inspection of the cells.
- o provide gamma and neutron biological shielding equivalent to that provided by the enclosure walls in which they are installed.
- o ensure continuity of process cell containment.

The number and the characteristics of glass slabs in the shielded windows are determined by the wall thickness and composition and the characteristics of the radiation sources. The relative sizes of slabs and their respective positions in the window insert determines the angle of vision.

A master-slave manipulator is comprised of a master arm and a slave arm connected through a wall penetration. This penetration allows mechanical connections (possibly associated electrical connections) between master and slave so that the operator's hand movements on the master hand is reproduced at the slave hand. These manipulators have at least 6 degrees of freedom and provide feedback to the operator.

The number of windows and associated master-slave manipulators necessary to perform maintenance will be:

- 8 windows and associated manipulators in the consolidation cell
- 2 windows and associated manipulators in the canister cell

Servomanipulator (SMN)

In addition to the master-slave manipulators, a servomanipulator (SMN) will be available for off-normal operations. The SMN will not be located in the process cells during normal operations and will be brought into the cells as needed. Consequently it will be used only for off-normal operations that are difficult or impossible to reach with the master-slave manipulators.

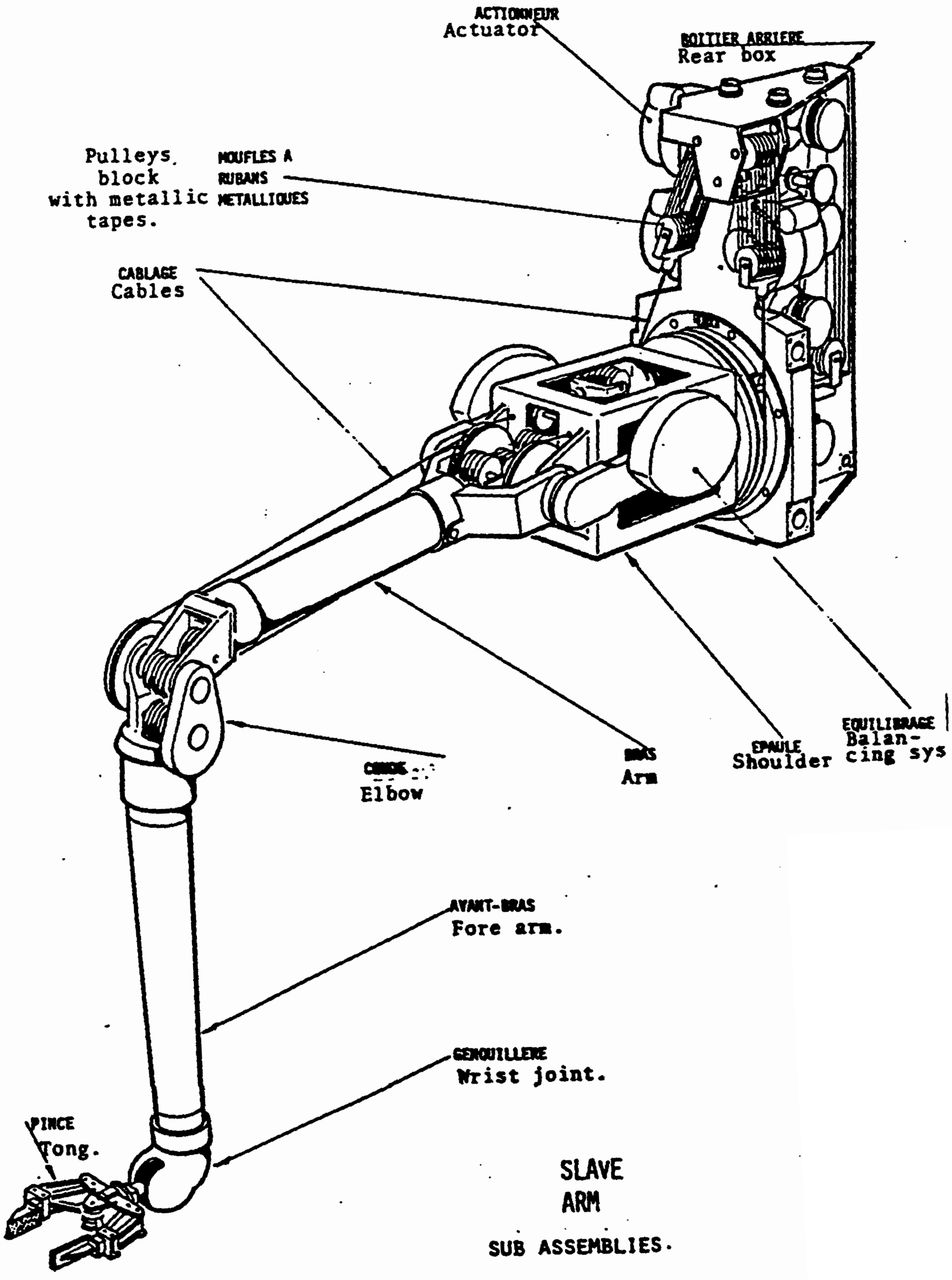


Figure 2-22 Slave Arm

The servomanipulator is basically an articulated arm master slave manipulator with an electronic servo-system giving a force feed back to the operator on all motions. The distance between the master and slave is in principal unlimited. Connection between the two is by multicore cable.

The load capacity in any position is 50 lb. The force feedback ratio between slave and master (S/M) is 4:1. The form of the arms is very similar to the human arm but with a two-fingered tong in place of a hand. This feature of the SMN permits the operator to carry out remotely all the operations which he could perform directly by hand. The design of the slave arm support will depend on the situation or the type of work which the SMN is intended to perform.

The slave arm (Figure 2-22) consists of a fixed part, called the rear body, and a moving part which is an articulated arm comprising all the parts of the human arm (shoulder, upper arm, elbow, forearm, wrist and hand).

The rear body is an open framework with an axial dividing plate. One side of this plate contains six of the seven electric drums. The pulleys of the reduction system are housed in the shoulder box. All motions are tape and cable driven except for the wrist and tong where gears are used.

Other Cell Wall Penetrations

The wall penetrations can be classified in two categories:

- penetrations for electrical wires, hoses, etc.
- penetrations for motorized or hydraulic drives

All the wall penetrations are designed to minimize transmission of radiation and to maintain confinement. The penetration configuration which meets these requirements and has been shown to be the most practical is a simple S-bend through the wall. If shielding analyses proves it necessary, additional shielding could be added. For example, steel plates can be inserted in the wall around the penetration opening.

Penetrations for Motorized and Hydraulic Penetrations

These penetrations are used to allow motors or hydraulic cylinders to be located outside the cells in non-contaminated areas (see Appendix II for further detail). The general layout of a mechanical penetration is shown in Figure 2-23.

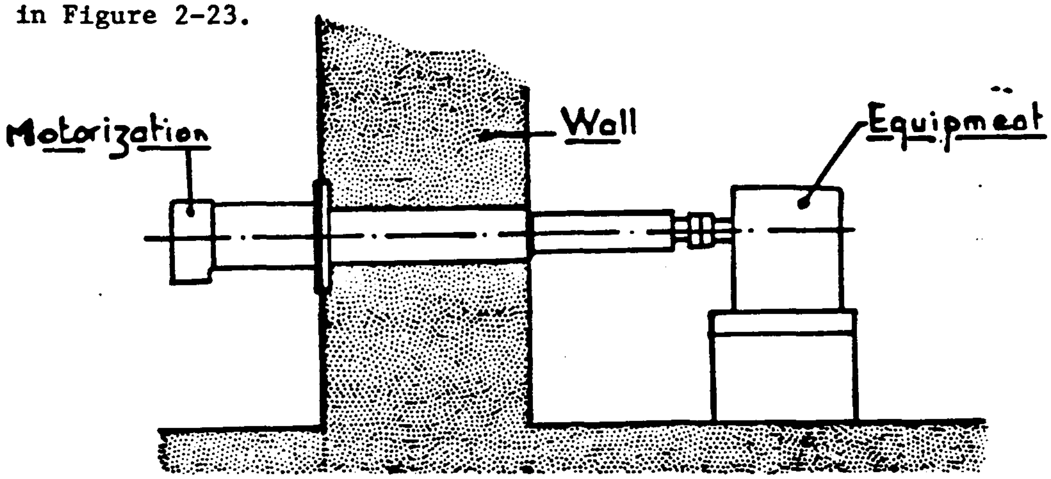


Figure 2-23. Mechanical Penetration

Penetrations are designed to ensure confinement during normal operations and special procedures are prepared to avoid any breach of confinement when a penetration needs to be removed. The need to remove these penetrations is highly improbable since the only parts in the penetration which could fail are bearings and seals:

- seals are protected by the penetration design
- the design life of the bearings is longer than the design life of the plant

In the generic facility, the main mechanical penetrations are for:

- the rod packaging station musher drive
- the translation of the intermediate wall plug drive
- the lowering of the mold (reconfiguration station)

No penetration of hydraulic lines into the process cells is necessary in the generic facility because the two hydraulic cylinders are located outside the process cells. One cylinder translates the transfer table and the other cylinder activates the rod removal station. The activator rod from the first cylinder penetrates the wall separating two clean cells (canister cell and material transfer cell) and therefore no special protection is needed. The other cylinder is located in the canister cell and is protected by a metallic cover. The penetration for the activator rod is in the wall between the canister cell and the rod consolidation cell.

In-Cell Lighting/Closed Circuit Television (CCTV)

The in-cell lighting/CCTV has a double purpose:

- give the operator in the control cell a general view of the cells and of the equipment during normal operations
- help the operators behind the windows during off-normal operations or during maintenance by focusing on specific equipment to be examined.

Both fixed cameras (for the general view) and moveable cameras for closeup views of specific equipment are provided. They will be moved by the cranes. The cameras will be the highest definition cameras available so as to produce the best quality image possible for remote operation. The monitors used with the cameras will have the same definition as the cameras. There will be two to four cameras for each monitor. The operator selects the camera that projects the desired image. The lighting system associated with the cameras must have the proper brightness to provide for good vision with the camera but not blind the operators. Furthermore proper placement of the lights will minimize shadows which could obscure good vision (with windows or cameras). The lighting system is designed to be maintained remotely. The number of lighting-CCTV systems will depend on the placement of the equipment in the cell.

Audiomonitoring

Microphones are located in the two process cells to provide for audiomonitoring. The noises in the cells can give good indications of equipment performance. Abnormal noise can be a sign of an impending failure or failure. One audio speaker will be located at each control post. One microphone is provided in the rod canister cell and two in the rod consolidation cell (one to monitor the sounds from the mechanical equipment and one to monitor noise in the whole cell).

Equipment Decontamination

Normally, equipment modules are disposed to waste without decontamination. In case a failed module is contaminated such that the radiation activity is too high for the shielded evacuation cask, it would be decontaminated in the cell by means of manipulator operated vacuum cleaners or smear-brushes.

At the end of their life-time (i.e. 30 years), the cells will be decontaminated using remote cleaning with vacuum cleaners and, if necessary, a spray-nozzle, all operated by the servo manipulator. For this purpose, plugs will be located in several places in the cell to connect flexible hoses for the vacuum-cleaner and spray nozzles.

2.3.2 Cell Support System

The in-cell maintenance system is by far the most important cell support system. This system is largely the result of designs that are intrinsic with the process equipment, and the maintenance equipment design. This section describes these design features.

Equipment Removal/Replacement

The process equipment will be of a modular design so as to facilitate removal and replacement of all key parts. An equipment module is made up of a number of functionally and spacially linked parts which, whenever possible, will be components with similar reliability. Modularization reduces the MTTR (mean time to repair) of components which otherwise, would have been too long to be acceptable and which could impact the average availability of the plant and reduce the probability of achieving the desired throughput capacity.

Generally speaking, a module performs a function or an operation. In addition to the functional parts, a module is also fitted with a base plate, a gripping system, a guiding and locking system, and male or female parts to mate with the support location. In each piece of equipment, the modules will be located so as to facilitate direct accessibility with the crane and manipulators.

The most commonly used locking system is the wedge system (see Figure 2-24) which consists of a male sloped key and springs fitted on the module. During installation or removal, the handling frame and the module constitute a couple. Specific levers of the frame keep the male sloped keys in the disengaged position. When the module is installed on the support, the module is positioned and set in place and the handling frame is withdrawn. This releases the male sloped keys and they are pushed by springs to lock into the female sloped keys of the support.

The modules will be designed to have dimensions so that they will fit into a NFBC canister or are easily disassembled into parts that do not fit into the NFBC canisters.

Maintenance Equipment

The maintenance operations require working space and equipment. Working space is provided in the process cell specifically to perform maintenance, and equipment is provided in cell storage areas. The equipment necessary to perform the remote module operation are:

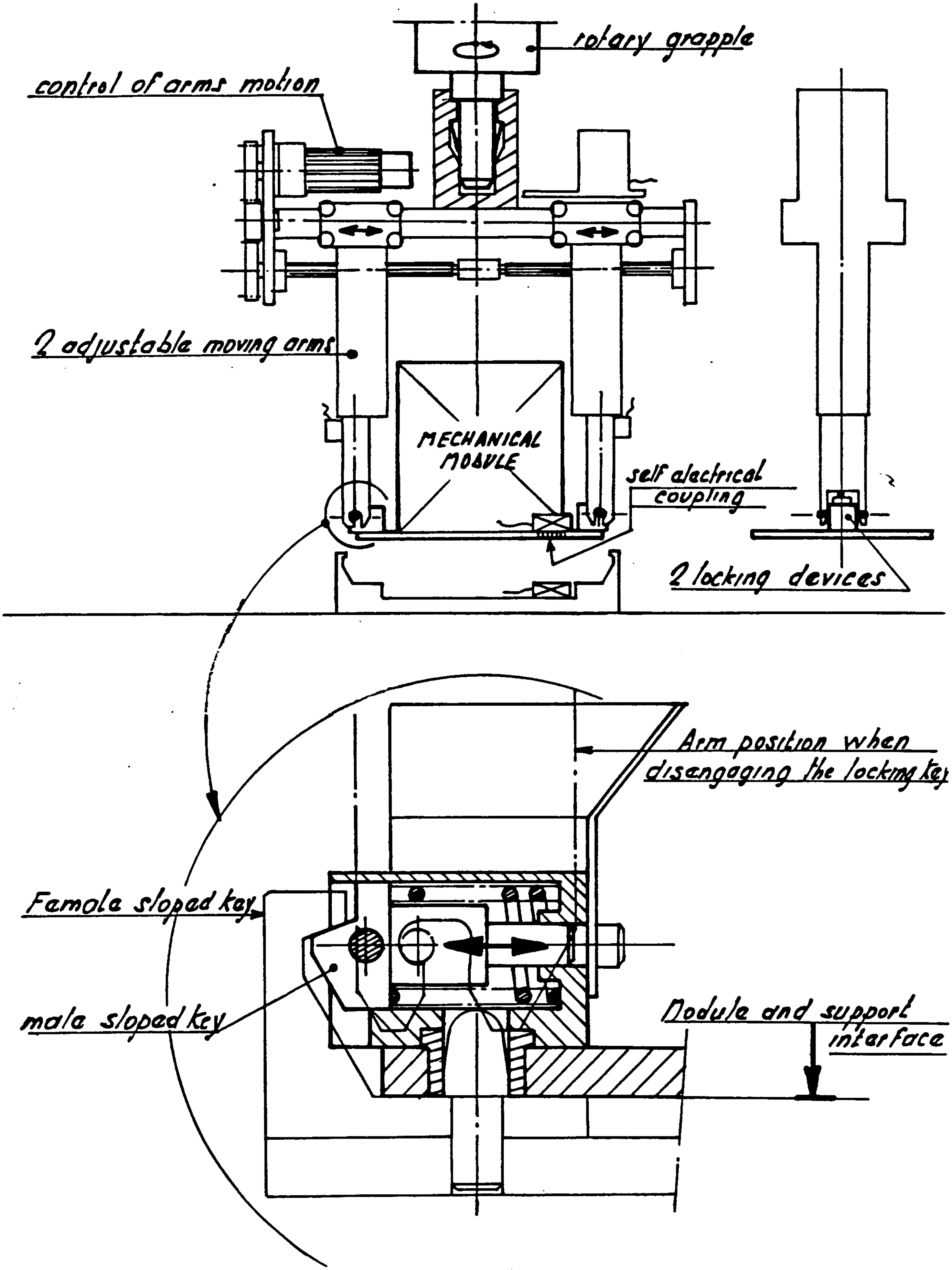
- lifting beams (already described)
- screw driving machines and similar small equipment
- working tables, on which cell repair can be performed
- dismantling equipment necessary to dismantle equipment which cannot be packaged in an NFBC canister because of its dimensions

2.3.3 Cell Support Services

Cell support services are those services that are shared with the scope of the larger facility whether it be a MRS or repository. These

Figure 2-24

MECHANICAL MODULE REMOTE REMOVEABLE SYSTEM



services are utilities, HVAC, secondary waste, analytical services, fire protection and facility safety and licenseability.

Utilities

The cell will be supplied with:

- 120 V, 210 V and 480 V electrical power
- electrical control power
- demineralized water for decontamination and for hydraulic cylinders inside the cell
- air for ventilation
- compressed air for possible pneumatic tools (90 psi)
- oil tank oil cylinders (rod removal stations, shearing machines, tilting device)
- nitrogen

HVAC

The building is separated into several types of cells which are classified as a function of the contamination risks (both normal risks and off-normal risks).

Ventilation is used as a contamination "barrier". It ensures a dynamic confinement and a cascade of pressures with air flows from the least contaminated to the most contaminated and irradiated zones.

Ventilation is also required to keep the temperatures in the cells at an acceptable level. The acceptable level set for the "Rod Consolidation Cell" is between 80-90°F so as not to disturb the equipment adjustments.

The level of pressure in the different zones and pressure differentials are ensured only for normal operation of the facility. In case of malfunctions, only the direction of air flow will be ensured, without any guarantee of the value of the pressure differentials.

From a thermal point of view, calculations take into account both exterior thermal data (outside temperatures and relative humidity) and interior heat sources (fuel elements, lighting and motors). Calculations also take into account the thermal resistance of the building materials.

The air supply ducts will be, as far as possible, circular in shape. Air blown into active cells will be filtered by a high efficiency filter prior to introduction. Air removal is through welded stainless steel pipes for ease of decontamination. For active cells, two total flowrate blowers are installed. The ventilation system for active cells has two types of filters: alpha protection filters and gamma protection filters.

For the rod consolidation cell, filtration is accomplished by two very high efficiency filters. Pressure and temperature will be regulated. Pressure, pressure differentials, temperature and filter plugging will be monitored. In active cells, the filters will be fire resistant. In case of a loss of power, air removal blowers will be redundant.

Secondary Waste

Generic facility solid waste volumes depend primary on the future conditioning process which will be chosen by DOE. The waste volumes given in the following sub-paragraphs are based on the TAN facility, i.e. the waste other than element skeletons is put in NFBC canisters which are not separated into four compartments. It appears that a shearing machine and compactor for the skeleton in the generic facility would lead to a significant reduction of waste volume and on the overall dimensions of the NFBC canisters.

NFBC waste for PWR elements includes:

- the top end-fitting with the uppermost spacer grid and the attached portions of guide tubes
- the skeleton (fuel element structure) including lower end fitting, residual spacer grids and guide tubes

The volume of waste generated and the number of NFBC canisters required for consolidating PWR fuel elements for the generic and TAN operations are given in Table 2-3.

TABLE 2-3

NFBC WASTE VOLUMES FROM PWR FUEL ELEMENTS

GENERIC FACILITY

Type	Flows	Weight per Unit	Number of Canisters
Top Nozzle	14/day (during PWR campaign)	10 lb	35 (28 top nozzles/ canister)
	976/year		
Skeleton	14/day (during PWR campaign)	60 lb	224 (4 skeletons per canister)
Top Nozzle	14/day (during PWR campaign)	10 lb	4 (28 top nozzles/ canister)
Skeleton	14/day (during PWR campaign)	60 lb	26 (4 skeletons per canister
	102/year		

After cutting the guide tubes from inside, the tube, the top end-fitting is removed by the cutting machine. It is then dropped into a non-compartmented NFBC canister via chutes placed under the end-fitting removal work stations. The chutes from the two stations converge above the NFBC canister. The opening can be automatically opened and closed by a plug.

After all the rods are removed from the skeleton, the transfer table is returned to the initial position in alignment with the tilting device. The tilting device is then rotated to the horizontal position. The skeleton is clamped on it and the tilting device is rotated to the vertical position so the crane can grapple the skeleton and transfer it into a compartment of an NFBC canister.

BWR Fuel Elements

Two cases were investigated.

- 7x7 fuel elements
  NFBC waste includes:
  - the upper end-fitting and tie rod springs and nuts
  - the lower end-fitting with portions of tie rod end plugs (sheared portion)
  - the spacer grids

- 8x8 fuel elements
  NFBC waste includes:
  - the upper end-fitting and tie rod springs and nuts
  - the lower end-fitting with portions of tie rod end plugs (sheared portions)
  - the skeleton (spacer grids plus one or two water rods, depending on the fuel element type)

The difference between 7 x 7 elements and 8 x 8 elements is due to the spacer capture rod(s): in 7 x 7 elements, the spacer capture rod is fueled and is thus loaded in the canister with the other fuel rods, in the 8 x 8 elements the capture rod is non-fueled and is thus left in the skeleton.

Waste Volumes

To calculate waste volumes, it is assumed that the relative number of 7 x 7 elements and 8 x 8 elements is: 20% 7 x 7 elements and 80% 8 x 8 elements.

In the TAN operation, no 7 x 7 elements will be processed.

A summary of the NFBC wastes generated is given in Table 2-4.

TABLE 2-4

NFBC WASTE VOLUMES FROM PWR FUEL ELEMENTS

GENERIC FACILITY

Type	Flows	Weight per Unit	Number of Canisters
Lower End-Fittings	14/day (during BWR campaign) 1622/year	8 lb	
Upper end-fitting	14/day (during BWR campaign) 1022/year	4 lb	60 (56 end-fittings per canister)
Spacer grids (7x7)	98/day (during BWR 7x7 campaign)	5 lb	
Skeletons (8x8)	14/day (during BWR 8x8 campaign) 1080/year	35 lb	270 (4 skeletons/ canister)
For TAN Facility			
Upper end-fittings	14/day (during BWR campaign) 80/year	4 lb	
Lower end-fitting	14/day (during BWR campaign 80/year	8 lb	3 (56 end-fittings per canister)
Skeletons	14/day (during BWR campaign) 80/year	35 lb	20 (4 skeleton/ canister)

Waste Disposal Process

Once the tie-rods have been cut, the two end-fittings are placed into the chutes located beneath the work stations, which lead to the NFBC canister.

After the rods have been removed, the grids remain on the transfer table. An electrically actuated rake located on the transfer table "sweeps" the grids into the chute located at the lower end of the fuel element.

The skeleton from the BWR 8x8 fuel element (one or two non-fueled water-rods and the spacer grids) is placed in the NFBC canister using the same procedure as for the PWR skeletons.

Crud

There are two types of crud:

- "loose" crud that is easily removed and consists of small particles. This type of crud is found mainly on the BWR elements.
- "tough" crud which is firmly attached to the rods. This type is found mainly on the PWR elements.

The quantity of crud is a function of the type of reactor (from GE, CEA and COGEMA experience). It is estimated that there is about 500 gm of loose crud on a BWR element and that there is 250 gm of tough crud on a PWR element.

For PWR elements, it is assumed that about 15 percent will be removed during rod consolidation by scraping, i.e. about 40 gm per PWR element. For BWR elements, it is assumed conservatively that about 80 percent will be removed during consolidation, i.e. about 450 gm per BWR element.

Conclusion:

Generic Facility

BWR 1652 elements i.e.: 740 kg/year
PWR 1000 elements i.e.: 40 kg/year

TAN Facility

BWR 80 elements i.e.: 96 kg/year
PWR 102 elements i.e.: 4 kg/year

Cuttings

Cuttings are generated during the PWR top end fitting removal operation. The volume of the cuttings is very limited and can be calculated from the cladding thickness and the width of the blades.

A calculation based on these parameters gives:

- Generic Facility: 4 liters/year
- TAN Facility: 0.4 liter/year

Furthermore, the volume of cuttings released to the cell will be reduced for the following reasons:

- the blades are designed to direct the cuttings into the tubes
- during operation, nitrogen is blown past the cutters and into the guide tubes
- the operations are performed while the fuel element is inclined

All these measures cause the cuttings to stay in the guide tubes. Nevertheless, in case cuttings fall outside the guide tubes, they fall on the transfer table where they will be vacuumed.

Disposal of Crud and Cuttings

A crud and cuttings collection device is attached to the transfer table where the fuel elements are disassembled. It consists of a frame enclosed on four sides, the face of the transfer table has suction ports placed in front of each spacer-grid of the fuel element. These suction ports are connected to a common vacuum device. The vacuum system contains a filter where crud and cuttings from rod removal operations are trapped. This filter is remotely changeable and is packaged in a canister as solid waste.

To further remove loose crud from the fuel rods brushes linked to the rod removal working station will be used to remove the loose crud which as not been removed by scraping of the rods on the spacer grids.

Fuel Pellets

Based on the fuel rod clamping design, breaking a rod and consequently spreading the fuel pellets is considered as a very highly improbable event. Nevertheless a catch-tray is located beneath the rod removal work station to collect the occasional loose fuel pellets and particulate fuel material.

To recover fuel pellets and particulates all the comb modules will be removed and the catch tray vacuumed with a vacuum operated by the master-slave manipulators, servo-manipulator or cell process crane.

For accountability, the fuel pellets and particulates picked up by the vacuum cleaner are collected in a clean removable filter which will be removed after each cleanup and placed in the broken rod fuel canister.

Solid Wastes

Solid wastes from the process cells are the sub-assemblies from process equipment, filters, limit-switches, electric wires, air and hydraulic hoses, and damaged tools. The volumes will be reduced as much as possible by designing the process equipment for long life expectancy and by choosing materials and equipment whose behavior is compatible with the radiation exposures expected in the process cells.

Solid wastes will be packaged as much as possible into canisters similar to NFBC canisters.

Liquid Wastes

Liquid wastes are generated by the decontamination process. The processes selected minimize liquid waste production. The volume of liquid waste is expected to be less than 30 ft^3 per year.

Analytical Services

After the contamination monitoring of the canisters, the smear-brush is sent by pneumatic transfer to a laboratory, where it will be analyzed and to determine if the exterior surface of the canisters is contaminated. The requirement is that the exterior surface of the canisters must be less than or equal to 2200 dpm/100 m^2 beta/gamma and less than or equal to 220 dpm/100 m^2 alpha.

Regularly, (for example every year), the level of contamination of the rod consolidation cells will be checked. Several samples will be taken by servo or master-slave manipulator and sent to the laboratory to be sure the level of contamination is acceptable.

Fire Protection

The risk of fire in the cell is highly improbable since:

- The potential for the pyrophoric ignition of zirconium, fires and explosion will be minimized by the introduction of nitrogen at the equipment level. The disassembly and consolidation operations will be stopped if the flow rate is too low.
- Simultaneous presence of flammable or combustible materials and a source of ignition (sparks) will be avoided.

Nevertheless, to cover any possibility of fire, it will be verified that the maximum energy released by a fire can be removed by the ventilation system of the cells. The pre-filters located in the cell will be made of non-flammable materials.

2.3.4 Facility Safety and Licensability

The facility design will be relied on to provide:

- Radiation Protection and Contamination Control
  Structural layout and ventilating air control should assure flow of air from low hazard areas to higher hazard areas. Walls separating the rod consolidation cells from other operating areas of the facility will provide shielding to limit the dose rate to the design level set for each occupied area. Uncontaminated access to the cell from below is required for access/egress of canisters.

- Low and High Level Radwaste Systems
  Safe disposal of the liquid and solid wastes generated in the rod consolidation process cells is assumed to be accomplished by the facility radwaste systems.

- Flood Protection
  Criticality evaluation of the rod consolidation equipment design assumes that there is no water or other moderator in the process cells in sufficient quantity to provide significant moderation to the fuel material in the cells. The facility design and/or site selection must preclude flooding of the process cells. If this is not the case the rod consolidation equipment design will need to be re-evaluated to assure it is critically safe under flooded conditions.

- Protection from Natural Phenomena
  The design of the rod consolidation equipment assumes that the facility provides protection from high winds, snow loadings and tornado generated missiles.

- Physical Protection and Safeguards
  As defined by 10CFR73.2 the rod consolidation cells will contain material access areas and vital areas and therefore must be in a protected area of the facility.

2.4 TAN INSTALLATION

Requirement 17 of the Generic Functional Requirements states that the system shall be capable of being installed in the TAN enclosure. This requirement is cause for some independent design innovation when compared to the generic design. Fundamental objectives which cause differences in these systems are the differences in material balance and lifetime requirements, the TAN facility constraints, equipment arrangement, equipment design and decontamination requirements.

2.4.1 Process System

The material balance has been established on the basis of processing of 100 BWR 8x8 elements and of 100 PWR 15x15 elements in one year. The number of end-fittings, and skeletons per fuel element is the same as for generic facility. The difference is the spacer grids as no BWR 7x7 fuel elements will be consolidated in TAN. The material balance for the TAN operation is given in Figure 2-25.

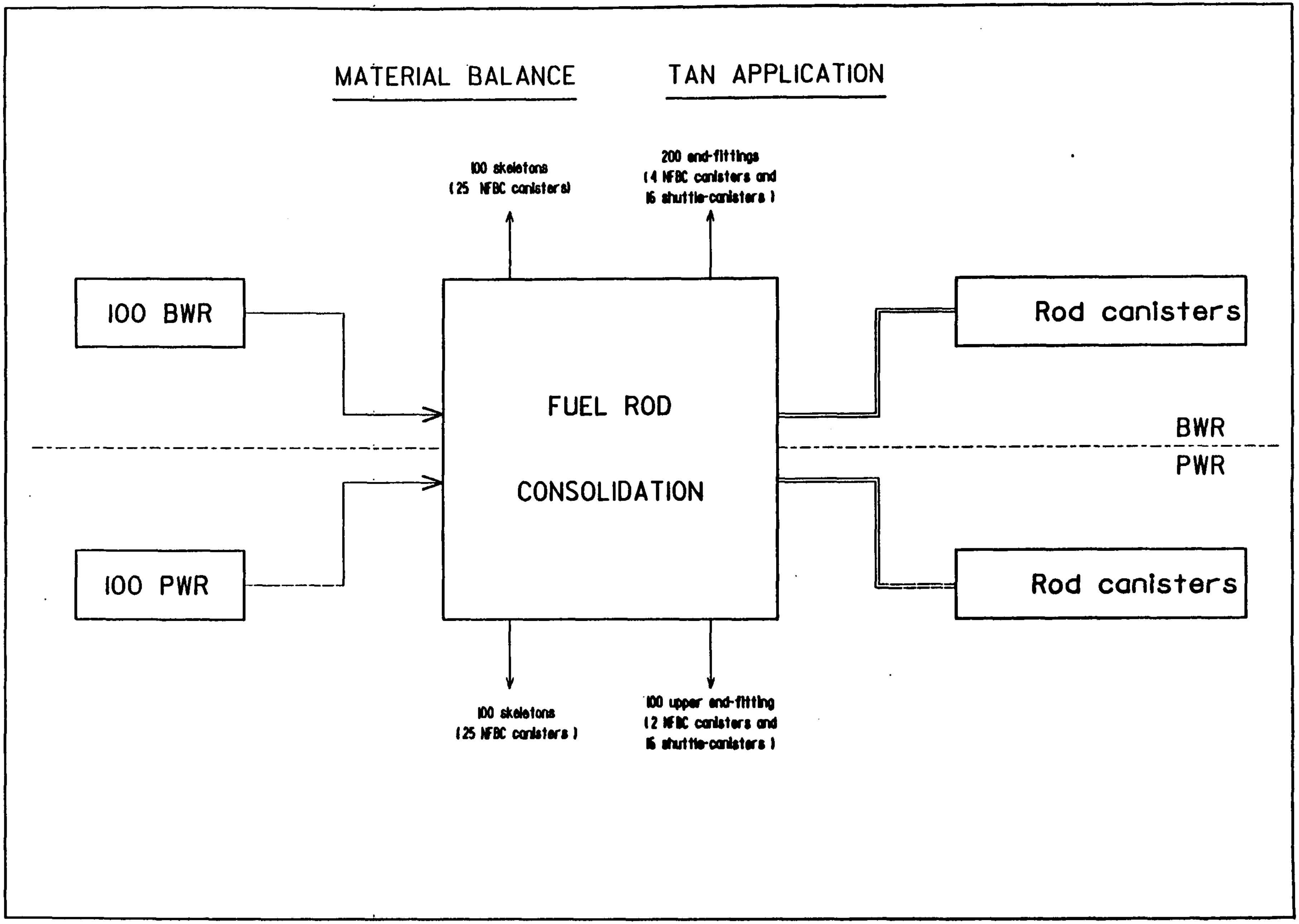
2.4.2 Equipment Arrangement (See Drawing PI 1886 20 002)

The outline of the equipment arrangement in TAN is similar to the arrangement of the Generic Facility. The main pieces of equipment are arranged following the same four parallel longitudinal lines:

- BWR end-fitting removal station
- PWR end-fitting removal station
- Fuel rod removal station
- Fuel rod reconfiguration and packaging station

The transfer of the fuel element between the three first lines of equipment is accomplished by a transfer table as in the generic facility.

Figure 2-25 TAN Material Balance



The difference in equipment arrangement between the TAN and generic facilities is due mainly to the requirement to have all the equipment inside the TAN enclosure. This particularly affects the canister loading device and the hydraulic cylinder of the rod removal station. Furthermore, it requires that all the manipulators be inside the TAN enclosure which has no windows, the use of servo-manipulators for all remote operations and the use of TV cameras in place of windows.

2.4.3 List of Equipment

The following equipment list (Table 2-5) is divided into two parts:

- process equipment list
- support equipment list

For each item the following information is given:

- reference for the equipment in the list
- reference for the equipment in the lay-out (PI 1886 20 002) when the equipment is shown in the lay-out
- designation of the item
- number of items per type of fuel element (column A)
- number of items (or sets of items) to accommodate all the types of fuel elements (column B)

TABLE 2-5

EQUIPMENT LIST FOR TAN FACILITY

Item	Reference on Drawing PI.2171.20.001	Description	A	B	
				PWR	BWR
A. PROCESS EQUIPMENT					
1	1	Tilting device	1		
1.1		Structural frame	1		
1.2		Tilting hydraulic cylinder (demineralized water)	1		
1.3		Driving hydraulic cylinder	1		
1.4		Fuel assembly clamping device	1	1	1
2	2	PWR top end fitting removal station	1		
2.1		Support structure with one actuator	1		
2.2		Instrument tube drill	1	1	
2.3		Multiple blade cutting machine	1	1	
2.4		Top end-fitting removal device	1	1	
3	3	BWR end-fitting removal station	1		
3.1		Upper end-fitting shearing machine	1		
3.1.1		Support structure with one actuator	1		
3.1.2		Shearing machine with 4 hydraulic cylinders	1		1
3.2		Lower end-fitting shearing machine	1		
3.2.1		Support structure with one actuator	1		
3.2.2		Shearing machine with 4 hydraulic cylinders	1		1

TABLE 2-5

EQUIPMENT LIST FOR TAN FACILITY

Item	Reference on Drawing PI.2171.20.001	Description	A	B	
				PWR	BWR
4	4	Fuel rod removal station	1		
4.1	5	Transfer table, rails and one actuator	1		
4.1.1		Clamping devices	1	1	1
4.1.2		2.5 ton clamping plate and one actuator	1		
4.1.3.1		Set of friction plates	1	1	1
4.1.3		Fuel element restraining device	1	1	1
4.1.4		Vacuum device	1		
4.1.5		Rake	1		1
4.2		Bench	1		
4.2.1		Bench frame with rails	1		
4.2.2		Comb modules	5	1	1
4.2.3		Drive actuator to rotate horizontal combs	1		
4.2.4		Three hydraulic cylinder unit to clamp the gripping head	1		
4.2.5		Three hydraulic cylinder unit to unclamp the gripping head	1		
4.2.6		Gripping head support cart with rollers	1		
4.2.7		Hydraulic cylinder with 10 ton pulling capacity to pull the rods	1		
4.3		Gripping head	1	1	1
4.4		Accountability module	1		
4.4.1		Support with one actuator	1		
4.4.2		Counter	1	1	1

TABLE 2-5

EQUIPMENT LIST FOR TAN FACILITY

Item	Reference on Drawing PI.2171.20.001	Description	A	B	
				PWR	BWR
5	6	Rod reconfiguration station	1		
5.1		Longitudinal table for fuel rod transfer	1		
5.2		Trays			
5.2.1		Five-arm structure (tray support)	1		
5.2.2		Pusher (pusher B)	1		
5.2.3		Trays	5	1	1
5.3		Five-arm fuel-rod pusher (pusher A)	1		
5.4		Support table with its covering plate	1		
5.5		Mold	1		
5.5.1		Reconfiguration modules	6 (1 per type of canister)		
5.5.2		Positioners to stop the fuel rod row	5	1	1
5.5.3		Reconfiguration module incremental drive unit	1		
5.6		Blades and notched braces			
5.6.1		Set of five blades to support the fuel rods which enter the reconfiguration module	1	1	1
5.6.2		Set of three notched-braces and shutters, with their support	1	1	1
5.6.3		Driving bar and actuator	1		

TABLE 2-5

EQUIPMENT LIST FOR TAN FACILITY

Item	Reference on Drawing PI.2171.20.001	Description	A	B	
				PWR	BWR
6	7	Packaging station			
6.1		Pusher head	6 (1 per type of canister)		
6.2		Superposed electric cylinders	1		
B. SUPPORT EQUIPMENT					
1		Handling equipment			
1.1	8	Handling crane (2-ton capacity)	1		
1.2		Grapple for fuel element skeleton and canisters	1	1	1
1.3		Shuttle canister handling grapple	1		
2	9	Tilting device for rod canisters	1		
2.1		Structural frame	1		
2.2		Tilting hydraulic cylinder	1		
2.3		Driving hydraulic cylinder	1		
2.4		Canister clamping device	1		
3		Storage racks	1		
3.1	10	Storage rack for 28 bundles (either PWR or BWR)	1		
3.2	11	Storage rack for 8 NFBC canisters	1		
3.3		Storage rack for 3 shuttle canisters	1		
3.4	12	Storage rack for 14 rod canisters	1		
3.5	13	Storage rack for 6 nonconsolidated fuel assemblies	1		

TABLE 2-5

EQUIPMENT LIST FOR TAN FACILITY

Item	Reference on Drawing PI.2171.20.001	Description	A	B	
				PWR	BWR
4	14	Broken and/or stuck rod recovery station	1		
5	15	Decontamination station	1		
5.1		Rotating station with one actuator	1		
5.2	16	Frame for rod canisters	1		
5.3		Frame for NFBC canisters	1		
6	17	Maintenance equipment and working area	1		
6.1		Set of maintenance tools	1		
6.2		Module removal lifting beam	1		
7	18	Plug with gripper rod packaging station and the canister to be loaded	1		
8	19	Servomanipulator + working	1		
		stands9	20	TV cameras	
9.1		TV camera attached to the crane	1		
9.2		Movable TV camera + receiving stations	1		
9.3		Stationary TV cameras	2		
10		Control system with panels, CCTV monitors	1		

2.4.4 Equipment Description

As a general rule, all the process equipment will be made of the same materials as specified for the Generic Facility to be as close as possible to the generic equipment. The support equipment will be made of less expensive materials due to the limited lifetime of the TAN operation. As a consequence, no stainless steel will be used in the support equipment.

A less expensive option would be to use lower grade materials for the process equipment due to the very short lifetime requirement for the TAN equipment.

Fuel Rod Consolidation Equipment

The equipment necessary to perform the rod consolidation (end-fitting(s) removal station, fuel rod removal station, fuel rod reconfiguration equipment) are the same as for the generic design except some minor modifications which do not affect the process.

These modifications are mainly:

- the rod removal actuator, which in the generic design is one cylinder, is two sequentially operated cylinders, each cylinder being responsible for half the translation. This was done to meet the floor space requirements.
- the location of the cylinder of the transfer table is inverted in TAN because of the floor space requirements
- the drive mechanism for the reconfiguration module step by step downward motion is in the process cell since there can be no mechanical penetrations of the cell.

Rod Packaging Station

The process is the same and consists of pushing the reconfigured bundle in the canister. Due to floor space requirements, the bundle is pushed from the end corresponding to the upper end-fitting by two sequentially operated cylinders.

This modification, which at first appears to be an important difference because of its effect on the layout, is in fact minor because the process is the same.

Handling Devices

There will only be one crane in the enclosure since the goal of the tests is not long term production but to demonstrate that the system meets the generic requirements. The crane is based on the same principles as the cranes of the generic facility, i.e redundancy of the lifting motion drive systems and the traveling motion drive systems. The differences are due to the limited lifetime requirements for the TAN enclosure. These are:

- the canister cell crane will not be of a modular design
- the crane will not be made of stainless steel
- the drive systems will be as far as possible off-the-shelf components

These differences reduce the cost of the crane.

Grapples will be based on the same principle as for the generic facility, but:

- they will not be made of stainless steel
- the skeleton gripping system will have two positions, one of which will allow grappling of the canisters (see drawing PE 1886 02 013).

Tilting Devices

Tilting devices will be the same as in the generic facility.

Canister Closure

For the TAN application, the canisters will not be closed by a welding machine but by a mechanical process because of the very limited number of rod canisters (about 75) and in order to minimize the cost of the facility. The exclusion of welding is proposed to minimize the cost since welding has been successfully performed on many full size containers (see Appendix II).

The lid of the canister is locked into the canister by a ratchet device. After the canister is loaded with rods, the plug which contains the lid is returned to its initial position and the gripper inside the plug replaces the canister lid and pushes it so that the ratchet is engaged (see Figure 2-26). A seal ring in the lid ensures an acceptable tightness.

The NFBC canisters are closed in the same way as in the generic facility.

Decontamination

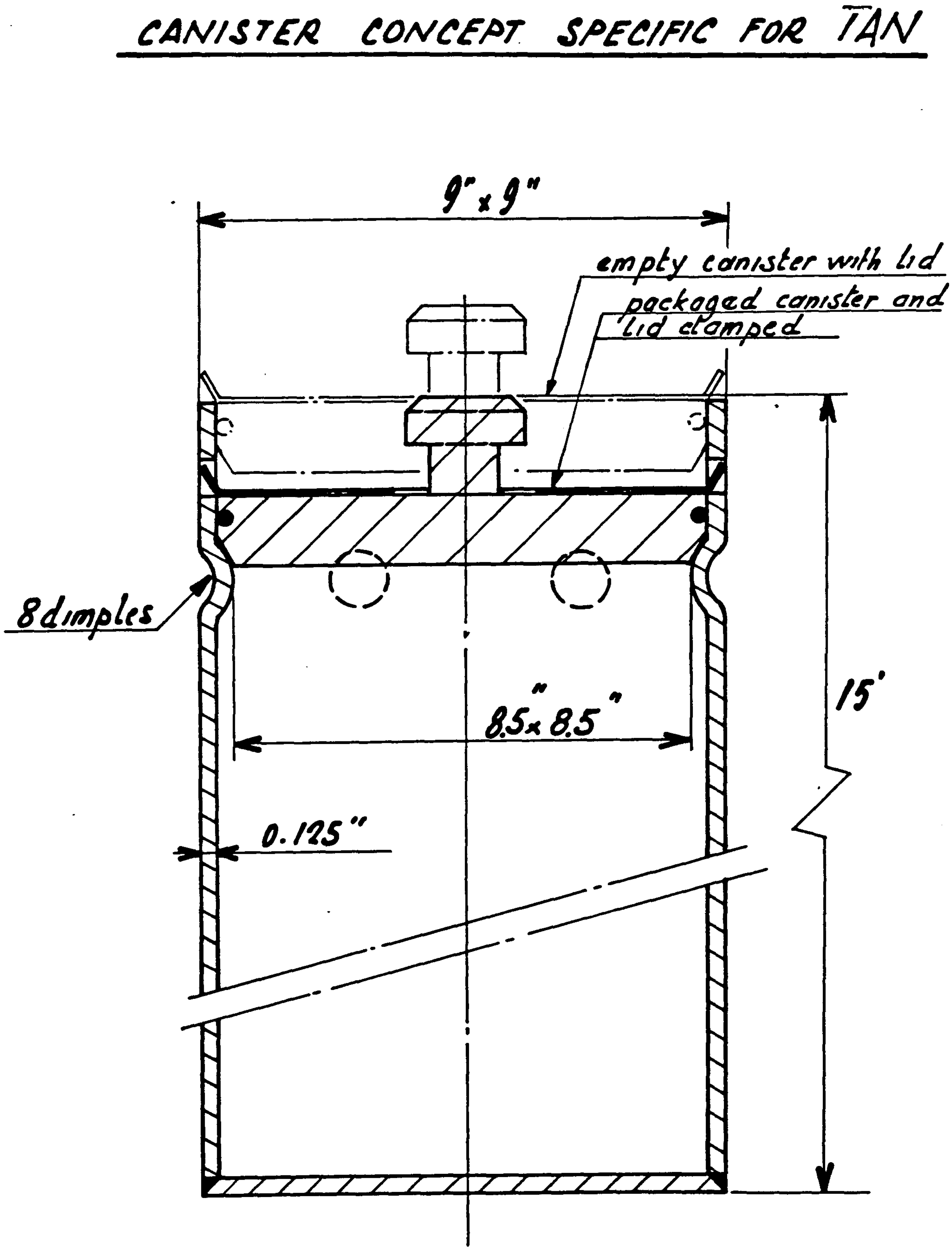
The main difference between the TAN and generic applications is due to decontamination. Since the process cell is not a clean cell, it is necessary to decontaminate all the fuel rod and NFBC canisters before removal from the enclosure. The process is the same, high pressure decontamination is used, but the equipment is different for it must be able to decontaminate the whole surface of either fuel rod or NFBC canisters. The requirement is to decontaminate the exterior surface of the consolidated fuel canisters and NFBC canisters to less than or equal to 2200 dpm/100 cm^2 beta/gamma and less than or equal to 220 dpm/100 cm^2 alpha.

In TAN facility, the decontamination station will be a rotating system in order to save cell floor space. This station has three positions:

- loading of the canister from the cell
- decontamination of all the canister surfaces
- removal of the canister to the TAN hot cell storage

The three positions are located 90 degrees from each other. Movement from one position to the other is performed by rotation of the system. Rotation is powered by an electrical actuator.

Figure 2-26 Canister Lid (TAN)



The process is as follows: The canister to be removed is grappled by the crane and placed in the decontamination station where it is held in place by a frame which is designed for that canister (either a fuel rod canister or NFBC canister). The system is then rotated to the decontamination station where it is made leak tight by inflatable seals and high-pressure decontamination is performed. When decontamination is finished and confirmed by monitoring of the decontamination liquid, the seals are deflated and the system is rotated 90° once again to the removal station where the canister is grappled by a crane in the TAN hot shop and removed. Monitoring and removal of the canisters is not the same as in the generic facility for the following reasons:

- floor space requirements in TAN
- the rod canister cannot be returned to the process cell after decontamination since the TAN process cell is not a clean cell
- in the Generic Facility, decontamination is considered as an improbable event.

The large difference in decontamination concepts is acceptable for the TAN demonstration because the equipment used in the Generic Facility has already been tested in other cells.

NFBC Treatment

As a result of the requirements on the dimensions of the TAN facility, it is not possible to use the same method to process the NFBC. Chutes cannot be used to carry the end-fittings and grids directly to the NFBC canister since the NFBC canister cannot be connected to the cell floor. Consequently, intermediate devices are necessary to transfer the end-fittings and grids from the work stations to NFBC canisters which are stored vertically in the cell.

These intermediate devices are shuttle-canisters. Shuttle canisters are small canisters, about 3 1/2 feet high and about 24 in x 24 in cross section. After the end fittings have been removed, they drop into the shuttle canisters. Once the shuttle canisters are filled, they are picked up by the cell crane and put into a non-compartmented canister. The skeletons are processed in the same way as for Generic Facility; i.e., they are grappled by the crane after having been put in a vertical position by the tilting device.

With regard to free spacer grids, though no BWR 7 x 7 campaign is scheduled in the TAN facility, the same device as for Generic Facility will be provided to allow a possible test of the machine.

The differences between the Generic Facility and TAN facility are not a disadvantage for the tests because shuttle canisters are the equivalent of the chutes in the generic design.

Lag Storage

The lag storages in TAN are as small as possible, since production is not the goal of this facility. The rule is to provide lag storage for two days production storage; i.e. 28 fuel elements, 7 four compartment canisters, 1 non-compartmented canister and 14 rod canister.

Lag storage of fuel elements is only 28 fuel elements. Fuel element storage will be reconfigured as a part of the change-over from BWR to PWR fuel elements or PWR to BWR as the case may be. Separate lag storage is provided to store 6 fuel elements which are found to be unsuitable for consolidation.

Each lag storage system is made up of storage cells, the height of which is nearly the same as the elements or canister to be stored.

Manipulators

As no windows or master slave manipulators are available in the TAN facility, all the remote operations will be performed by the servo--manipulator similar to the one which will be used in the Generic Facility and which is described in Section 2.3.

Instruments, Controls, Alarms, Panels

The principles of the control system for TAN installation will be the same as for Generic Facility (redundant organization, mode selection, architecture of the control system).

The difference between TAN Facility and Generic Facility is the absence of a local control room, since no window is available. Control will be performed from a remote control room using Closed Circuit Television (CCTV).

3. SYSTEM OPERATIONS DESCRIPTION

This section will describe operation and maintenance systems, normal production operations and off-normal operations.

3.1 OPERATIONS AND MAINTENANCE SYSTEMS

Operation and maintenance systems include the cell operations system, equipment maintenance systems, personnel requirements, and operational safety and licenseability.

3.1.1 Cell Operations System

The cell operations system is designed for automatic control of normal sequences with safety interlocks and data processing systems support functions. Operation is normally from a remote main control room using supervisory control over a distributed control system, coupled with visual and audio feedback and manual override capability. Operation is possible from local controls which are designed to accomplish off-normal and maintenance functions with assistance from manual operation of master slave manipulators. Eight sets of viewing windows equipped with master slave manipulators are provided in the consolidation cell and two sets are provided in the canister cell. Unusual operations can be completed using a servomanipulator which is attached to the modular crane in the consolidation cell. The servomanipulator normally is stored outside the process cell.

The control system is designed to perform remote control of the process systems while protecting the safety of the staff and the environs, protecting the equipment, centralizing control operations, and monitoring cell status.

The control system is comprised of a process control subsystem and an equipment protection subsystem. The process control subsystem controls all consolidation process operating sequences. The protection subsystem protects the various process equipment, indicates equipment failures, prevents equipment operation until the configuration is complete and safe, and stops operations in the event of a large scale incident (such as earthquakes). The process control subsystem and the protection subsystem are designed as independent systems which use separate sensors, transmitters, controllers and power supplies. The power supplies use redundant power sources and independent cable routings.

The main control room operator is provided with the option for controlling the process either from the main control room or from the local control room. Normal operation control will be from the main control room. During testing and during off-normal and maintenance operations, operators will work locally to control the process, to operate the master slave manipulators, and to perform maintenance and housekeeping operations. The control system is designed to provide these options to the operator.

The architecture of the process control system is illustrated in Figure 3-1. The control hierarchy illustrates supervisory control from the main control room over programmable logic controllers over a distributed control system. Also illustrated are the local controls.

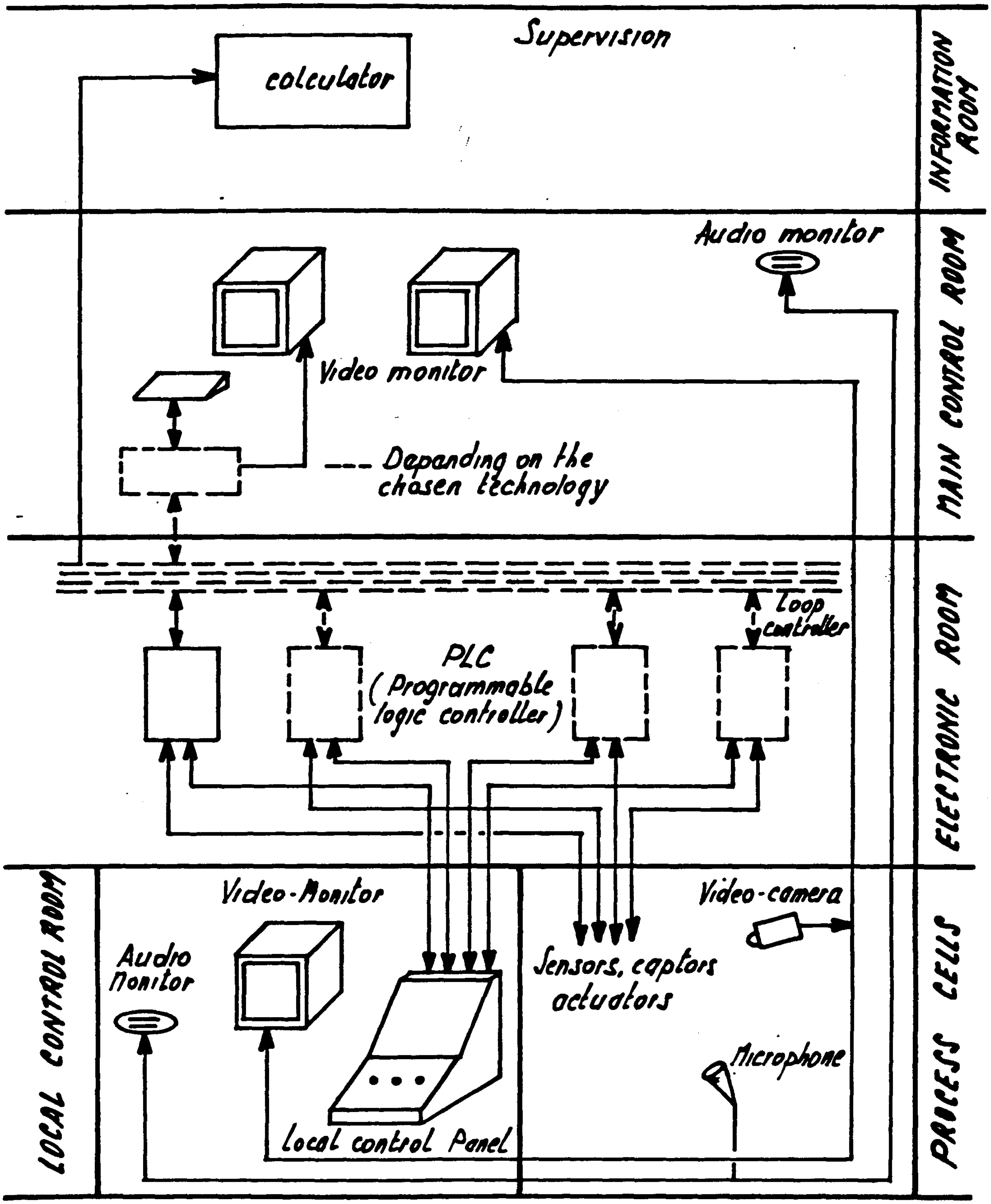
The main control room operator directs the process by selecting and authorizing operation cycles using a process monitor for key parameters, a video monitor, an audio monitor and a keyboard.

The local control operator directs the process using similar monitors and displays including a display of local manual commands and the alarm and warning signals.

Data processing can either be located in the main control room or in a separate room. The data processing computer serves to complete a) a historical accounting of the process, its equipment failures and alarms, b) material balance information including accountability, and c) data such as tool and module status and location and process configurations for various fuel types. This computer can also be programmed to complete certain calculations on request from the programmable logic controller.

The operating modes that the main control room operator can select are automatic, semiautomatic, shutdown, controlled manual, and test manual.

Automatic control is provided by combining the process operating sequences (steps) into cycles and upon operator authorization executing that cycle.



PRODUCTION SYSTEM ARCHITECTURE

Figure 3-1

Semiautomatic control is similar to automatic control except that the operator must authorize each step of the cycle.

Controlled manual control allows the operator to select individual controls corresponding to each elementary step of the process. During these operations the process control subsystem and the protection subsystem function to control the remaining process functions and the safety interlocks remain active.

Test manual control is the same as controlled manual with the exception that the operator may unlock the protection system and safety interlocks. This procedure can be performed only under strict administrative control.

A listing of the protection system and safety interlocks is provided on Drawing SH-1886-20-005-A. This listing shows the required limit switches, safety interlocks, hydraulic pressure switches, automatic programs and programmed visualizations associated with each equipment operation. Approximately 127 items are identified by number, function and equipment, including 68 limit switches, 35 safety interlocks, 2 memorized visualization, and 2 automatic programs. These features assure continuous and safe operation of the equipment.

3.1.2 Equipment Maintenance System

Systems are provided which permit both preventative and corrective maintenance. The total system will include a preventative maintenance program specifically designed to maintain equipment reliability using predictable failure data and statistical data gathered from manufacturers and operating experience. The system will also include procedures for corrective maintenance of all major modules.

The equipment maintenance systems include the cell maintenance area, cell cranes, master-slave manipulators, tools and storage areas, materials transfer cells, and ex-cell mockup facilities. The servomanipulator is also used for special maintenance tasks. Most in-cell maintenance systems are required for normal and off-normal process operation as well.

The process equipment and crane have been designed using modularization of all components which are replaced during equipment reconfigurations or which will fail or wear. Equipment modules have been sized for access and egress through the material transfer area and for disposal. Repair in-place is expected to be the normal maintenance procedure replacing the defective module with a new module. A cost trade off decision will be made to determine if the module will be repaired in-cell or discarded. SGN experience indicates that normally it is not cost effective to repair modules. Module repairs will be conducted using the in-cell maintenance location indicated on the cell layout. The cell maintenance area is accessible to the cell crane and to two sets of master-slave manipulators

Reconfiguration and maintenance changeovers require remote tooling such as grapples, yokes, and lifting beams. These tools will be standardized for multiple applications to minimize their number and type. The data processing system will contain location and application data for each tool.

3.1.3 Personnel Requirements

The staff required to operate the rod consolidation equipment in a single production line is envisioned as part of a larger organization structure needed to operate the entire facility. A typical facility organization structure is outlined in Table 3-1, showing rod consolidation as a functional entity responsible for operation of the equipment with support from plant engineering and maintenance and other operating and service groups in the facility. A more detailed organizational structure for rod consolidation is shown in Table 3-2 to reflect the requirements for multiple shift operation and on-shift support for personnel safety, materials accountability and equipment maintenance.

Personnel assignments to the rod consolidation line would be on three levels: the first, such as operations technicians, would be fully dedicated; the second, such as manipulator maintenance technicians, would be shared by all the remote process cells in the facility; and the third, such as support and administrative personnel, would be shared with the other process and utility systems in the facility.

Operation of the rod consolidation equipment is assumed to be on a 2 shifts per day, 5 days per week basis. Operation of the other process and utility support systems would be on a three shifts per day, seven days per week basis. Technical and administrative support would be on one shift per day, five days per week basis.

The rod consolidation equipment is operated by technicians stationed in a remote control room and supported by operations technicians available to intervene with master-slave manipulators at the cell windows. Spent fuel would be provided to the lag storage area in the rod consolidation cell during off-shift hours by technicians normally operating the receiving and storage system. Similarly, the product and waste canisters would be removed from the rod canister cell by off-shift technicians. Services to rod consolidation operations would be provided by facility support personnel, such as laboratory analysts, materials handlers and utility operators.

Maintenance of the rod consolidation equipment would be performed by a team of technicians highly skilled in using master-slave manipulators and shared by all the remote process cells in the facility. The team would be dedicated to the hot cells in the facility and assigned to day shift. Maintenance of support systems, such as instruments, ventilation, power and utilities, would be by technicians shared by the total facility with some available on shift. Work assignments for maintenance of the various equipment systems is assumed to be on the basis of individual skills and training without strict jurisdictional restrictions.

The facility support staff would also include management and administrative personnel and the engineering and technical support personnel required for rod consolidation operations. The former would include employee relations, financial accounting and materials procurement and the latter production planning, materials accountability and equipment maintenance engineers and analytical laboratory and health physics technicians.

A staff estimate for operation of the equipment at full production levels is shown in Table 3-3. Staffing is based on the operating plan and organization structure discussed above. Fractions mean that rod consolidation represents a portion of a given persons responsibility. The total is the equivalent of 30 full-time employees.

TABLE 3-1

TYPICAL FACILITY ORGANIZATION

MANAGEMENT AND ADMINISTRATION

PLANT ENGINEERING AND MAINTENANCE

FUEL RECEIVING AND STORAGE

ROD CONSOLIDATION

CANISTER STORAGE AND DISPOSITION

PLANT UTILITIES AND SERVICES

TABLE 3-2

ROD CONSOLIDATION ORGANIZATION

MANAGEMENT AND ADMINISTRATION

DAY OPERATIONS

SUPERVISOR

- OPERATIONS PLANNERS
- OPERATIONS ENGINEERS
- OPERATIONS TECHNICIANS
- OPERATIONS CLERKS

PROCESS LINE 1 OPERATION

PROCESS LINE 2 OPERATION

PROCESS LINE 3 OPERATION

PROCESS LINE 4 OPERATION

SHIFT SUPERVISOR

- OPERATIONS TECHNICIANS
- SAFETY TECHNICIANS
- ACCOUNTABILITY TECHNICIANS
- MAINTENANCE TECHNICIANS
- UTILITY TECHNICIANS

TABLE 3-3

PRODUCTION STAFF ESTIMATE

Work	Number
Operations Mgr	0.25
Secretary	0.25
Day Supervisor	0.25
Operns Planner	1
Operns Engineer	1
Operns Techs	2
Operns Clerks	1
Shift Supvr	2
Operns Techs	6
Maint Techs	2
Safety Techs	1
Accnt Techs	1
Lab Techs	0.25
Utility Techs	0.25
Off Shift Supvr	0.25
Operns Techs	2
Maint Techs	0.5
Safety Techs	0.5
Maint Supvr	0.25
Maint Planner	0.25
Maint Engineer	0.5
Manip Engineer	0.5
Manip Techs	1
Mech Techs	0.5
Instr Techs	2
Maint Clerk	0.25
Process Supvr	0.125
Proc Engineer	0.5
Process Clerk	0.125
Safety Supvr	0.125
Safety Techs	0.5
Safety Clerk	0.125
Accnt Supvr	0.125
Accnt Eng	0.25
Accnt Tech	0.125
Accnt Clerk	0.25
Lab Supvr	0.125
Lab Chem	0.125
Lab Techs	0.25
Utility Supvr	0.125
Utility Eng	0.125
Utility Techs	0.25
TOTAL	30

3.1.4 Operations Safety and Licenseability

Operations safety and licensing* considerations include the qualifications of the personnel, the quality of operator certification programs and materials, technical specifications, materials, accountability system, ALARA and quality assurance including compliance auditing.

Operator Qualification

Prior to hot startup all operations and maintenance personnel would be certified as satisfactorily completing a formal training for operations and maintenance staff. Both supervisors and technicians should have proven skills and experience gained in previous remote mechanical cell systems. Their training would be in the specifics of the rod consolidation equipment through interaction with design engineers and studying design reports and drawings. The operating core team would also prepare training manuals and operating procedures and provide instruction for less experienced personnel added later to the staff. Training materials would include reports, lectures, video programs, models of the equipment and a mockup hot cell station.

Technical Specifications

Technical specifications would be prepared during a later stage which will indicate the acceptable ranges of any process or facility parameters which might impact public safety or operator safety. Specific actions and plans to first prevent exceeding a limit and second to recover from any such event would be in place.

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*The GE/SGN/LSI team have defined licensable and licensed as interchangeable in terms of the preliminary design provisions to meet this requirement.

Accountability

Accountability of SNM in fuel elements in a spent fuel storage facility is by count or Item Control, when the isotopic content of an element is determined by fuel manufacturer's data and the element exposure. When elements are consolidated and placed in serialized canisters, the isotopic content of the canisters will be established by the total elements or fractions of elements contained. If an element contains no broken rods, the total isotopic content of that element will be assigned to the canister. If there is a broken rod or rods in the element, the broken rod or rods will be removed from the consolidation system and placed in a special serialized failed rod canister designed to handle broken rods and loose fuel pellets or particulate fuel material from broken rods. Each broken rod plus the fuel debris from that rod will be assumed to contain 1/n of the element isotopic content, where n is the number of rods in the original element. After the pieces of the broken rod are removed from the disassembly fixtures all loose fuel material, pellets and particulates, will be collected in a manipulator operated shop vacuum cleaner. The filter of the vacuum will be placed in a compartment of the failed rod canister.

The rod consolidation design includes sensor modules which assure detection of missing or broken rods. Accountability of fuel rods is performed after the rods have been pulled from the element skeleton and are held in the original element array by the vertical and horizontal combs. The sensors will detect rods that are stuck in a partially extracted position such that they extend from the skeleton to the combs or broken rods in which the lower portion of the rod remains in the element skeleton. The configuration of the fuel rod array in the element is stored in the computer memory and compared to the information received from the sensor modules. This permits ready determination of the exact location of the broken rod or rods in the combs and in the element skeleton. The reconfiguration system is designed to allow the process to proceed with the good rods in the combs being transferred to the canister loading fixture and the broken rod pieces removed from the combs and transferred to broken rod canister. Special procedures will then be used to recover the broken piece or pieces of fuel rod from the element skeleton and the collection of all fuel material from the rod, pellets or particulate. This material is also placed in the broken rod canister.

ALARA

ALARA has been considered in the design and layout of the rod consolidation facility as well as in the operation. Normal controls are remote, and off-normal and maintenance operations are completed through the cell walls. No direct maintenance is planned.

The dominant radiation sources in the process cells will be spent fuel elements and canisters of consolidated fuel rods. Contamination sources in the process cells are activated crud from the fuel assemblies, activated metal from the shearing and cutting operations used to remove the tie plates, and particulate spent fuel material from failed fuel rods. The dose rate from these contamination sources will be low compared to the dose rates from spent fuel and will not be significant in determining the shielding requirements.

The source terms from the spent fuel elements were estimated from measurements made at the General Electric Morris Operation and analysis with the PROGEM2 shielding computer code.

Design basis fuel was assumed to be 10 year cooled with a maximum burnup of 45,000 MWD/MTU for PWR fuel and 38,000 MWD/MTU for BWR fuel. The estimated surface dose rates are 22,000 Rem/hr for a PWR element and 18,600 Rem/hr for a BWR element. The difference is due primarily to the assumed higher burnup of the PWR fuel. The maximum surface dose rate for a canister of fuel rods is also estimated to be 22,000 Rem/hr for a canister of PWR fuel rods. The dose rate from a canister of fuel rods is estimated to be less the 1% higher than from a fuel element due to the high self shielding of UO_2. Analyses made for dry storage casks have shown that while rod consolidation doubles the volumetric source intensity, the strong self shielding of the fuel material reduces the gamma flux from the surface of the fueled region to a value less than 1% higher than that for fueled bundles in the same locations. These analyses show that the dose rate adjacent to a fuel assembly is 96% from the first row of rods and 99.6% from the first two rows or rods. The 3.6% contribution from the second row or rods is due to the unattenuated line-of-sight contribution of the second row through the spaces between the rods in the first row. Consolidating the fuel rods has the effect of moving this fuel forward one rod pitch to fill the space with little or no change in the dose rate since the element approximates an infinite plane source for a point close to its surface.

Shielding requirements for the process cell walls depends on the design basis dose levels set for operation of the facility. Based on 10CFR20 requirements and ALARA considerations these levels are set at 0.25 mRem/hr for normal access areas such as the operating galleries and clean crane maintenance cell, and 2.5 mRem/hr for areas that are occupied infrequently for maintenance such as the modular crane maintenance cell and the canister loading cell when all fuel has been removed.

Preliminary calculations show that the main process cell walls will need to be 1.6 meters (5.35 ft) of concrete (2.5 gm/cc - 156 lb/ft^3). The walls between the rod consolidation process cell and the canister loading cell and the clean crane maintenance cell will be 0.8 meters (2.6 ft) of concrete or an equivalent composite wall of concrete and steel.

<u>QA</u>

The rod consolidation quality assurance system would be a part of the larger facility QA system. The system would assure installation, operation and maintenance repairs all meet the requirements of the design. Formal audits of operations activities would be included.

3.2 NORMAL PRODUCTION OPERATIONS

Normal production will include those operations associated with processing campaigns of similar fuel elements. Thus, the normal campaign includes the reconfiguring of the equipment as well as normal production and service operations. Since this facility will depend on the interface facility (MRS or repository) for the logistics of accumulating the lot of fuel for each campaign, it is also necessary to provide a set of fuel acceptance criteria to that facility. Thus, this section will describe the fuel element selection criteria, equipment productivity, production and maintenance changeovers, time-line analyses, and materials and consumables.

3.2.1 Fuel Element Selection Criteria

The rod consolidation process requires specific mechanical equipment configurations to process each different LWR fuel assembly design. Furthermore, unsound fuel elements whose rods are likely to break when exposed to the handling required may also be present in the fuel element population, especially when dealing with the older fuel elements. Such reconfigurations and off-normal operations will impact consolidation process availability to an extent that requires evaluation of incoming elements prior to processing. The following criteria have been developed for the purpose of defining this interface between rod consolidation and the facility.

Fuel elements entering the consolidation cell shall meet the following criteria:

1. Elements of common design and operating experience shall be queued into lots for consolidation with a normal lot being at least 56 assemblies.

2. Elements must be free of channels prior to consolidation.

3. Elements must be clampable on the initial downender upon receipt in the cell.

4. Elements must pass a visual inspection for fuel or other process sensitive damage prior to consolidation.

5. Elements shall be free of liquid water in order to meet 10CFR60.135 requirements on the canister.

6. Elements shall be accompanied by historical data to the extent possible as an aid to consolidation screening decisions.

7. Fuel elements shall be out-of-reactor at least TBD years.

8. The consolidation Information System shall be capable of correlating element historical and observed element conditions against observed consolidation process abnormalities as an aid in assessing potential problem fuel elements.

Screening will occur within the rod consolidation cell. Each element will be visually inspected as it is lifted for processing. Next the element is clamped to the tilting device. The clamping arrangement will act as a gauge because elements with bending in excess of 5/8 inch will not enter the tilting device. Also, elements with excessive twist and bow will be detected when the element is placed on the transfer table.

3.2.2 Equipment Components Productivity

Each equipment component has been selected on the basis of proven or calculated throughput capability and reliability. The design has carefully minimized movements and moving parts. Essential parts have been identified so careful specification of materials and shapes will occur in later stages of the design. The time and requirements for each process operation are identified on the equipment data sheets (Appendix IV).

3.2.3 Production and Maintenance Changeovers

Prior to each production campaign, the system will be configured for the specific fuel element lot to be processed. The data processing system will contain the required configurations and storage locations for each module that must be in place.

During the preliminary design, the component designs were standardized as much as possible to minimize changeovers. Also, those component modules which must be changed have been designed for easy access and replacement using proven remote module techniques. Remote tooling required for these operations is stored in the cell. The tooling is also standardized to handle as many modules as possible and minimize their number.

The main equipment modules which must be changed are:

- Tilting Table Clamps
- End Fitting Removal Modules
- Fuel Rod Gripping Heads
- Combs
- Fuel Rod Accountability Module
- Fuel Rod Trays
- Rod Reconfiguration Guides

- Rod Reconfiguration Shutters

Certain other equipment will require adjustments to match element grid locations.

The production configuration status will be computerized and controlled such that operation of an uncertified configuration is not possible.

A typical reconfiguration is estimated to take one day (two shifts) to complete.

3.2.4 Time-Line Analyses

The results of time-line analyses for PWR and BWR fuel consolidation are diagrammed on Drawings SH-1886-20-002 and 003. The operation times given on these time-lines were estimated on the basis of SGN experience (fuel element handling), tests (fuel rod removal and PWR upper end-fitting removal) or by extrapolation form existing experience with equipment with similar functions. Appendix IV contains step by step detailed times for each step in the process and supports these diagrams. The only difference between the two time-lines is due to the number of fuel elements packaged in one canister (2 PWR versus 4 BWR) and (at times) the additional step required to remove the PWR fuel element skeleton.

These time-lines show that sixteen BWR or PWR elements can be consolidated in 15 hours, 36 minutes.

The required throughput of 750 metric tons of heavy metal per year is equivalent to about 14 fuel elements per day based on 75 percent availability and 2 shifts per day and some margin. Fourteen elements per day meets the requirement in 186 days with 9 days margin to accomplish 75 percent availability. Three hours per day are available for startup, shutdown, and minor maintenance.

3.3 OFF-NORMAL RECOVERY OPERATIONS

Off-normal operations are described in this section. Anticipated off-normal operations are required to recover from the presence of broken rods, released rods, jammed equipment, loose pellets, powder and parts, and loss of power and services.

3.3.1 Broken Rods

Broken rods are detected by a rod counter which compares a memorized matrix to the detected matrix. The operator is notified and provided the row and column locations of any broken rods.

When this condition is observed, the main control room operator changes from the automatic control mode to the test manual mode and an operator proceeds to the local controls adjacent to the shielded windows. The operator then completes the following operating steps which are illustrated in Figure 3-2.

1. The element skeleton containing the broken rod is set aside onto the stuck or broken rod recovery table to be dealt with later (area 6 on Drawing P1-1886-20-001-B) and Figure 3-2, 2, and the operator is ready to recover the rod piece that is mingled with the other rods in the transition station.

2. The transfer table is moved away and a specially designed intervention system is aligned with the rod reconfiguration station using the transfer table rails as a guide (see Figure 3-2, 3).

3. The recovery tray is placed on the invention system using the master slave manipulator helped by rollers on the intervention system.

4. The reconfiguration system is operated by processing one vertical row at a time until the vertical row containing the broken rod is next. (Figure 3-2, 4 .)

5. The recovery tray is placed in a slot on pusher B as shown at Figure 3-2, 5 .

6. The vertical rod column containing the broken rod is transferred to the recovery tray.

7. With the help of the master slave manipulator, the intervention system is retracted in order to access the rods in the recovery tray.

8. The intervention system is removed and the system is ready to return to normal operation.

9. The broken rod is removed from the recovery tray using the master slave manipulator, (Figure 3-2, 9) and placed in a storage box for broken rods.

10. Broken rods are collected until the operator determines a time effective opportunity to place them in a canister.

11. Intact rods are returned to the reconfiguration station for processing.

Upon completion of steps 1 to 11, the operator turns his attention to the broken rod piece in the skeleton that was set aside in Step 1. The approach is to determine the length (location) of the broken rod segment and shear the skeleton until the rod segment is accessible. These operations are completed using the master slave manipulator and special shears and a single rod gripping device. Since many different situations are possible, the operator makes use of as much information as possible by knowing the length of the rod segment which already has been recovered and the location of the segment in the matrix and by using the in-cell TV. Also the operator can insert a short length (about 20 inches) of 0.5 inch diameter steel rod into the rod location and assure that the fuel rod segment is not present prior to shearing the skeleton. Once the fuel rod segment is recovered, it is placed in the in-cell storage box and disposed in a fuel canister.

3.3.2 Stuck Rods

Stuck rods are detected by the "flags" which lead the rod counter as it is lowered into position to count the rods in the matrix. This operation takes place in the space between the fuel rod skeleton and the pulled rods in the fuel rod removal station (Figure 3-3, 1). Contact with a rod stops the rod counter movement and it is retracted out of the way. The stuck fuel rod is removed using the following operating steps.

1. The fuel assembly skeleton is pulled away from the rod removal station onto the stuck rod recovery area so that the stuck end is determined.

2. The exposed end of the fuel rod is clamped using a special device (Figure 3-3, 3) and the skeleton structure pulled away (Figure 3-3, 4) using the master slave manipulator.

3. If steps 1 and 2 are not successful, the fuel skeleton is sheared away and the rod is gripped and pulled the opposite way using the master slave manipulator.

4. The recovered rod is returned to the reconfiguration station.

3.3.3 Jammed Equipment

The process equipment with moving parts has been designed to prevent jamming of the mechanical processes. Since jamming is expected to be a low probability event, specific scenarios are not defined. However, the design and maintenance philosophy that has been described, which utilizes easily removable modules for essential operations supported by access by both the cell crane, master-slave manipulator, and the servomanipulator should resolve any possible jamming.

3.3.4 Loose Pellets, Powder, and Parts

Loose fuel fragments are not expected to be a normal situation as a large population of broken rods is not present. However, the design anticipates the presence of these and other small objects and particles on the working surfaces.

The transfer table is enclosed by a frame around both the PWR and BWR fuel elements which forms a channel. This channel is swept by air which is excavated through a vacuum system which includes remotely changeable filters. Normally the filters will collect cruds and cuttings, but when broken rods are involved they will also collect fuel particles.

The rod removal station is equipped with a tray located below the equipment. Any loose parts, powder, or parts will fall on this tray. Periodically, the comb modules must be removed and this tray vacuumed using the master slave manipulator.

Any piece of fuel rod that might be broken and dropped during off-normal operations will be picked up using the manipulataor-held vacuum cleaner.

3.3.5 Loss of Power and Services

The major outside supplies are electric supplies, diminerized water (decon and hydraulics), nitrogen, fuel and canister logistic services, and waste services.

The consolidation system is designed such that loss of major services causes a fail safe condition using redundant systems for essential featgures and fail safe mechanical features. On failure of a major service the system automatically enters the fail safe mode with adequate permanent monitoring capability to verify that condition.

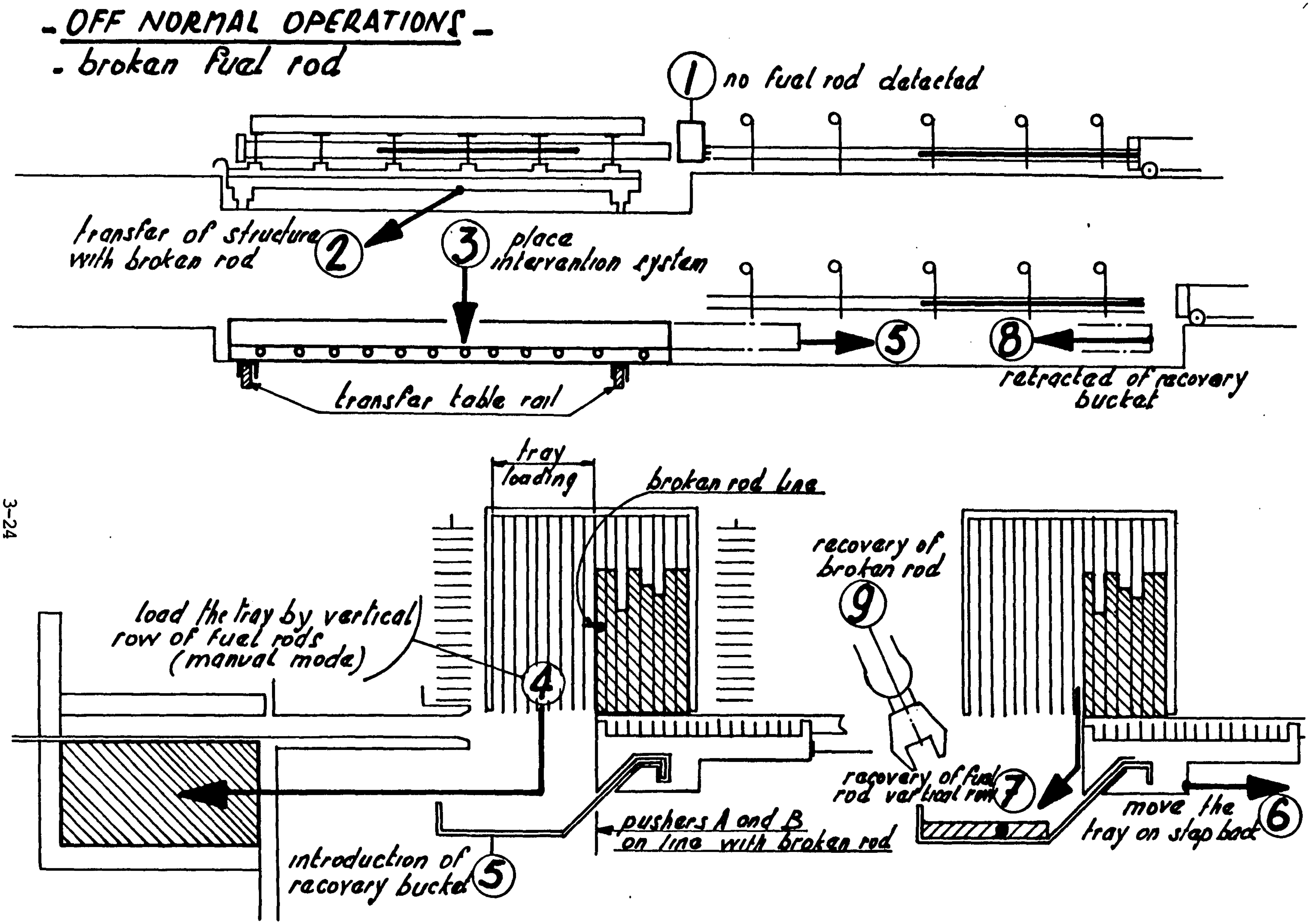

Figure 3-2

Broken Fuel Rod

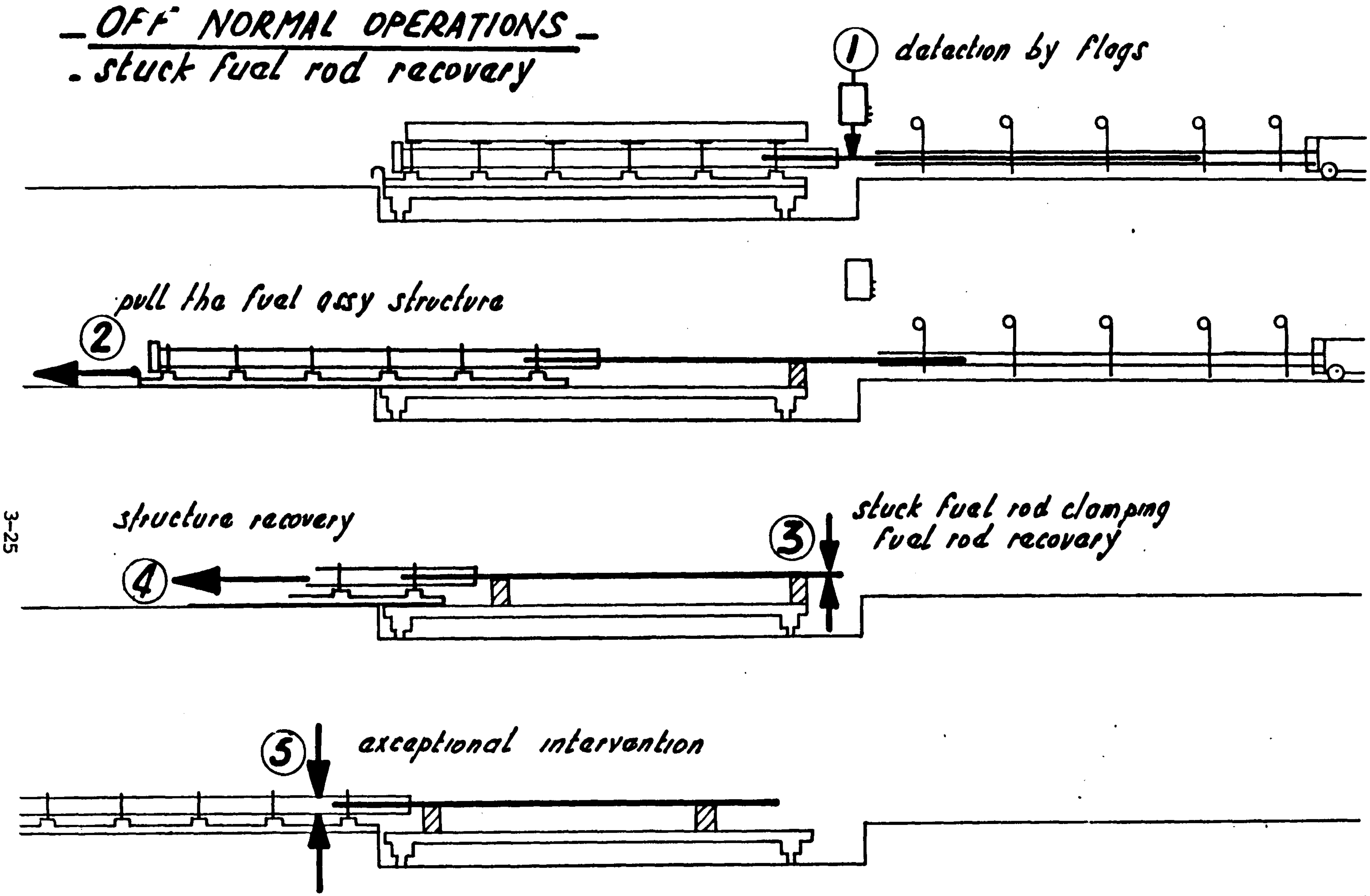

Figure 3-3

Stuck Rods

4. SYSTEM PERFORMANCE EVALUATION

This section will describe the bases, methodology, and results of PCDP Phase 1 performance evaluations including the verification of each DOE functional and TAN specific requirement. A concluding portion will develop the confidence level for meeting the DOE requirements that the GE/SGN/LSI team have accomplished during Phase 1.

4.1 PERFORMANCE EVALUATION SUMMARY

The GE/SGN/LSI performance evaluation covers a range of effort which includes equipment tests in support of design, reliability/availability analyses, operability evaluations and analysis and formal design review. These evaluations, tests and reviews have confirmed the preliminary design and have predicted a 83% confidence that the throughput requirements can be met. As is shown, every DOE requirement has been met by this design.

4.2 EVALUATION BASES AND METHODOLOGY

The design/testing effort described is complemented by performance evaluations which placed emphasis on the operational considerations of the system. A structured approach was applied which balanced the sometimes conflicting input-output (throughput) aspects and the operational aspects of the design, i.e. operability, maintainability, safety, reliability and producibility. The approach was to assemble a team of experts representing each of the operational viewpoints and to cause this team to interact with the designers on three occasions - initially to assure a uniform and comprehensive understanding of the DOE requirements, in mid-phase to guide design trade studies, and finally, during the formal Design Review.

4.2.1 Experience and Testing

As previously described, the GE/SGN/LSI approach to concept design has been to combine parts, materials and processes with known histories of successful application in similar environments with new parts, materials and processes where required, due to unique DOE requirements. Where new designs were required, selective key feature, component and end item performance tests were conducted. Appendix II describes these activities in some detail for fuel element handling, end-fitting removal, fuel rod pulling and in-cell support systems. These tests and experience represent an important portion of the performance evaluation.

4.2.2 Availability/Reliability Modeling

The bases for these design performance evaluations were both quantitative and qualitative. The quantitative base was a process simulation model designed to determine the throughput capability of the system in a 260-day working year with two 8-hour shifts/day. The model included all key operations and is flexible to allow increasing sophistication as the design detail matures. A set of simulation rules was developed and simulation parameters selected in concert with the system designers. Key parameters are operating schedule, normal delay times, quantities and probability of encountering a process delay. The analyses were carried out in two iterations recognizing that many design features were being developed concurrently. A preliminary set of simulation experiments was performed after the initial Requirements Analysis meeting on August 25. These results were documented and distributed to the design and evaluation team.

Subsequently, after a system design review at SGN was completed in early October, a second set of simulation experiments was performed. The model was modified for the second series to reflect primarily changes in the method of introducing spent fuel to the consolidation cell and to more closely mimic the designated time sequences of the various operating equipment. In each series, the simulation parameters were systematically altered to determine their impact on the overall throughput performance. The results of these analyses are described in Section 4.3.2.

4.2.3 Operability Evaluation

The qualitative performance evaluation base was the evolution of design constraints into design requirements consistent with operability, maintainability, safety, reliability and producibility aspects of the system. The process used was to conduct requirements analysis using a peer group of experts to identify these design requirements as described in Section 1.3.2 and thereby establish a requirements baseline. This requirements baseline was used as the basis for the design, for performance evaluation and for the design reviews.

4.2.4 Special Safety Evaluation

Certain special safety evaluations were conducted in the areas of criticality, crud contamination control and fines pyrophoricity control. The results of these evaluations were given in Section 2.3.4. The basis for these evaluations were largely prior experience and scoping analyses based on prior analysis of similar applications.

4.2.5 Formal Design Review

A formal design review was conducted on October 29 and 31, 1986. The basis for this review was the requirements baseline. An independent review was conducted simultaneously to evaluate confidence in the design by considering GE/SGN/LSI performance based on the quality and completeness of the requirements baseline, performance evaluations, test data and reports, the design including analysis, trade studies and drawings, and the design review itself.

4.3 DESIGN REQUIREMENTS VERIFICATION

The following describes the verification of each of the applicable documents and the DOE Functional and TAN-Specific requirements. The verification is expressed in terms which are relative and appropriate for a preliminary design. In some cases, the design reviewers expressed comments which will require consideration during the detailing of this design. This is normal practice and these comments are documented in this section to preserve them for future considerations. These comments are considered to be an adjunct to the design until they are finally considered.

4.3.1 Specifications

The consolidated equipment design complies with the appropriate requirements of the codes, standards, specifications and guides listed in Section 1.3.1.

During the formal design review, it was pointed out that ANS 51.10 (Draft), "Design Criteria for Consolidation of LWR Spent Fuel" requires that the design provide for removal of the fuel from the equipment in the event of equipment failure (an off-normal event). The current design has not been designed specifically to meet this requirement, nor was it known; however, the design philosophy has been for all maintenance and repair to be possible using remote means without the need to remove fuel. See Section 3.1.2.

It was also pointed out that 10CFR60.135 specifies that the waste package "shall not contain free liquid in an amount that could compromise thee ability of the waste package to achieve the performance objectives --". This requirement was interpreted and included in the fuel element acceptance criteria as "canisters shall be free of liquid water" and "fuel elements shall be free of liquid water". Experience at General Electric would indicate that DOE should continue to address these requirements because of the severe impact that would result in the facility fuel element inspection operation. Water inside the fuel rods could be common in the older fuel element in the light water fuel element population.

4.3.2 Generic Functional Requirement FOR-1

The system shall consolidate 750 metric tons of heavy metal (MTHM) per year of spent nuclear fuel. This throughput rate is based on an availability of 75% for operation two shifts/day and five days/week over a 30-year lifetime. As a basis of design, 60% of the spent fuel, on a metric ton heavy metal basis, will be PWR, and 40% will be BWR.

The system has been designed to meet the required throughput based on SGN experience, available reliability data, tests and extrapolations of operation of equipment with similar functions. Both PWR and BWR functional time-line analyses were completed using the above inputs and the results indicate a 3-hour margin each day for completion of minor maintenance, housekeeping, etc. See Section 3.2.4 and Appendix IV.

The time-line analyses were verified using reliability and availability analyses, including a simulation model of the process. Key availability parameters and event probabilities were varied and their effect on annual throughput determined. The simulation model was used to establish bounding sets of conditions which meet 750 MTNM/year at 75% confidence. These condition sets were iterated with the SGN design team and a reference set of design conditions were established. Using these conditions, the simulation parameters were altered systematically to determine their impact on the overall throughput performance. The details of these analyses are described in Appendix V. The conclusions drawn from this activity are as follows:

a. Rod Consolidation System process time for 750 MTHM is < 188.4 days with 83% confidence (includes $1^{]}$).

b. The calculated process time is based on the premise that the availability of equipment functions are:

End-Cutting Function	65.2%
Rod-Pull Function	65.2%
Rod Reconfiguration Function	84%

Canister Closure Function	71%
In-Cell Crane #1	90.4%

c. The process time also is based on the premise that the failure probabilities are <.002 of the spent fuel bundles processed (approximately 5.2/year) and that the spent fuel is always available on demand.

d. The margin of 71.6 days allows for further decreases in availability of the four equipment functions and in-cell Crane #1.

e. The principal equipment item pacing the throughput based on the above premise is the consolidation cell crane.

A key assumption of these analyses is the failure probability of <.002 of the spent fuel bundles processed. This assumption relates to the requirement for fuel bundle acceptance criteria and inspection prior to consolidation so that the failure rate is not exceeded. These criteria are given in Section 3.2.1 and represent a beginning set which will be modified as this program matures.

The design review has surfaced concerns that intermediate lag storage capability may be required and that the process includes one step which requires back-tracking (NFBC skeleton removal). Because the time-line and reliability/availability analyses have indicated more than adequate throughput capability, these concerns have not impacted the preliminary design, but will be considered as the design matures.

4.3.3 Generic Functional Requirement FOR-2

The system shall package all rods from two PWR fuel assemblies or from four BWR bundles in one canister. The system shall be capable of consolidating most configurations of PWR and BWR fuel used in the United States LWR industry.

The preliminary design is capable of packaging two PWR fuel bundles or four BWR bundles in rectangular (square), triangular, trapezoidal, hexagonal, or round canisters. See Section 2.1.5.

4.3.4 Generic Function Requirement FOR-3

The system shall be capable of being modified to utilize canisters of one of the following cross sections: square, round, triangular, hexagonal or trapezoidal.

The reconfiguration and canister packaging systems are compatible with all required canister geometries. See FOR-2 and Section 2.1.5.

4.3.5 Generic Functional Requirement FOR-4

The system shall operate on a continuous basis.

The system is designed for automatic control of all normal operations. The control system also is capable of semi-automatic, stop, controlled manual and testing manual modes. Automatic control is defined as a complete rod consolidation cycle for a given fuel bundle. The operator must initiate each cycle and is provided with manual overrides in case of off-normal events. See Section 3.1.1.

4.3.6 Generic Functional Requirement FOR-5

The system shall operate remotely during normal and off-normal operations. The system shall be semi-automatic or fully automatic.

The system is designed for automatic, semi-automatic, controlled manual, and test manual control modes. Automatic is for a complete cycle of operating sequences. Semi-automatic requires authorization for each step in the cycle. Controlled manual requires operator authorization for each elementary step for selected sequences, and test manual is the same except that the protection interlocks can be deactivated.

All operations within the rod consolidation cell are designed for remote operation. See Sections 3.1, 3.2 and 3.3.

4.3.7 Generic Functional Requirement FOR-6

The system shall provide for remote monitoring of operations from the consolidation process equipment control panels. Monitoring shall include audio monitoring of the equipment operation and monitoring of the system operation by instrumentation and alarm.

The system is monitored and controlled remotely using a distributed control system located in a main control room and a local control room with sensors located in the cell. Audio and visual monitors are provided in each area to display images and provide audio information on equipment performance to the operator. Suitable sensors and transmitters are located in the cell to operate the process system and to monitor equipment performance during automatic, semi-automatic or manual modes with alarms for key off-normal conditions. See Sections 2.3.1, 3.1, 3.2 and 3.3.

4.3.8 Generic Functional Requirement FOR-7

The system shall minimize the generation of radioactive crud, fines, and cuttings, as well as the potential for breaching fuel cladding.

Fines and cuttings are generated during PWR guide tube drilling and end-fitting removal. The designs selected for these operations reduces the quantity of metal fines to near zero, minimizes the quantity of cutting chips and provides for their collection and disposal. The cutter used to cut the guide tubes of PWR assemblies is designed to control dispersal of the Zr chips generated by directing them into the guide tubes where they are removed from the cell with the fuel assembly skeleton.

The end fittings are removed from BWR assemblies by shearing the 8 tie rods at the surface of the tie plates. This method produces no fines and very few chips. The top end fittings are removed from PWR assemblies by cutting the guide tubes from inside with a tool that ensures a narrow cutting width with a minimum of cutting chips and very few fines. Loose chips from either process are collected on catch plates below the end fitting removal stations and are cleaned up with the manipulator operated vacuum as required to limit the accumulation to a safe amount.

Loose crud will be wiped from the rods and collected with a vacuum system as the rods are pulled from the assembly skeleton into the vertical and horizontal combs. This will minimize the amount of loose crud generated in the transition from bundle spacing to final canister configuration. Loose crud will be vacuumed from the table surfaces below each disassemble/consolidation operation whenever a significant accumulation is visually detected using a manipulator held vacuum. The process cell will be thoroughly cleaned with the remote vacuum at the end of each campaign.

The pulling heads used to extract the fuel rods from the assembly skeleton are designed such that they will slip off of the end of a stuck rod before the pulling force is sufficient to rupture the fuel cladding. See Sections 2.1.3, 2.2.3, 2.2.4, and 3.3.4.

4.3.9 Generic Functional Requirement FOR-8

The system shall provide for collection/control of such radioactive crud, fines, cuttings, and fuel pellets and/or dust as may be generated.

Each work station is designed to capture and collect crud, fines, cutting and fuel fragments. The tables supporting each step of the disassembly/ reconfiguration process are designed with an open mesh top with a catch tray below to catch any small pieces or particulate material generated.

The transfer table is equipped with a suction device which collects any fines which are generated by friction between the spacer grids and the fuel rods. The element clamping plate creates a channel which promotes the sweeping action of the suction. In addition, the design allows easy recovery and cleanup of the material on the table using a manipulator operated vacuum cleaner. See Sections 2.2.3 and 2.2.4.

4.3.10 Generic Functional Requirement FOR-9

The system shall provide for remote tooling changes, remote maintenance, remote component replacement, and remote decontamination of all consolidation and supporting equipment.

The system is designed for remote reconfiguration prior to each production campaign. Computerized diaries will indicate the tooling changes required and the tool location for each type of fuel element. Each equipment station is designed with the operating modules attached to a supporting structure. The frequently changed modules for reconfiguration are stored at specific in-cell locations and are easily replaced. All modules can be replaced as required for maintenance and replacement. Remote decontamination of equipment modules will be possible in the maintenance cell; however, the normal expected mode is to perform the equipment maintenance in-cell or replace it with a new module. See Section 2.3.2 and 3.2.3.

4.3.11 Generic Functional Requirement FOR-10

The system shall permit and facilitate accountability for all special nuclear material during the rod consolidation process. Accountability shall be provided for intact fuel rods, broken fuel rods and fuel pellets.

Accountability is based on item control with the minimum item being one rod, defined for accountability as having 1/n of the SNM of the element with "n" rods from which it came.

The rod pulling fixture is designed to detect missing or broken rods and facilitate removal of the pieces of broken rods and all their components, pellets or particulate matter, from the fixture. The broken rod pieces and any loose pellets and particulate matter will be placed in the failed rod canister and accounted for as one rod.

SNM material which exists in the cell as liquid waste will be assayed and accounted in the facility material balance area.

See Section 2.1.8.

4.3.12 Generic Functional Requirement FOR-11

For criticality control, the system shall maintain K_{eff} less than 0.95 for all normal and off-normal conditions.

Criticality control for lag storage of elements or canisters will be accomplished by the design of the storage racks in the lag storage pits. If the facility design precludes flooding of the storage pits, the design will be based on a dry unmoderated condition. If flooding is a possibility, the racks will be poisoned to accommodate the optimum moderation condition.

Criticality control during the rod consolidation/reconfiguration process is assured by the limited amount of fuel in the process at any time, the absence of moderator material in the process cell surrounding the consolidation equipment. Only one PWR or one BWR fuel element is disassembled at a time. The rods from the first PWR element or first 3 BWR elements assigned to a given canister are in the transition device during disassembly of the next element. In these fixtures, the transition device or the canister loading device, the rods are removed from close proximity of the disassembly station and are held in close packed arrays. See Section 2.1.8.

4.3.13 Generic Functional Requirement FOR-12

The system shall minimize the potential for the pyrophoric ignition of zirconium or any other material(s) capable of pyrophoric ignition.

The choice of cutting methods to remove the end fittings reduces the production of Zr fines to a very low value. The majority of the cuttings produced while cutting the PWR guide tubes will be chips that are too large or to promote pyrophoric ignition. As a further precaution, cuttings are directed into the guide tubes using nitrogen flow around the cutter and gravity such that there will only be a very small amount in each tube which is disposed of with the skeleton. The small amount of chips that are not directed into the guide tubes by the PWR cutting heads and any chips produced by the shearing of the BWR tie rods will collect on a surface below the end fitting removal stations and will be collected by the manipulator operated vacuum cleaner as required to assure no probability of pyrophoric ignition. The vacuum cleaner filter bag will be disposed of with the NFBH, except when known SNM is present it will be disposed of in a fuel canister. See Section 2.1.8.

4.3.14 Generic Functional Requirement FOR-13

The system shall minimize the occurrence of and demonstrate the ability to recover from off-normal events occurring in the consolidation of spent fuel rods. Such events, which shall be identified by the contractor, should include: handling and packaging of a fuel assembly that has been partially disassembled when inspection criteria dictate that the specific fuel assembly cannot continue to be consolidated; rod rupture; rod sticking during disassembly; recovery of dropped fuel pellets; recovery of fissile material in the form of fines as the result of fuel rod rupture; fire; equipment breakdown and repair; loss of electrical power or other utilities and loss of ventilation.

The system is designed to minimize the occurrence of off-normal events through careful attention to bundle acceptance criteria, maximizing the number of like bundles in each campaign, visually inspecting each fuel bundle, data logging all off-normal behavior along with cause, if known (learning curve), limiting loads and forces exerted in the various operations and providing off-normal detection devices so that recovery operation may be conducted before more serious damage occurs. The special off-normal conditions such as fire and loss of essential utilities are limited through minimizing the amount of zirconium fines and using redundant utility systems.

Recovery from off-normal events is normally accomplished using the equipment under manual controls, remote manipulators, and redundant systems. Off-normal events considered in the preliminary design were damaged bundle handling and packaging, broken fuel rods, stuck rods, loose fuel pellets, powder and particles, fire, equipment breakdown, loss of power, or other utilities, and loss of ventilation. Off-normal operation is described in Section 3.3. Equipment breakdown is described in Section 3.2.3.

4.3.15 Generic Functional Requirement FOR-14

The system shall meet the requirements of quality assurance standards established in ASME/ANSI-NQA-1 (1986) with all revisions.

The program has been performed with a documented Quality Assurance Plant which addresses the requirements of ASME/ANSI NQA-1 and implementing procedures. The following activities were completed:

a. Pass through to the subcontractor the requirements of ASME/ANSI NQA-1.

b. Review of the subcontractors system description of how the requirements are implemented.

c. Form audits of internal project activities.

d. Established records requirements and implemented requirements.

e. Provided surveillance of supplier activities.

f. Review of design activities by design review to include both independent and peer review. Documented results of review.

See Section 1.4.2.

4.3.16 Generic Functional Requirement FOR-15

The system shall include all equipment for the handling of materials, components and containers.

Logistics required for consolidation system operation includes facility services, as well as in-cell handling equipment. The concept consists of two shielded cells serviced by equipment situated above and below the cells. The shielded cells include one highly contaminated consolidation cell and one "clean" canistering cell. The facility services the contaminated cell by supplying fuel bundles and NFBC canisters from "clean" corridors located below the cell and by providing material access/egress to a materials transfer cell. The facility services the "clean" cell by supplying and removing fuel canisters using "clean" corridors located below the cell, by providing material access/egress to a materials transfer cell and by providing crane maintenance service capability from above the cell.

The contaminated conssolidation cell handling equipment includes a modular crane supplemented by eight set of shielded windows with master-slave manipulators and a servomanipulator, if necessary. The crane is used for normal, as well as off-normal transfers. The master-slave manipulators are used to assist remote maintenance, and for reconfiguring the equipment. The servomanipulator is used only for unusual occasions in difficult to reach locations. This combination provides the most capable system to meet all handling situations envisioned. See Section 2.3.1.

4.3.17 Generic Functional Requirement FOR-16

The system shall minimize the external contamination of the consolidated canisters during all operations involved in the rod consolidation.

The fuel rod and NFBC canisters are protected from contamination during all system operations. The canisters enter and exit the consolidation operation through clean corridors. Canister loading, in both cases, is accomplished using transfer hatches that are designed to prevent contamination of the canister including the lid. The hatch design has been proven through similar applications in France.

Although not expected to be required, decontamination is possible as yet another feature of the hatch design.

Contamination monitoring equipment is provided as a check that the hatch has operated without an unexpected contamination problem. See Sections 2.2.5 and 2.2.6.

4.3.18 Generic Functional Requirement FOR-17

The system shall be capable of being installed in the TAN enclosure.

TAN enclosure equipments arrangements were completed to assure that the system was capable of being installed in the TAN enclosure. A similar alignment of the main equipment stations and the transfer arrangement between stations was possible.

Major differences between the Generic and TAN arrangements are due to the necessity to have all equipment within the enclosure. Thus, the canister loading device and rod removal station cylinder are placed inside the cell thereby complicating potential maintenance activity. Also, the inability to modify the TAN shielding walls causes the design to place all actuators inside the cell, to change to a servomanipulator for maintenance and reconfiguration, and to use TV cameras in place of windows.

See Section 2.4.

4.3.19 TAN-Specific Functional Requirements TAN-1

The system shall package all rods from two 15 x 15 PWR fuel assemblies or from four 8 x 8 BWR fuel bundles in one canister.

The generic design meets this requirement so the TAN concept will also.

4.3.20 TAN-Specific Requirement TAN-2

The system shall include a means to place the consolidated rods into square canisters with inside dimensions of 8.5 inches by 8.5 inches by 15 feet in length.

The generic design has the flexibility for filling square canisters along with many other geometries.

4.3.21 TAN-Specific Requirement TAN-3

The system shall provide for closure of the loaded consolidation canisters. The closure system shall provide a closure capable of maintaining the fuel rods within the canister and, if the closure involves the canister lid, the closure shall be of sufficient strength to support the weight of the loaded canister. If welding is used for closure of the loaded canister then the system shall provide for non-destructive examination (NDE) of the seal weld(s) for the loaded consolidation canister.

Prototypical demonstration of canister closure is judged to have lower priority in TAN than the rod consolidation and packaging process. Thus, the TAN concept illustrated in this report is a mechanical closure which meets the above requirements.

See Section 2.4

4.3.22 TAN-Specific Requirement TAN-4

TAN 4. The system shall operate on a batch basis for the Hot Demonstration.

Adequate lag storage and crane capability is included in the TAN concept for two days production. This capacity is a carefully selected compromise between the restricted space and the need to demonstrate production throughput. Storage capacity is 28 fuel elements, 7 NFBC skeleton canisters (four compartments) and one end fitting canister (no compartments) and 14 rod canisters. Facility services are assumed to accommodate all input/output logistics.

See Section 2.4.

4.3.23 TAN-Specific Requirement TAN-5

Due to the limited availability of shielded windows for the Hot Demonstration, the system shall provide for remote operation utilizing CCTV for viewing.

All remote operations in the TAN concept are performed by a servo-manipulator similar to the one described for exceptional conditions in the generic facility.

See Section 2.4

4.3.24 TAN-Specific Requirement TAN-6

The design shall include a decontamination system which shall decontaminate the exterior surface of the consolidated fuel canisters and NFBC containers to 2200 dpm/100 cm^2 beta gamma and less than or equal to 220 dpm/100 cm^2 alpha.

Decontamination capability is a major difference between the TAN concept and the generic concept. Since the TAN cell will become contaminated, decontamination of all canisters will be necessary. The TAN concept will apply high pressure water decontamination and confirmation of the entire surface of all canisters.

See Section 2.4.

4.3.25 TAN-Specific Requirement TAN-7

TAN 7. **The system shall provide for placing the intact fuel assembly skeleton (after fuel rod removal) into a container. The skeleton may or may not have the lower end fitting attached. The container and lid will be provided by DOE and will be approximately 20 inches wide by 20 inches high by 15 feet long. The container will be subdivided into four 10 inch by 10 inch compartments to accommodate four fuel assembly skeletons.**

The TAN concept will require two configurations of the NFBC canister. One will be divided into four compartments and will accept PWR bundle skeletons. The second will be a single compartment and will accept the lower end fittings.

The TAN concept provides for handling the NFBC skeletons using the servomanipulator, the lower end-fittings are collected in intermediate containers (in lieu of the chute in the generic facility) then transferred into the single compartment NFBC container.

See Section 2.4.

4.3.26 TAN-Specific Requirement TAN-8

For the Hot Demonstration, the system shall provide the following:

(1) A storage rack for the storage of unconsolidated spent fuel.

(2) Storage capacity for empty and loaded consolidated fuel rod canisters. This storage area shall maintain a "clean" environment for the empty and loaded fuel rod canisters.

(3) Storage capacity for empty and loaded NFBC drums. This storage area shall maintain a "clean" environment for the empty and loaded NFBC drums.

(4) All required instrumentation, controls, alarms and panels necessary for operation, observation, and data collection.

The TAN-concept contains storage racks for fuel elements, reject elements, NFBC canisters, and rod canisters. Storage capacity is 28 fuel elements, 7NFBC skeleton canisters (four compartments), 1 end fitting canister (no compartments), 14 rod canisters of 6 reject elements. There is no divider in the TAN enclosure in the current concept to separate a clean canister handling room from a contaminated process room because of the severe cost penalty for additional servomechanisms and ventilation rearrangements. Instead the philosophy is to capitalize on the process capability to eliminate fines and control cuttings and crud collection. This process capability permits the concept to meet the intent of this requirement by controlling canister contamination levels and decontaminating each canister as it leaves the enclosure.

4.4 DESIGN CONFIDENCE VERIFICATION

This section will describe the approach and the results of the project teams effort to verify that all DOE requirements were met at the 75% confidence level. The approach was to use six distinct areas of evaluation which together constitute confidence that the F&ORs will be met. These areas are:

1. Requirements Definition
2. Performance Evaluation
3. Test Data and Experience
4. Design Analysis, Trade Studies and Drawings

5. Design Review
6. Availability Simulation Model Based on Data Provided by the Designers

Since any evaluation of the quality and completeness of the above areas is largely subjective, an independent review team made up of Nuclear Waste Repository Project personnel was called upon and chartered with providing an objective evaluation of each area in the perspective of the preliminary design objectives.

A summary of the effort and the independent evaluation is given for each of the areas.

4.4.1 Requirements Definition

A team of experts was assembled and chartered with a systematic review of the DOE F&ORs from each of seven viewpoints. Viewpoints represented were:

- Design
- Operation
- Maintenance
- Safety and Licensing
- Quality Assurance
- Reliability
- Producibility

Each viewpoint reviewed each F&OR from the perspective of accomplishing every function required to meet specific end objectives. Every function was expressed in terms of attributes required for success of that function. Every attribute was reduced to a specific requirement. The specific requirements were collected and integrated into an expanded Baseline of Preliminary Design Requirements. The Requirements Baseline was reviewed by each viewpoint to assure that representative integration and compromise had occurred. The completed Requirements Baseline was issued as a project document for use by the designers, the performance evaluators, and the design reviewers.

Phase I Equipment Design and Facility Interface Requirements Baseline generally satisfy DOE's Generic Functional Requirements and no inconsistencies were noted.

Additional requirements impacting canister design and fabrication criteria are recommended. Canister interface features and criteria essential to meet Rod Consolidation system performance should be identified. (Although it is recognized that canister design is not part of the rod consolidation design activities, the requirements for canister processing may result in imposition of canister design criteria).

4.4.2 Performance Evaluation

The same team of experts reviewed the preliminary design drawings, design basis and available performance analyses from their viewpoints. Emphasis was placed on operability, maintainability, producibility in USA and licenseability.

The reliability viewpoint interacted iteratively with the SGN designers and determined capacity and lag storage considerations during the preliminary design process (see Reliability below).

System and component presentations describing operation indicated a high probability that performance objectives will be satisfied. Normal and off-normal conditions were thoroughly evaluated and it was concluded that anticipated conditions could be handled adequately.

Statements of confidence level (75%) and system availability (75%) were found to be confusing; clarification is recommended. For instance, using data provided in the design review package, it could be concluded that a performance goal is 75% confidence that the system will be available 75% of the time, whereas this is not intended.

There are also technical concerns with the proposed canister assembly, inspection, and decontamination operations.

A potential exists for entrapping crud or contamination resulting from installation of the rods into the canister, between the canister end and the lid. Foreign materials may adversely affect weld performance and the ability to decontaminate the canister. The potential for this occurrence should be evaluated and corrective actions proposed as part of the final design phase.

Canister weld inspection and acceptance criteria need to be considered to the extent they may impact canister closure welding. For example, if a helium leak test is required, it may be necessary to introduce helium into the canister prior to welding. This additional step may influence canister lid installation equipment.

As shown, only the end of the canister will be decontaminated, as required, prior to welding. Provision to decontaminate the full length canister is recommended. Also, during decontamination with the high pressure water spray, incidental admission of water into the canister should be avoided.

4.4.3 Test Data and Experience

SGN has described available test data, presented video demonstrations and photographs during the design review and has described these tests and operating experience in this report, Appendix II. Although proprietary details have not been disclosed, sufficient detail to illustrate feasibility and operability were provided.

It was apparent from the videos and slides shown during the design review that significant testing of components and systems had been performed. However, objective test data, in the form of reports, were not presented. Test results were presented in a general manner, with specific data cited in response to reviewers questions.

4.4.4 Design Analysis, Trade Studies and Drawings

A portion of the design verification was provided by documenting the preliminary analyses and trade studies (Appendix I) and issuing approved drawings (Appendix III) with independent reviews of the design by the GE performance evaluation team.

Design analyses had been performed as part of the design process. However, results were cited only in response to questioning during the design review meeting.

Drawings and sketches present sufficiently depicted general system function and were adequate to verify adequacy of system performance. However, additional drawing information describing materials of construction, major components, dimensions, tolerances of features critical to performance are recommended.

Although much thought has obviously been given to the remote hot cell operating environment, the operation, maintenance, and reliability of equipment and components can not be readily assessed from some of the sketches. Final design activities during the next phase should fully satisfy this concern.

4.4.5 Design Review

The independent review was consummated with a formal design review with SGN presentation of the design and the design rationale and the performance evaluation teams reviewing and developing findings relative to the Baseline Requirements. The extent of the findings constitute a measure of the confidence in meeting the F&ORs.

The design review process as applied to the rod consolidation was through and objective. Excellent presentations by GE, SGN and LSI personnel stimulated questions and thoughtful recommendations by the Design Evaluation Team.

With the responses to the findings, the design review was complete with no serious open questions or issues that were not brought forward for future consideration.

4.4.6 Availability Simulation Model

The reliability/availability evaluation for PCDP Phase was structured around a simulation process of the rod consolidation system. Key availability parameters and event probabilities were varied to determine their effect on an annual throughput of spent fuel tonnage.

The simulation model was used first to establish bounding sets of conditions which meet the 750 MT/HM/yr at 75% confidence. These sets were iteratively discussed with the SGN design team ending with a reference set of design conditions. These conditions were simulated to a degree sufficient for establishing at least 75% confidence that the annual throughput requirement will be met. The results show an 83% probability that the throughput requirements will be met.

Results from the simulation model added to the confidence that the performance requirements would be fully satisfied. The system design features are consistent with the model assumptions and results. Time for periodic cleanup, decontamination, and maintenance of the equipment has been included.

The failure rate of equipment can be anticipated to increase with time due to wear, radiation damage, etc. Increasing failure probability (with time) can be used to establish planned maintenance and replacement cycles to further ensure system availability.

4.4.7 Accumulative Design Confidence

Through the combination of the above subjective and analytical evaluations, confidence in the design has been accumulated. In order to develop a response to the DOE request that the design exhibit at least a 75% confidence in meeting all requirements, the subjective issues were made quantitative by pre-assigning a portion of the confidence in each area. The independent review team was asked to rate the project teams performance in each area. The results were as follows:

Area	Confidence Range	Confidence Rating
Requirements Definition	7-10%	10%
Performance Evaluation	10-15%	10%
Test Data and Experience	0-15%	10%
Design Analysis, Trade Studies and Drawings	15-25%	20%
Design Review	20-35%	35%
Reliability/Availability-Simulation	*	
	Total	85%

*Included under Performance Evaluation

The independent review team rating was established without the benefit of reviewing the material in this report. Thus, some of their concerns have been addressed and reconciled and this would tend to increase their confidence rating.

APPENDIX I

DESIGN TRADE-OFF STUDIES

A variety of technical alternatives present themselves for consideration during the conceptual design phase for a given mechanical or process requirement. The designer must select the best available alternative from among these for the specific application at hand. The purpose of this appendix is to explain the reasoning behind certain key technical selections made prior to the design of the spent fuel rod consolidation system.

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APPENDIX I

DESIGN TRADE STUDIES

A. FUEL ELEMENT HANDLING

1. Functional Description

The primary function of the spent fuel rod consolidation system is to reduce the storage volume of fuel rods from spent fuel elements by a factor of at least two. To accomplish this, fuel rods are removed from the fuel elements and placed in storage canisters in a ratio of from two to four fuel elements to one canister. The fuel elements and rods undergo several handling operations inside the rod consolidation system cell, the main ones being fuel element endfitting removal, fuel rod removal, fuel rod reconfiguration and fuel rod packaging.

2. Requirements

The rod consolidation system must meet all of the functional and operating requirements set forth in section 1.3 of this Preliminary Design Report. In particular, the system must minimize the occurrence of off-normal events such as rod rupture, which could occur as a result of either traction or of the dropping of the fuel element/rod.

3. Alternatives

The rod consolidation system operations described above may, individually or collectively, be performed with the fuel elements/rods in either the vertical or the horizontal positions.

4. Selection and Reasons

It was decided to perform all rod consolidation operations with the fuel elements and fuel rods in the horizontal position, based on several criteria, described below.

a. Risk of rods dropping

During the fuel rod removal operation, the rods would need to be gripped and pulled out of the fuel element by mechanical means. In a vertical operation, if one of the rods should slip out of the gripping mechanism it would fall to the cell floor, necessitating a potentially delicate and time-consuming recovery operation. In a horizontal operation, the risk of rods dropping inside the cell is eliminated.

b. <u>Recovery of stuck rods</u>

If a rod is stuck inside the fuel element during the removal operation, the operations and equipment needed to recover the rod are greater for vertical operations than for horizontal operations. In the vertical position, the stuck rod would need to be clamped or held by amaster slavemanipulator or other device to avoid bending and breaking, while another manipulator carefully pulled the rod out of the fuel element structure.

In the horizontal position, the entire fuel element can be retracted to disengage the stuck rod from the other withdrawn rods, which reduces the traction applied to the rod and thus the risk of breaking. The retracted rod can then be recovered by a single manipulator.

c. <u>Ease of maintenance</u>

The rod consolidation system must consolidate 750 metric tons of heavy metal per year in one line. A high degree of facility availability must therefore be achieved, and thus downtime for maintenance must be minimized. To accomplish this, the system can be designed as a serie of modules, each of which can be easily and quickly replaced. Such replacement operations are easier if the modules are in a horizontal as opposed to a vertical arrangement. In the vertical arrangement, modules would have to be removed with manipulators in a first step, and then moved with a lifting beam and an overhead crane to the equipment lay-down area or out of the cell. In the horizontal arrangement, only the overhead crane and lifting beam would be required for maintenance.

d. Equipment lay-out

When the equipment is in the horizontal position the work stations, shielded windows and remote control panels are all on the same floor. A vertical configuration would result in a high cell requiring several floors, each with its own shielded windows and work stations.

B. END-FITTING REMOVAL

1. Functional Description

Removal of the rods from the fuel elements requires the prior removal of the upper end-fitting for PWR fuels, and of both the upper and the lower end-fittings for BWR fuels.

2. Requirements

The rod consolidation system must be capable of handling several different types of PWR and BWR fuel elements, which have different end-fittings. The methods adopted for end-fitting removal must therefore accommodate these different types, while maintaining the integrity of the fuel rods and minimizing the generation of radioactive cuttings and dust.

3. Alternatives

A number of mechanical systems were considered for the removal of both PWR and BWR end-fittings, which may be grouped into two categories : sawing, or cutting/shearing. A third option was considered for BWR fuel elements only, and consists of unscrewing the tie rods from the end-fittings.

4. Selection and Reasons

It was decided to remove the upper end-fitting of the PWR fuel element with a cutting device, and both the upper and lower end-fittings of the BWR with a shearing device, as opposed to screwing orunscrewing the tie rods. The reasons for these choices are set forth below.

a. Ease of operations and maintenance

Prior experience with a variety of saws used for sawing large components in a hot cell environment has shown that saws are difficult to control, particularly when a straight cut is necessary, and that they wear out quickly and thus require frequent replacement. With respect to unscrewing BWR tie rods, the inaccessability of the tie rod screws in certain BWR elements creates an added operations step to gain access, and the unscrewing operation itself can be slow and difficult. The removal of end-fittings by cutting or shearing, on the other hand, can be done cleanly in one step without undue wear of the cutter/shear.

b. Access to the rods

As mentioned earlier, the integrity of the fuel rods must be preserved at all times. Sawing of the end-fittings would risk touching the rods, since in the BWR fuel element they fit inside an indentation in the end-fitting, and in certain PWR fuel elements swelling from irradiation can cause some rods to expand until it touches the end-fitting. In the case of the BWR, a device consisting of multiple shears can be used to simultaneously cut all of the tie rods of the end-fittings, enabling the latter to be removed without touching the fuel rods.

In the case of the PWR, particularly the 17 x 17, the problem is somewhat different. The same phenomenon that causes some of the fuel rods to expand from irradiation can cause the spacer grids to expand, releasing some fuel rods. These fuel rods, which fall to the lower end-fitting, no longer extend beyond the upper spacer grid. Thus, removal of the upper end-fitting alone of the 17 x 17 element does not provide sufficient access to the fuel rods for easy removal. One solution consists of removing the lower end-fitting and pushing the rods through the element towards the gripper, but this would entail additional equipment and space requirements. The option selected consists of cutting the guide tubes from the inside just beyond the upper spacer grid, and removing the spacer grid and end-fitting together.

c. <u>Minimization of secondary waste</u>

Removal of the end-fitting by sawing generates radioactive fires, cuttings and dust that must be collected, controlled and contained using additional in-cell devices. The shearing and cutting techniques greatly reduce the generation of this type of secondary waste. The cutting technic provides the additional advantage of allowing any cuttings to remain inside the PWR guide tubes.

C. FUEL ROD REMOVAL

1. Removal of All Rods vs. Rows of Rods

a. <u>Functional Description</u>

After removal of the end-fitting, the fuel element is transferred to the rod removal work station, where two operations are performed, the rods are removed from the fuel element structure, and they are counted to verify their presence or to detect missing or broken rods.

b. <u>Requirements</u>

The rod removal system must minimize the occurrence of offnormal events such as rod rupture, while achieving the 750 MTHM throughput rate established for the facility.

c. Alternatives

Fuel rod removal can be performed on a row of rods, or on the entire fuel bundle.

d. Selection and Reasons

It was decided to remove the entire bundle of fuel rods simultaneously as opposed to row-by-row, for three primary reasons described below.

i. Increaed Throughput

Removal of all of the fuel rods simultaneously and subsequent counting reduces the number of operations required and thus the turn-around time necessary for each fuel element. The required throughput rate can be achieved without increasing the number of processing lines or equipment requirements, which would be the case for a system that removes rows of rods and counts each row individually.

ii. Ease of operations

The manipulation of several fuel rods is simpler and safer than that of a single rod, where the likelihood of rod rupture is greater. Furthermore, the rigidity of an entire fuel bundle is greater than that of a row of rods, which also facilitates handling.

iii. Accountability

Rod counting to detect the presence of intact, broken and missing rods for accountability purposes is performed only once in normal operations in the case of removal of an entire fuel bundle, rather than several times as in the case of row-by-row removal.

2. Rod Counter Location

a. Functional Description

After removal of the rods from the fuel element structure, they must be counted to verify that they are all present and intact. Detection of missing or broken rods will permit corrective actions to be undertaken to recover the rods. The method of rod counting, chosen based onpositive experience with it in hot cells, consists of sensors that probe the extremeties of the fuel rods to determine if the plug is intact, using a system of "flags" to signal broken or missing rods. The "flags"probe the area between the element structure and the pulled rods as the counter is lowered into position.

b. Requirements

The system must permit and facilitate accountability for all special nuclear material during the rod consolidation process. Accountability must be provided for intact fuel rods, broken fuel rods and pellets.

c. Alternatives

There are several alternative locations where the rod counter might be placed. These are a, at the lower and upper ends of the entire fuel bundle after removal from the fuel element structure, but prior to fuel rod reconfiguration (see Section D of the Appendix), b,at the lower and upper ends of one row of rods that are in the reconfiguration device, and c, at the lower and upper ends of the entire reconfigured fuel bundle.

d. Selection and Reasons

The location at the end of the fuel rodswas selected for rod counting due to the accuracy of detection and ease of recovery it allows.

i. <u>Accuracy of detection</u>

Counting of the rods after removal from the fuel element but prior to their reconfiguration gives highly accurate detection, becausea direct correlation still exists between the location of a fuel rod in the gripping device and its location in the fuel element structure. For example, a missing or broken rod detected in coordinant X of the rod array in the gripping device corresponds to a whole or partial rod in coordinant X of the fuel element structure. This exact correlation no longer exists once the fuel rods are reconfigured. Furthermore, the precise geometry of the reconfigured rods cannot be known. Thus, if a rod is stuck in the fuel element structure, its location cannot be detected accurately once the rods have been reconfigured because the rod immediately above it would have taken its place, as illustrated below :

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oooooo      ooxooo
oooxoo      oooooo
oooooo      oooooo
oooooo      oooooo
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x locations of the stuck rod

o rods

This is the main reason the other locationswere eliminated from consideration for rod counting, since all of these involve reconfigured fuel. The location at the opposite end of the rodswas eliminated because it cannot determine if a given rod is intact or broken, since the upper plug of the rod would be present in both cases, and because it cannot determine if a missing rod is wholly or partially stuck in the fuel element structure.If the above situation were not detected, rod reconfiguration could proceed with the rod being broken as a result.

ii. Ease of recovery operations

If, despite the above reasoning, rod counting were performed on reconfigured fuel, recovery of broken fuel rods from within the reconfigured row or bundle of rods would entail special devices and/or operating procedures that would slow system throughput.

D. FUEL ROD PACKAGING

1. Reconfiguration Funnel vs. Stacker

A. Functional Description

After the fuel rods have been removed from the fuel element structure, they must be consolidated so as to reduce their initial volume by a factor of at least two. This entails arranging the fuels rods into a close array and in a configuration compatible with the consolidated rod storage canister, and then loading the storage canister with the reconfigured fuel.

B. Requirements

The rod consolidation system must be capable of packaging two PWR fuel elements or four BWR fuel elements into one storage canister. The cross-section of the canister may be square, round, triangular, hexagonal or trapezoidal. The integrity of the fuel rods must be maintained throughout the consolidation operations.

C. Alternatives

The operations necessary to change the array of the fuel rods may be performed by a funnel that loads the rods directly into the storage canister, thus "forcing" them into the desired array, or by a device that stacks the rods into the desired configuration prior to loading into the storage canister.

D. Selection and Reasons

Given the variety of cross-sections to be considered for the consolidated rod storage canister, it was decided to utilize a rod reconfiguration device rather than a funnel. With a reconfiguration device, the fuel rods are stacked inside a rod reconfiguration receiver whose geometry has been configured to complement that of the storage canister. The entire reconfigured fuel bundle is then pushed through a contamination barrier wall into a clean storage canister. In the case of a funnel, the horizontal combs that hold the fuel rods in their original configuration are withdrawn, while the vertical combs remain in place. The rods thus fall into vertical rows, and the semi-reconfigured fuel bundle is pushed through a funnel in the wall to the storage canister. The funnel forces the rods into the smaller dimensions of the canister, and in this manner the rods are reconfigured.

The funnel system works well enough when the storage canister has a square or rectangular cross section, since reconfiguration in this instance only involves the width of the bundle. However, the funnel is at a disadvantage for circular, triangular, hexagonal or trapezoidal geometries, since reconfiguration would involve both width and height. For these canister geometries, the rods could tangle as they are pushed through the funnel.Thisproblem is eliminated with the rod reconfiguration device, where canister loading is simply a matter of transferring the previously reconfigured fuel bundle.

.2. Mechanical Closure vs. Welding of Canister

a. Functional Description

After loading of the consolidated fuel rods into the storage canister through the contamination barrier wall, the canister is provided with an interim seal, rotated to a vertical position, lowered into a welding pit, and seal-welded.

b. Requirements

The canister must be capable of maintaining the fuel rods within the canister lid. If the closure involves the canister lid, it must be of sufficient strength to support the weight of the loaded canister. If welding is used in the closure process, then the system must provide for non-destructive examination of the seal weld for the loaded consolidation canister.

c. Alternatives

The canister can be sealed either by mechanical means, consisting of clamping a lid onto the opening of the loaded canister when it is in the vertical position, or by welding, for which there are several processes.

d. Selection and Reasons

It was decided that the canisters would be automatically sealed-welded, using an autogenous plasma arc both for the TAN and for the generic facility, due to the superior weld that can be obtained. This choice is supported by the experience of welding high level, vitrified waste canisters at the AVM and AVH high level waste vitrification facilities in France, and at the WVP vitrification plant in Great Britain.

d.1. Advantages of seal welding

Subtantial work has been performed in France to qualify the-selected welding process for the above facilities, as well as to automate the process. As a result, the key operating parameters and their admissible range of variation for the production of high integrity welds have been identified, such as tension, intensity, speed, gas flow rate, etc. These parameters are continuously recorded during welding operations to ensure that a high integrity weld will be produced, or that operations are interrupted if threshholds are surpassed. The resulting weld has been demonstrated to be both leak-resistant and strong, allowing handling of loaded canisters to be performed without constraint.

d.2. Disadvantages of seal welding

The welding machine is more sophisticated than a mechanical system would be, since it is computer-integrated and controlled. In addition, welding requires utilities such as demineralized water, nitrogen, etc.

d.3. Advantages of mechanical closure

A mechanical closure system can be relatively simple compared to seal-welding, particularly since it does not require sophisticated computer controls. Such a system also does not require additional utilities other than electrical power. Both of these features contribute to a lower overall system cost.

d.4 Disadvantages of mechanical closure

The gaskets used for canister closure in a mechanical system have a limited lifetime, and thus long-term leaktightness cannot be guaranteed.

d.5. Conclusion

Since it is anticipated that the canisters will be stored for a long period of time, under conditions that are not now known with certainty, it was determined that leaktightness of the canister is a major criterion to be met. The welding process described above has demonstrated its ability to achieve leak-tight welds.

F. IN-CELL SUPPORT SYSTEMS

1. Water vs. Ultrasonic Canister Decontamination

a. Functional Description

The consolidated rod storage canister is located inside the consolidation cell in the case of the TAN facility, and must be decontaminated in its entirely prior to removal. In the generic facility, the storage canister is located in a clean area, and only the head of the canister is potentially exposed to contamination through the hatch into the consolidation cell. In the latter case, filled canisters will be capped, retracted from the hatch monitored for contamination at the head, and returned to the air lock for decontamination if necessary.

b. Requirements

The exterior surface contamination of the consolidated fuel storage canisters as well as the NFBC canisters must be less than or equal to 2,200 dpm/100 cm^2 beta/gamma and less than or equal to 220 dpm/100cm^2 alpha.

c. Alternatives

SGN has substantial experience with both ultrasonic decontamination and pressurized water decontamination. Ultrasonic decontamination consists of a high-frequency generator that energizes a vibrating transducer connected to a bath where the parts to be decontaminated are located. The process often uses a chemical agent, such as nitric acid, to increase decontamination efficiency.

Pressurized water decontamination involves the use of spray nozzles that direct highly pressurized water (about 200 bars or 2900 psi), which may be either hot or cold demineralized water, toward the surface to be decontaminated. Detergent is sometimes added to the water as well.

d.. <u>Selection and Reasons</u>

Pressurized water was selected for canister decontamination due to the substantial experience acquired with this method, as well as its greater efficiency.

d.1. <u>Ultrasonic decontamination</u>

One of the advantages of this method is the low volume and toxicity of liquid waste generated by operations. However, the efficiency of decontamination decreases as the size of the ultrasonic bath increases. Since the canisters to be decontaminated are relatively large in size, the ultrasonic method is disadvantaged and expensive.

d.2. <u>Pressurized water decontamination</u>

This method of decontamination is very flexible since the nozzles can be arranged to accommodate most geometries. It has been used to decontaminate canisters that were loaded with high-level waste glass inside the hot cell at the AVM vitrification facility in France, and resulted in very low levels of residual contamination. The large-scale AVH vitrification facilities undergoing start-up in France and the WVP vitrification plant undergoing start-up in Great Britain will also utilize this method (refer also to Appendix II, Equipment Tests and Operating Experience). The disadvantage of highpressure decontamination is the volume of liquid effluents generated by this method, which is greater than for ultrasonic decontamination.

d.3. <u>Conclusion</u>

Considering that the most important criterion is the level of decontamination achieved, the pressurized water method selected. For the generic facility, such decontamination will not be systematic since the canister will be loaded in a clean area and are not expected to become contaminatead, which will reduce the volume of liquid effluents generated.

2. <u>In-Cell Repair vs.Replacement</u>

a. <u>Functional Description</u>

Various mechanical components of the rod consolidation system are subject to failure and may require maintenance.

b. <u>Requirements</u>

The rod consolidation system must achieve an operating availability of 75% and process 750 MTHM per year. Downtime for maintenance must therefore be minimized. Maintenance must be performed remotely, and the spread of contamination from maintenance operations must be as low as possible.

c. <u>Alternatives</u>

Maintenance may be performed remotely inside the rod consolidation cell to repair failed components, or it may consist of the remote replacement of whole components. A third alternative consists of locating access to components prone to failure, such as motors or jacks, outside the hot cell whenever possible, and replacing only those components.

c. <u>Selection and Reasons</u>

It was decided to replace rather than to repair components inside the cell, and to facilitate replacement by locating failure-prone components, especially motors and jacks, outside the cell. The trade-off thus is essentially one of the location of these components; i.e. inside or outside the cell.

c.2. Inside the cell

The first consideration for maintenance is to reduce the probability of component failure. In-cell motors would thus need to be designed with special covers so that their electronic and electrical components are protected from radiation, and hydraulic jacks would have to use demineralized water as a lubricant as opposed to oil, which loses its efficiency in a radioactive environment. Both of these increase the expense of the equipment. Furthermore, in-cell repair of such equipment requires special tooling in addition to the crane and lifting beam, and is difficult to perform and therefore time-consuming. Finally, equipment located inside the cell will be contaminated, and must be carefully packaged if it is to be removed from the cell.

The advantages of having the motors and jacks entirely inside the cell are their proximity to the equipment they power, and the absence of cell wall penetrations.

d.2. Outside the cell

Having the motors and jacks located outside the cell walls resolves all of the problems identified above for in-cell maintenance. Components located outside the cell are not contaminated, thus do not require special shielding or lubricants, and as off-the-shelf equipment are less costly. Replacement of these components can be performed in an accessible area, hands-on and without special tooling. Most important, replacement in this manner can be performed quickly, contributing to reduced system downtime.

d.3. Conclusion

Component replacement will be performed whenever possible outside the rod consolidation cell, particularly for the jacks of the rod removal station and of the fuel rod packaging station (see generic layout sketch no. Pl 1886 20 001

APPENDIX II

EQUIPMENT TESTS AND OPERATION EXPERIENCE

This appendix describes equipment tests and pertinent operations experience for each of the major mechanical operations in the rod consolidation process. The description describes recent tests and experience with equipment prototype as well as tests and experience at SGN over the past 20 years. Non fuel bearing component (NFBC) handling is the only operation for which SGN has no experience. Since the NFBC is handled integrally with the process a separate NFBC handling system is eliminated.

APPENDIX II EQUIPMENT TESTS AND OPERATION EXPERIENCE

A. Fuel Element Handling

B. End-Fitting Removal

C. Fuel Rod Removal

D. Fuel Rod Packaging

E. In-Cell Support Systems

APPENDIX II - EQUIPMENT TESTS AND OPERATION EXPERIENCE

A. FUEL ELEMENT HANDLING

1. Process Cranes

Since the beginning of its nuclear projects in 1952, SGN has dealt with the problems of materials handling in hostile environments. This led to the design of remotely operable and maintainable cranes, particularly for fuel element handling in both hot cells and spent fuel storage pools.

In-cell cranes are systematically designed with redundant hoists and drive mechanisms, as well as with redundant electrical power lines and circuits. The purpose of this redundancy is to enable an operation to be completed even if a component of the crane fails while the operation is in progress, and to allow the crane to be returned to the crane park where it can be repaired.

When such cranes are used in a contaminated environment, they are designed in modular fashion such that each of their components -- hoists, drive mechanisms, electric cable drums, etc. -- is removable remotely and can exit the cell in waste canisters.

The drive mechanisms of the cranes run on constant current so that very low speeds can be used to achieve a high degree of precision in maintenance operations that involve the replacement of equipment components. This precision, together with the modular design of the crane, eliminates the need for in-cell power manipulators.

SGN has designed and manufactured about 60 remote cranes to date, ranging in load capacity from 50 kg to 5 t, 30 of which are completely modular cranes used in the UP3 reprocessing plant at La Hague, France. SGN has also supplied cranes to nuclear facilities outside France, including the following :

- Tokai Mura reprocessing plant, Japan
- Eurex reprocessing plant, Italy
- Eurochemic reprocessing plant, Belgium
- Kaeri nuclear research laboraty, Korea.

2. Crane Tooling

The modular cranes described above can be remotely equiped with a variety of special tools adapted to the specific requirements of a particular operation. This is accomplished by the use of a module attached to the pulley block of the crane which locks onto the tool that is selected from among several in the tool rack, such as grippers, grapples, lifting beams, or maintenance tools. The tooling head module can be rotated by remote control, and is equipped with electronic load limiters, programmable positioners and a TV camera with its lighting. Fuel element grippers specific to each type of PWR and BWR fuel element were also developed by SGN to provide a greater level of confidence in the safety of fuel element handling operations. The grippers have fuel element proximity detectors and a hook screwing system that prevents the fuel element from falling even in the event of an electrical outage.

B. END-FITTING REMOVAL

SGN's earliest experience with the mechanical processing of fuel elements involved the decladding of gas cooled reactor fuels up to 1955 at which time SGN undertook the design and construction of facilities for the disassembly of heavy water reactor and light water reactor fuel elements.

1. 1965 : Dry Removal of Heavy Water Reactor Fuel End-Fittings (France)

SGN's first spent fuel element disassembly project involved fuels from the French EL4 heavy water reactor, which were disassembled in a hot cell by equipment that performed the following functions :

- separation of the upper end-fitting from the rods by milling
- separation of both end-fittings from the graphite sleeve
- removal of the rods
- packaging of the rods in a storage canister

The disassembly equipment is composed of a horizontal frame to support the 20 inch long fuel element to be disassembled, and two main tools, one for milling the weld joining each rod to the upper end-fitting, and the other for drilling the two rings that lock the end-fittings to the graphite sleeve. Both tools are driven by one mechanism. The disassembly equipment is slightly inclined so that the rods slide by gravity into the consolidated rod storage canister. A master-slave manipulator is used to arrange the rods in a consolidated array inside the canister. Debris generated by machining is continuously collected with a vacuum pipe connected to a HEPA filter. One fuel element can be disassembled with the system in less than 30 minutes.

SGN performed the detailed design of the system, and SERP (France) was selected to manufacture the equipment. Component testing using dummy fuels was performed to confirm the process and equipment performance, and hot operations were sucessfully conducted from 1965 to 1984.

2. <u>1967 : Dry Removal of PWR and BWR Fuel End-Fittings (Japan)</u>

As a part of its overall design of the Tokai Mura reprocessing plant, SGN examined the feasibility of removing the end-fittings from both PWR and BWR fuel elements prior to introduction of the fuel bundle in the shearing machine and subsequent dissolution of the sheared fuel rods.

This entailed the design, fabrication and operation of an inactive test stand where two band saws simultaneously removed both end-fittings of either a PWR or a BWR fuel element, which was positioned horizontally on a transfer table. About 40 end-fittings were removed from the dummy fuel elements in this manner. The equipment was manufactured by Verboom and Durouchard (France), which also manufactured the LWR bundle shear for the Barnwell Nuclear Fuels Plant (USA).

These tests helped to demonstrate that the removal of end-fittings by sawing is not a reliable process, especially in the case of BWR fuel elements, where pressure applied by the saw can result in rod rupture. In both the PWR and the BWR cases, the risk of the saw going astray with resulting rod rupture was difficult to control. In addition, the sawing process increases:

. the fire hazard created by burning cuttings
. the dispersion of contaminated cuttings
. the quantity of hot cell equipment
. maintenance requirements (frequent blade replacement).

It was ultimately decided to perform end-fitting removal with the horizontal bundle shear.

3. <u>1980 : Wet Removal of PWR Fuel End-Fittings (Korea)</u>

SGN designed and installed an underwater PWR disassembly machine for the KAERI nuclear research laboratory in Korea in 1980. The concept was adapted from the dry PWR disassembly equipment used at the Celimene hot cell at the (C.E.A.) French Atomic Energy Commission's nuclear research center in Saclay, in operation since 1975.

The PWR fuel element is disassembled in the vertical position using a band saw to remove the upper end-fitting. Fuel rods are then removed underwater one by one with a gripper operated by a 50 kg hoisting unit.

Since the facility was designed for laboratory-scale operations, the throughput requirements were minimal and thus maintenance and change-out of the saw were secondary issues. The fire hazard created by the band saw in a dry environment (see point 2 above) was also eliminated.

The disassembly equipment enabled the pulling strength required to extract one rod to be determined, as well as the resistance of the irradiated rods. Hot operations have been without incident.

4. 1984 : Dry Removal of LWR Fuel End-Fittings (France)

SGN was awarded a contract by Cogema in 1984 for the design of a dry spent fuel disassembly and fuel rod consolidation facility to be built at the LWR reprocessing plant at La Hague, France. SGN drew upon its previous experience to design a facility with a nominal throughput of 1,070 MTU/year based on 2 shifts per day, 5 days per week and a 75% plant availability factor. The facility is to disassemble and consolidate two types of PWR fuels in equal proportions, and must be capable of being adapted to BWR fuels. Given its past experience with end-fitting removal by sawing, SGN's design studies were oriented toward the use of cutters to perform this operation.

PWR End-Fittings

For this type of fuel element, only the upper end-fitting needs to be removed to permit consolidation operations. To accomplish this, a multiple blade cutter was designed that simultaneously cuts all the guide tubes from the inside. This approach offers the following advantages :

- the generation of radioactive cruds and cuttings is reduced;

- the cuttings can be contained inside the guide tubes;

- the entire upper end-fitting and spacer grid assembly can be removed together, providing greater access to the fuel rods for extraction;

- the reliability of the cutting device, which can perform several thousand cuts without changing the blades.

A cutting head with a single blade was fabricated for test purposes by SICN (France), and approximately 100 cutting trials were successfully performed on zircalloy tubing in April 1986. At the same time, a prototypical cutting head with 24 blades was manufactured by SICN, and cutting tests began at the end of August 1986 on a bundle of 24 zircalloy guide tubes. About 400 simultaneous cuts have been successfully performed to date on the tube assembly with no trace of blade wear, and Cogema considers the device to be readily qualifiable for operations. Other tests were conducted in parallel with those of the multiple blade cutter on a guide tube drilling device, with positive results.

BWR End-Fittings

At the start of the project, Cogema asked SGN to prepare a conceptual design only for the removal of BWR tie-rods. For the reasons described above and in Appendix I, sawing of the end-fittings was eliminated from consideration. A design was developed whereby the 8 tie rods that connect the upper and lower end-fittings are sheared simultaneously. This method has the advantage of avoiding the generation of radioactive cuttings.

The shearing method, proposed for the DOE-Idaho project, was put to the test by SGN using a dummy BWR fuel element with zirconium tubes and conical tie-rods held by spacer grids and screwed into the stainless steel lower end-fitting. The dummy fuel element was mounted on a test stand consisting of a sheet metal bending machine whose head was modified by the addition of a shearing device. The fuel element was clamped to the table of the machine in horizontal position. Both the fuel element and the test stand were manufactured by Verboom and Durouchard (France).

Sixteen tie rods were sheared at their conical section on the rod side of the end-fittings, with no noticeable deformation. A shearing force of approximately 4 tons was registered, and a shearing speed of 4 minutes.

C. FUEL ROD REMOVAL

As discussed in the preceding section of this Appendix, SGN has been involved in a number of projects involving fuel element end-fitting removal and fuel rod removal since 1965. Specific experience with fuel rod removal is further described below.

1. 1965 : Dry Removal of Heavy Water Reactor Fuel Rods (France)

Once the upper end-fitting was removed, the 19 fuel rods inside the graphite sleeve of the EL4 heavy water reactor fuel element slid by gravity into a canister without any mechanical extraction equipment being necessary. The horizontal fuel element support table was slightly inclined to facilitate this movement.

2. 1980 : Wet Removal of PWR Fuel Rods (Korea)

The objective of the spent fuel disassembly laboratory at the KAERI research center was to remove the upper end-fitting and extract a few rods, one at a time, from a PWR fuel element for analytical purposes. The rods are extracted from the bundle using a gripper and a 50 kg crane. Following this operation, the assembly is containerized and returned to storage.

Although this technique is of little interest for a production scale rod removal system, it served to determine the pulling force required (about 20 kg, or 40 lbs.) to remove the rods from the spacer grids of an irradiated fuel element. This in turn helped to determine the capacity required for the multiple rod puller for the DOE-Idaho project.

3. 1982 : Dry Removal of PWR and BWR Fuel Rods (France)

Several rod removal tests were performed at the (C.E.A.) French Atomic Energy Commissions's prototype test facility in Marcoule on both PWR and BWR fuel elements with a view to their subsequent shearing and dissolution. The tests were performed on actual fuel bundles prior to irradiation.

Removal was performed using grippers capable of removing a row of 17 rods at a time. The tests showed that the pulling force required for fresh fuel rods (about 50 kg) was greater than for irradiated fuel rods (about 20 kg).

The row-by-row removal method was considered to be a valid approach for fuel disassembly prior to small-scale reprocessing operations, but not for a high-throughput facility where it is essential to reduce the number of operations to a minimum in order to process a maximum of fuel elements.

4. <u>1984 : Dry Removal of PWR Fuel Rods (France)</u>

The spent fuel disassembly and fuel rod consolidation facility (see also Section B.4 above) was designed by SGN for Cogema to receive, disassemble, consolidate and package over 1000 MTU of PWR fuels per year in a fully remote and automatic operation. In order to achieve this capacity, which represents 14 fuel elements per day, it was decided to extract all of the rods simultaneously from the fuel bundle, as opposed to row-by-row removal. SGN thus developed a design for a gripper capable of removing all of the rods of a 17 x 17 PWR fuel element simultaneously.

The entire rod removal station, together with the prototypical gripper, was manufactured by SICN (France) for test purposes. The first semi-scale tests of rod removal were performed with partial PWR fuel elements in April 1986. Some 50 tests were performed on a row of 17 zirconium rods, in which the pulling force was progressively increased without the rods being released. These tests helped to demonstrate the rods' resistance to varying pulling forces using the gripper.

On October 3, 1986 the prototypical gripper intended for simultaneous removal of all the rods of a 17 x 17 PWR fuel element was ready for testing. Rod removal was performed on a test stand that included both the gripper head and the horizontal/vertical comb mechanism that maintains the original array of the fuel bundle after removal and prior to rod reconfiguration. After some initial adjustment, the gripper was demonstrated to be capable of simultaneous removal of the 264 zirconium rods of the PWR fuel element model, and the comb mechanism functioned well. The pulling force necessary to remove the rods confirmed that the force required to extract a rod from the spacer grids of a non-irradiated fuel element is on the order of 20 kg. As of October 22, 1986, 10 tests had been conducted on simultaneous removal of the fuel rods without a single rod being released. A total of 100 rod removal tests are planned in order to have the gripping head qualified by Cogema.

D. FUEL ROD PACKAGING

In the content of the spent fuel dissassembly and rod consolidation project for La Hague (see Sections B.4 and C.4 above), in which the end-fittings of fuel elements are to be removed followed by removal of the fuel rods to be consolidated, SGN designed a transition device for fuel rod reconfiguration before packaging. Such a device was manufactured and tested for SGN by AMCI (France). The tests enabled the mechanical process to be qualified by Cogema after a test cycle corresponding to the reconfiguration of 100 PWR fuel elements (17 x 17).

The transition device was designed to rearrange the fuel rods into a rectangular cross-section such that the rods from 2 PWR or 4 BWR fuel elements could fit into a canister and then one chamber of a pool storage basket, where normally only one unconsolidated fuel element would fit. The reconfiguration module can receive vertical rows of rods to a height corresponding to half that of the storage basket. However, since the rows are separated by vertical dividers that increase the overall width, a funnel is needed to guide the rods into the canister. This method of packaging presents no problems for canisters with cross- sections that permit vertical rod arrangements.

In the case of the DOE-Idaho project, the canister dimensions and the variety of cross-sections to be considered require that the rods be arranged with a triangular pitch in alternating rows. This led SGN to the design of a new device, called a rod reconfiguration module, that arranges the rods into horizontal rows inside the storage canister. The equipment test conducted on the transition device, especially with respect to rod distribution and their behaviour in a variety of test situations, contributed significantly to the design of the new device.

E. IN-CELL SUPPORT SYSTEMS

1. Telemanipulators

Master Slave Manipulators

Since its creation, SGN has specified the master slave manipulator requirements for all of the nuclear facilities it has designed. All of the commercially available master slave manipulators have been used in these facilities, including the M8 of CRL (USA) the A-100 of Walischmuller (Germany) and, since 1982, the MT-200 of the Calhène (France). Several thousand of these manipulators have been installed by SGN, 300 of which were for the UP3 reprocessing plant at La Hague alone.

Servo-Manipulators

In 1980, SGN developed a remote operating system called MTU (Mobile Teleoperation Unit) for use in hot cells with no master slaves or shielded viewing windows. The MTU uses the MA-23 servo-manipulator developed by La Calhène based on R+D performed by the French Atomic Energy Commission (CEA), and with more than 12 years of operating experience to its credit.

The MA-23 underwent qualification testing by the CEA at its Prototype Development Service in Marcoule, France. It is used in the decontamination and dismantling of radioactive facilities such as the hot cell of the AT1 breeder reprocessing pilot plant at La Hague. There are currently 12 MA-23 in operation in hot cells, two of which are in a reprocessing plant in Great Britain.

The MA-23 is composed of a mobile in-cell slave unit and a master unit that can be installed in a control room far removed from the hot cell. For the MTU to be used in a hot cell, several support systems are needed, as described below:

- a support structure to hold the slave unit; since the slave unit is electrically rather than mechanically connected to the master unit, its support structure may be placed wherever convenient in the cell by means of the in-cell crane;

- an in-cell crane to move the MA23 support structure and to substitute for the MA23 for heavy lifting operations, since the load capacity of servo-manipulators is low so as to provide for greater dexterity;

- closed circuit cameras, whether part of the MA23 itself so that the field of vision and the field of action coincide, or independent of the MA23 to provide a general view of the operations being conducted;

- a control unit installed outside the cell, which is the main control system linking the master unit with the slave unit.

The MA23 servo-manipulator provides several advantages with respect to in-cell operations:

- speed: there is a one-to-one correlation between the speed of most operator movements and those of the slave unit;

- dexterity: compared to an operation performed manually, the MA23 requires 5 to 10 times as much time;

- ease of maintenance: the MA23 is composed of modules that can be replaced individually as needed in the maintenance cell.

2. Remotely Removable Modules

In order to facilitate the maintenance of hot cell equipment while minimizing remote maintenance requirements, SGN designs equipment in remotely removable modules. With this approach, "consummable" components such as actuators, captors or machining heads, can be quickly and easily removed and new modules put in their place. All of the mechanical equipment, totalling over 200, as well as the cranes used in the hot cells of the La Hague reprocessing plants are designed with remotely removable modules.

The equipment is designed so that its various functional components can be lifted out and replaced with the in-cell crane. Each module is thus composed of the functional component, its base plate, a device for the crane to grip the module for removal, a device to guide the module into the correct position during replacement, and a locking system connecting the module to the equiment.

The modular equipment concept presents the dual advantages of eliminating the need for telemanipulators for most maintenance operations, while decreasing the down-time associated with maintenance, which is a direct result of the lack of dexterity of most telemanipulation systems. The net result of this is increased facility availability.

3. Decontamination

A variety of decontamination methods are used by SGN for its nuclear projects, including electro-chemical treatments, ultrasonic baths abrasives, and pressurized water.

It is the latter method that is the most widespread in the nuclear facilities designed and built by SGN for the French Atomic Energy Commission (C.E.A.), Cogema and foreign clients. Pressurized water decontamination consists of spraying demineralized water through nozzles at a force of at least 200 bars (2900 psi) and a speed varying between 0.5 and 1.5 m/min. The spray nozzles are placed at an angle of about 15 degrees and a distance of about 50 mm from the surface to be decontaminated. The process is more efficient when the demineralized water is at 60 degrees C. Substantial operating experience has been acquired with pressurized water decontamination; some examples are given below.

AVM Vitrification Facility (Marcoule, France)

The canisters of high-level vitrified waste are systematically decontaminated upon exiting the glass pouring cell using high pressure water (200 bars or 2900 psi), followed by a smear test to confirm the absence of residual contamination and then storage. Some 1500 glass canisters have been satisfactorily decontaminated to date in this manner.

UP3 Reprocessing Plant (La Hague, France)

Canisters containing the hulls from spent fuel shearing/dissolution operations are decontaminated at a rate of 3 canisters per day using high pressure water at 200 bars. The canisters measure 2.5 m H x 1.5 m diameter.

NPH Spent Fuel Receiving Facility (La Hague, France)

The spent fuel transportation casks are unloaded underwater, and are systematically decontaminated externally after removal from the unloading pool using high pressure water. Internal decontamination of the cask is performed using the same method during cask maintenance operations. The cask measures 6 m H x 2.5 m diameter.

The advantage of pressurized water decontamination is that it is quick as well as effective. It does, however, have the disadvantage of generating liquid effluents that require processing. This would not be the case in the consolidated rod canister decontamination system proposed by SGN, because only the upper end of the canister would be decontaminated, and only if contamination monitoring showed that decontamination were necessary.

To verify that the canister has not been contaminated, SGN developed a monitoring robot that moves a smear brush down the length of the canister at a predetermined speed and pressure. Non-contamination monitoring is performed both before and after decontamination. Four such robots are currently operational, two at the La Hague reprocessing plants and two at Sellafield, Great Britain.

APPENDIX III

FLOW DIAGRAMS AND DRAWINGS

The appendix is all the flow diagrams and drawings that were prepared for the preliminary design of the generic rod consolidation system. Also included is a TAN specific material balance and facility layout.

CONTENTS

E. Rod Packaging

- o Reconfiguration System PE-1886-20-008
- o Typical Square Configuration PE-1886-20-013
- o Typical Triangular, Hexagon Configuration PE-1886-20-012
- o Canister Welding System PE-1886-20-014

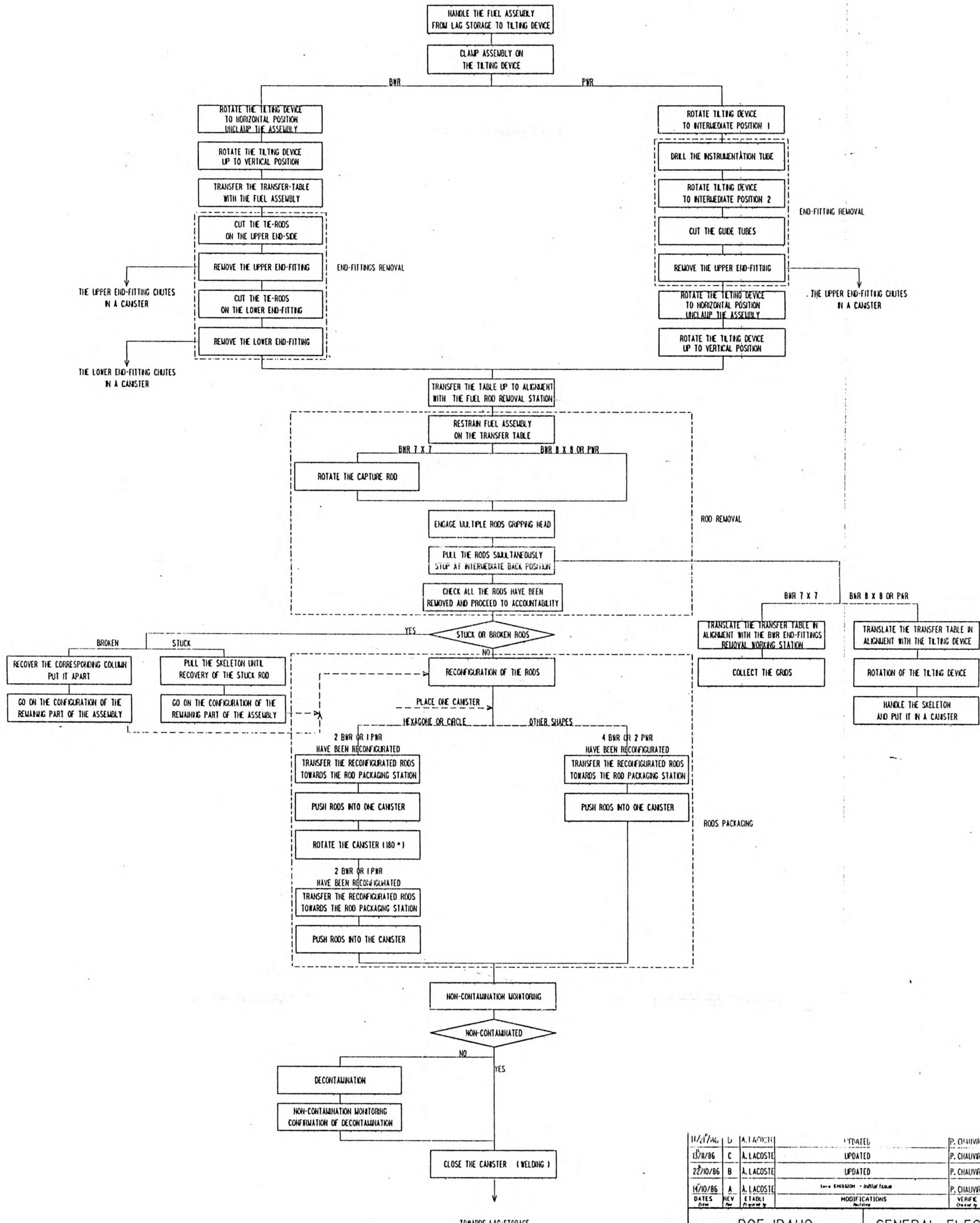
F. NFBC Handling

- o Skeleton Handling System PE-1886-20-016

G. Support Systems

- o Operations Signal-System and Safety Interlocks SH-1886-20-005

AI



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13/11/86	C	A. LACOSTE	UPDATED	P. CHAUVIRE	D. TUCOULAT
22/10/86	B	A. LACOSTE	UPDATED	P. CHAUVIRE	D. TUCOULAT
14/10/86	A	A. LACOSTE	1ere EMISSION - Initial Issue	P. CHAUVIRE	D. TUCOULAT

DOE-IDAHO
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GENERAL ELECTRIC
P.O. 190 RC 81286

ROD CONSOLIDATION SYSTEM PROCESS FLOWSHEET

SGN
1, rue des Herons - MONTIGNY le BRETONNEUX 78182 ST QUENTIN-YVELINES - CEDEX

Unite	Cut	Situation	Emetteur	Format
/	200	/	E42	AI

Typ. doc.	Activite	Cat. pl	N° d'ordre	Revision
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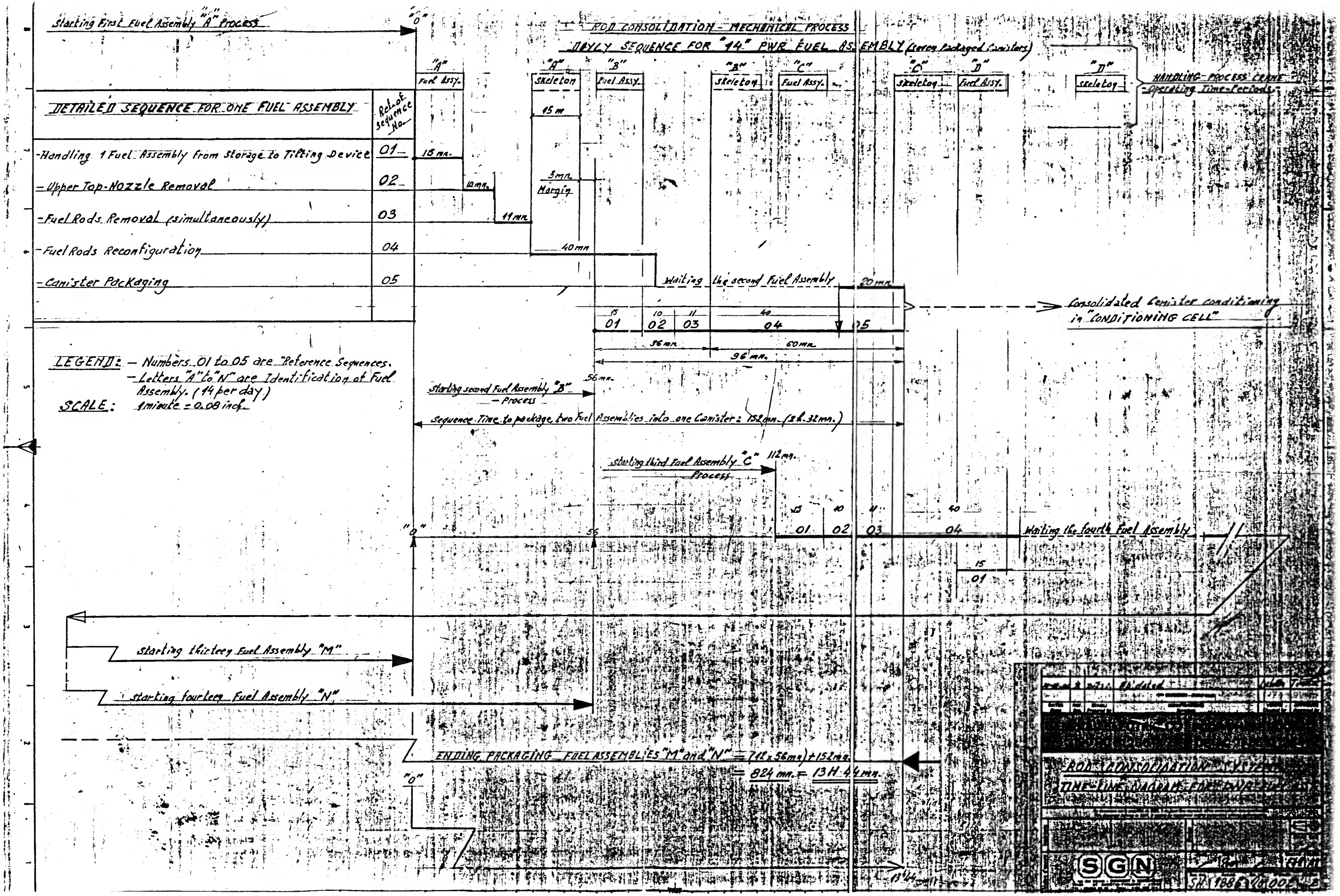
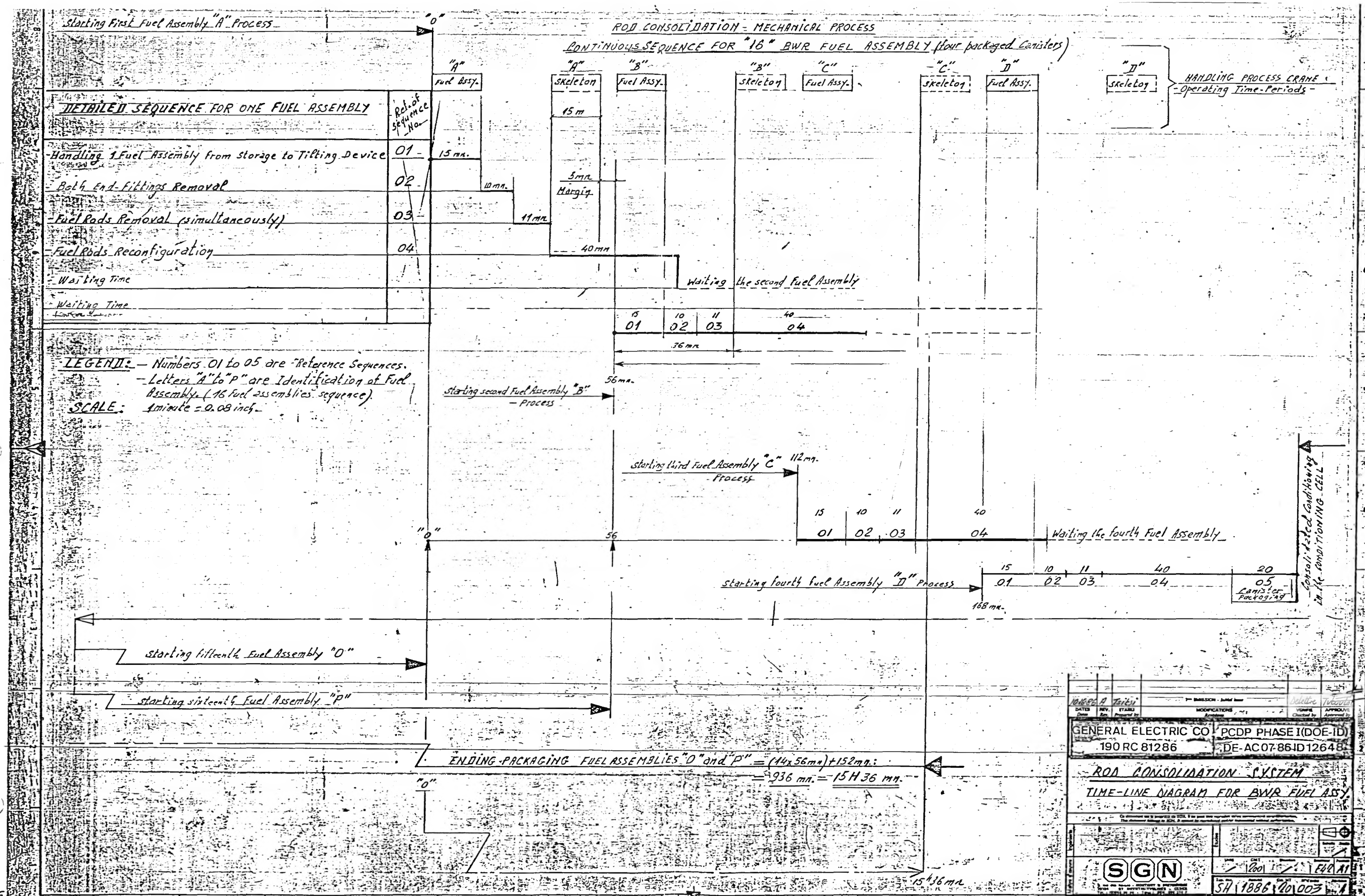
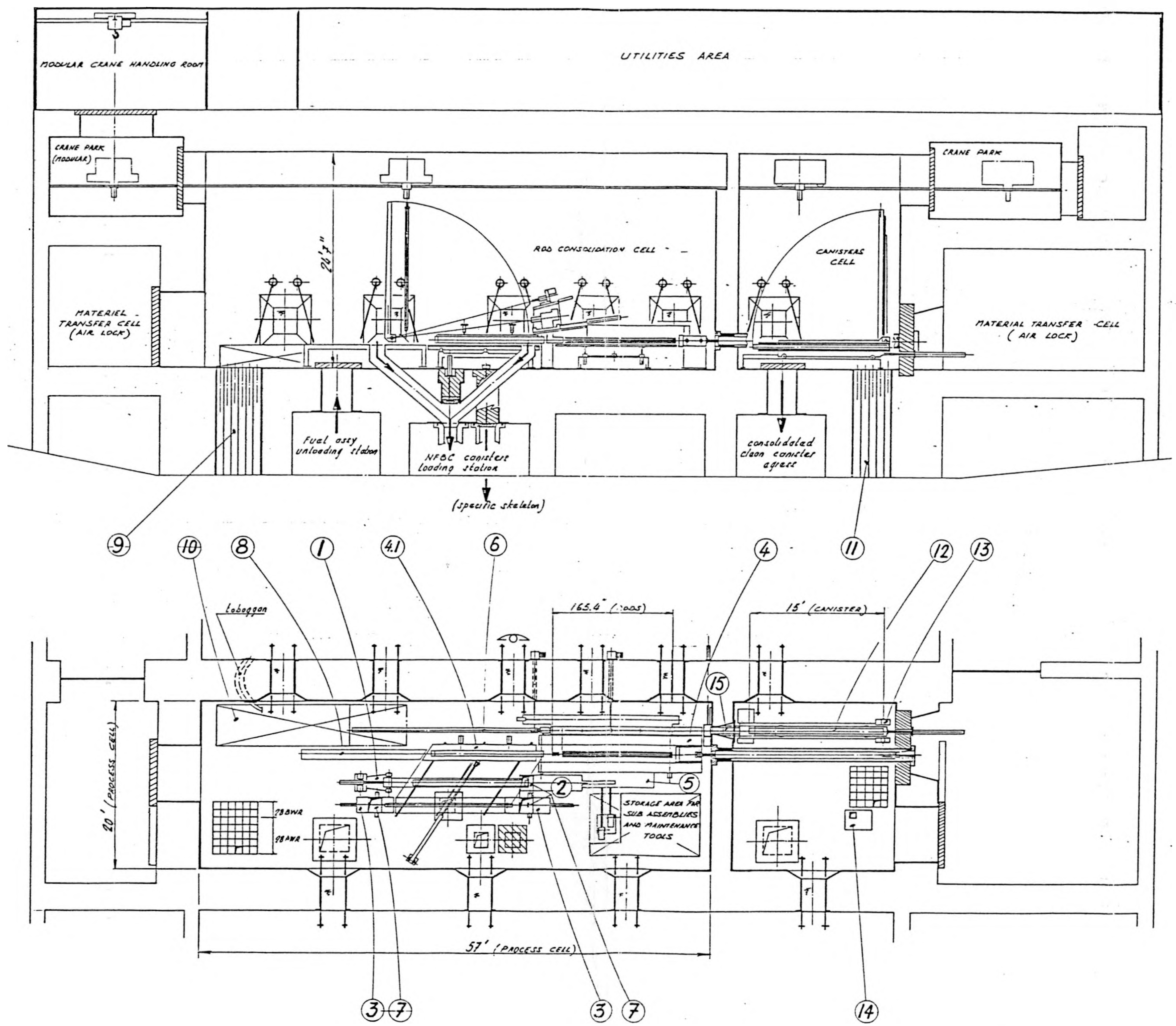
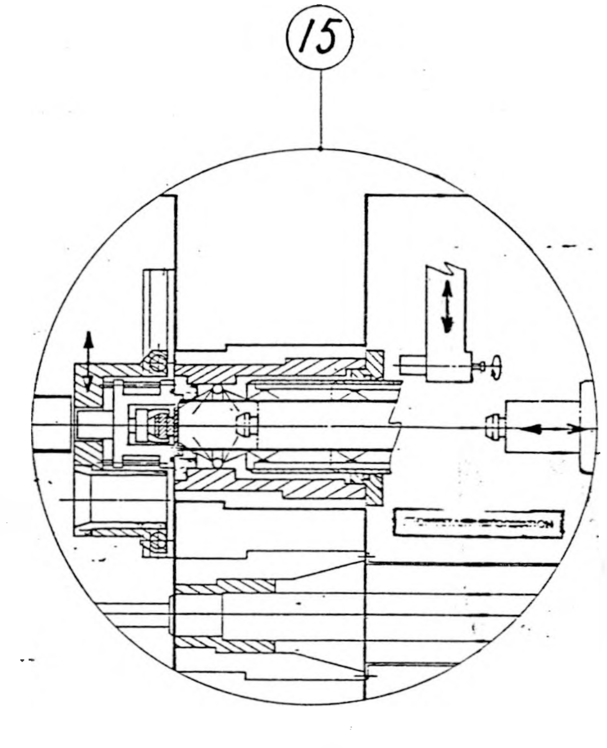

Starting First Fuel Assembly "A" Process
"0"
ROD CONSOLIDATION - MECHANICAL PROCESS
DAYLY SEQUENCE FOR "14" PWR FUEL ASSEMBLY (seven Packaged Canisters)
"A" Fuel Assy.
"A" Skeleton
"B" Fuel Assy
"B" Skeleton
"C" Fuel Assy.
"C" Skeleton
"D" Fuel Assy.
"D" Skeleton
HANDLING PROCESS CRANE - Operating Time-Periods
DETAILED SEQUENCE FOR ONE FUEL ASSEMBLY
Ref. of sequence No.
-Handling 1 Fuel Assembly from Storage to Tilting Device 01
-Upper Top-Nozzle Removal 02
-Fuel Rods Removal (simultaneously) 03
-Fuel Rods Reconfiguration 04
-Canister Packaging 05
15 mn.
10 mn.
11 mn.
15 m
5 mn. Margin
40 mn
Waiting the second Fuel Assembly
20 mn
Consolidated Canister conditioning in "CONDITIONING CELL"
01 02 03 04 05
56 mn
60 mn
96 mn.
LEGEND: - Numbers 01 to 05 are "Reference Sequences.
- Letters "A" to "N" are Identification of Fuel Assembly. (14 per day)
SCALE: 1 minute = 0.08 inch
Starting second Fuel Assembly "B" - Process
56 mn.
Sequence Time to package two Fuel Assemblies into one Canister: 152 mn. (2 h.32 mn.)
Starting third Fuel Assembly "C" Process
112 mn.
Waiting the fourth Fuel Assembly
starting thirteen Fuel Assembly "M"
starting fourteen Fuel Assembly "N"
ENDING PACKAGING FUEL ASSEMBLIES "M" and "N" = (12 x 56 mn) + 152 mn
= 824 mn. = 13H.44 mn.
13h44
SGN

A4



Starting First Fuel Assembly "A" Process
"0"
ROD CONSOLIDATION - MECHANICAL PROCESS
CONTINUOUS SEQUENCE FOR "16" BWR FUEL ASSEMBLY (four packaged Canisters)
"A" Fuel Assy.
"A" Skeleton
"B" Fuel Assy.
"B" Skeleton
"C" Fuel Assy.
"C" Skeleton
"D" Fuel Assy.
"D" Skeleton
HANDLING PROCESS CRANE - Operating Time-Periods -
DETAILED SEQUENCE FOR ONE FUEL ASSEMBLY
Ref. of Sequence No
Handling 1 Fuel Assembly from Storage to Tilting Device
01
Both End-Fittings Removal
02
Fuel Rods Removal (simultaneously)
03
Fuel Rods Reconfiguration
04
Waiting Time
Waiting Time
15 mn.
10 mn.
11 mn
15 m
5 mn Margin
40 mn
Waiting the second Fuel Assembly
36 mn
56 mn.
LEGEND: — Numbers 01 to 05 are Reference Sequences.
— Letters "A" to "P" are Identification of Fuel Assembly. (16 Fuel assemblies sequence)
SCALE: 1 minute = 0.08 inch
starting second Fuel Assembly "B" - Process
starting third Fuel Assembly "C" - Process
112 mn.
Waiting the fourth Fuel Assembly
starting fourth fuel Assembly "D" Process
168 mn.
05 Canister Packaging
Consolidated Conditioning in the CONDITIONING CELL
starting fifteenth Fuel Assembly "O"
starting sixteenth Fuel Assembly "P"
ENDING PACKAGING FUEL ASSEMBLIES "O" and "P" = (14x56 mn) + 152 mn: = 936 mn. = 15 H 36 mn.
15H36 mn
GENERAL ELECTRIC CO
190 RC 81286
PCDP PHASE I (DOE-ID)
DE-AC07-86ID12648
ROD CONSOLIDATION SYSTEM
TIME-LINE DIAGRAM FOR BWR FUEL ASSY
SGN
SH 1886 / 10 003





1	Tilting device
2	PWR top nozzle removal station
3	BWR end-fittings removal station
4	Fuel rods removal station
4.1	transfer-table
5	Rods reconfiguration station
6	Packaging station
7	Chutes
8	Stuck and/or broken rod recovery station
9	storage pit with 2 racks
10	Maintenance station
11	storage-rack pit for canisters
12	longitudinal table
13	Tilting device -
14	Welding machine
15	Hatch

C	Deletion	up-dated	
B	Deletion	up-dated	
A	Deletion		

GENERAL ELECTRIC CO
190 RC 81286

PCDP PHASE I (DOE-ID)
DE-AC07-86ID12648

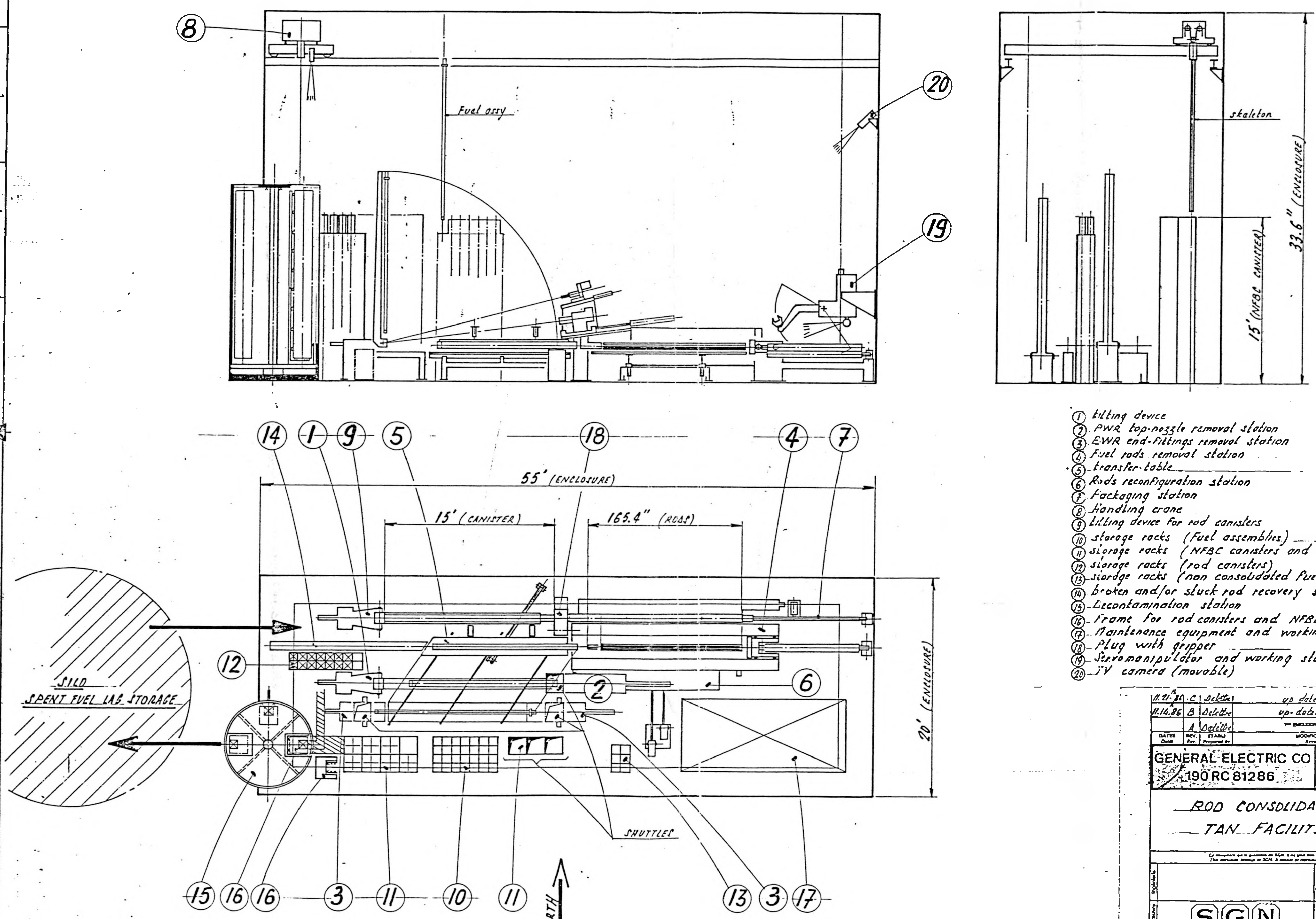
ROD CONSOLIDATION AND CANISTERS
CONDITIONING SYSTEM
GENERIC FACILITY LAY OUT

1/50

SGN

PD 1886 20 001 C

NF E04_507



1. tilting device
2. PWR top-nozzle removal station
3. BWR end-fittings removal station
4. Fuel rods removal station
5. transfer-table
6. Rods reconfiguration station
7. Packaging station
8. Handling crane
9. tilting device for rod canisters
10. storage racks (Fuel assemblies)
11. storage racks (NFBC canisters and shuttle canisters)
12. storage racks (rod canisters)
13. storage racks (non consolidated fuel assemblies)
14. broken and/or stuck rod recovery station
15. Decontamination station
16. Frame for rod canisters and NFBC canisters
17. Maintenance equipment and working area
18. Plug with gripper
19. Servomanipulator and working stands
20. TV camera (movable)

DATES	REV.	ETABLI	MODIFICATIONS	VERIFIE	APPROUVE
11.21.86	C	Delettre	up dated	Chauvin	[illegible]
11.14.86	B	Delettre	up-dated	Tsilsi	Tocoulet
	A	Delettre	1re EMISSION - Initial issue		

GENERAL ELECTRIC CO
190 RC 81286

PCDP PHASE I (DOE-ID)
DE-AC07-86 ID 12648

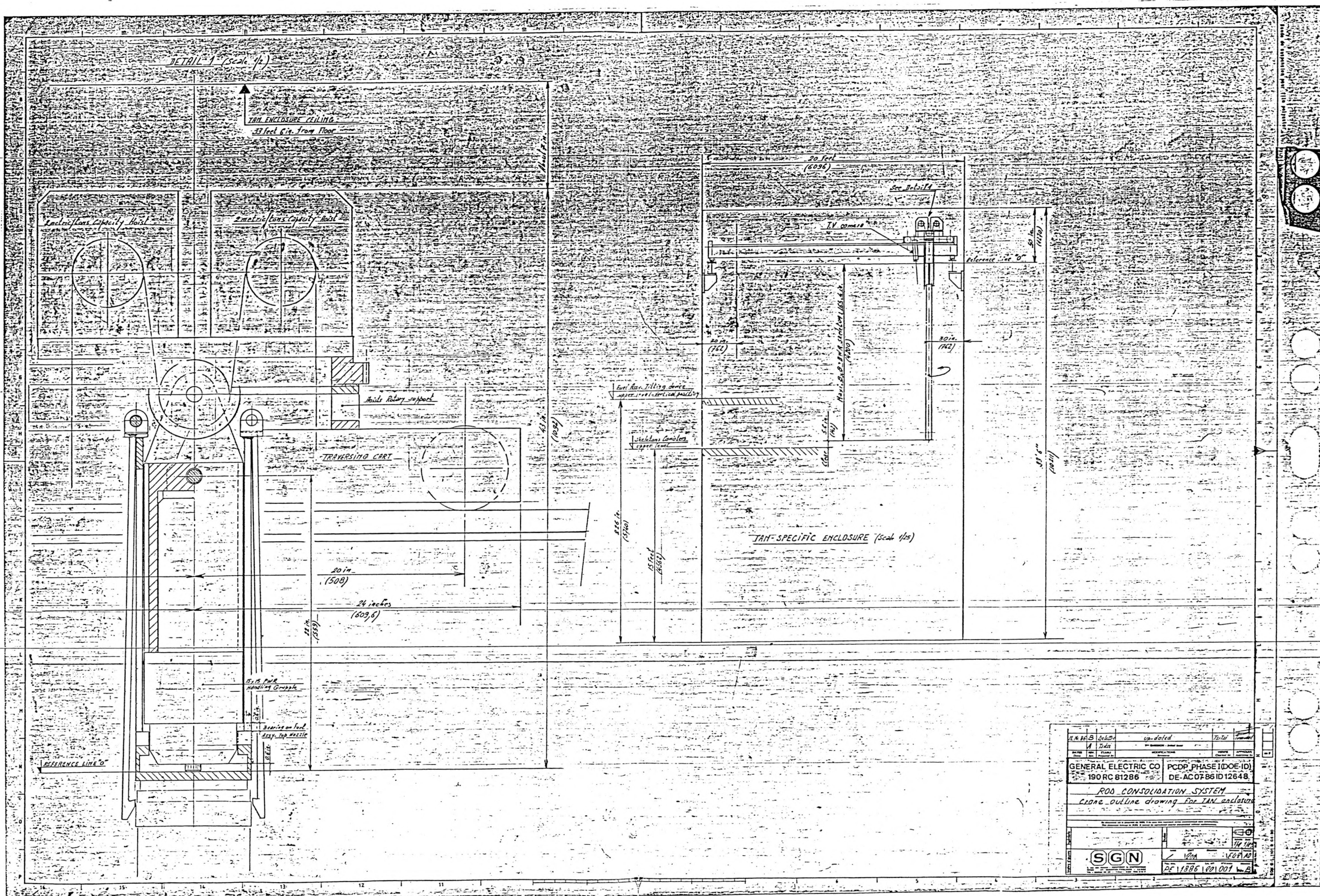
ROD CONSOLIDATION SYSTEM
TAN FACILITY LAY OUT

PI-1886-20-002 1/50e

SGN

/ 200 / E42 A1

A7


DETAIL 1 (Scale 1/2)
TAN ENCLOSURE CEILING
33 feet 6 in. from floor
TRAVERSING CART
Axial Rotary support
20 in. (508)
24 inches (609,6)
15x15 PWR Handling Grapple
Bearing on fuel assy. top nozzle
REFERENCE LINE "0"
20 feet (6096)
See Detail 1
T.V camera
Reference line "0"
TAN-SPECIFIC ENCLOSURE (Scale 1/25)
33' 6" (10211)
15 feet (4572)
GENERAL ELECTRIC CO
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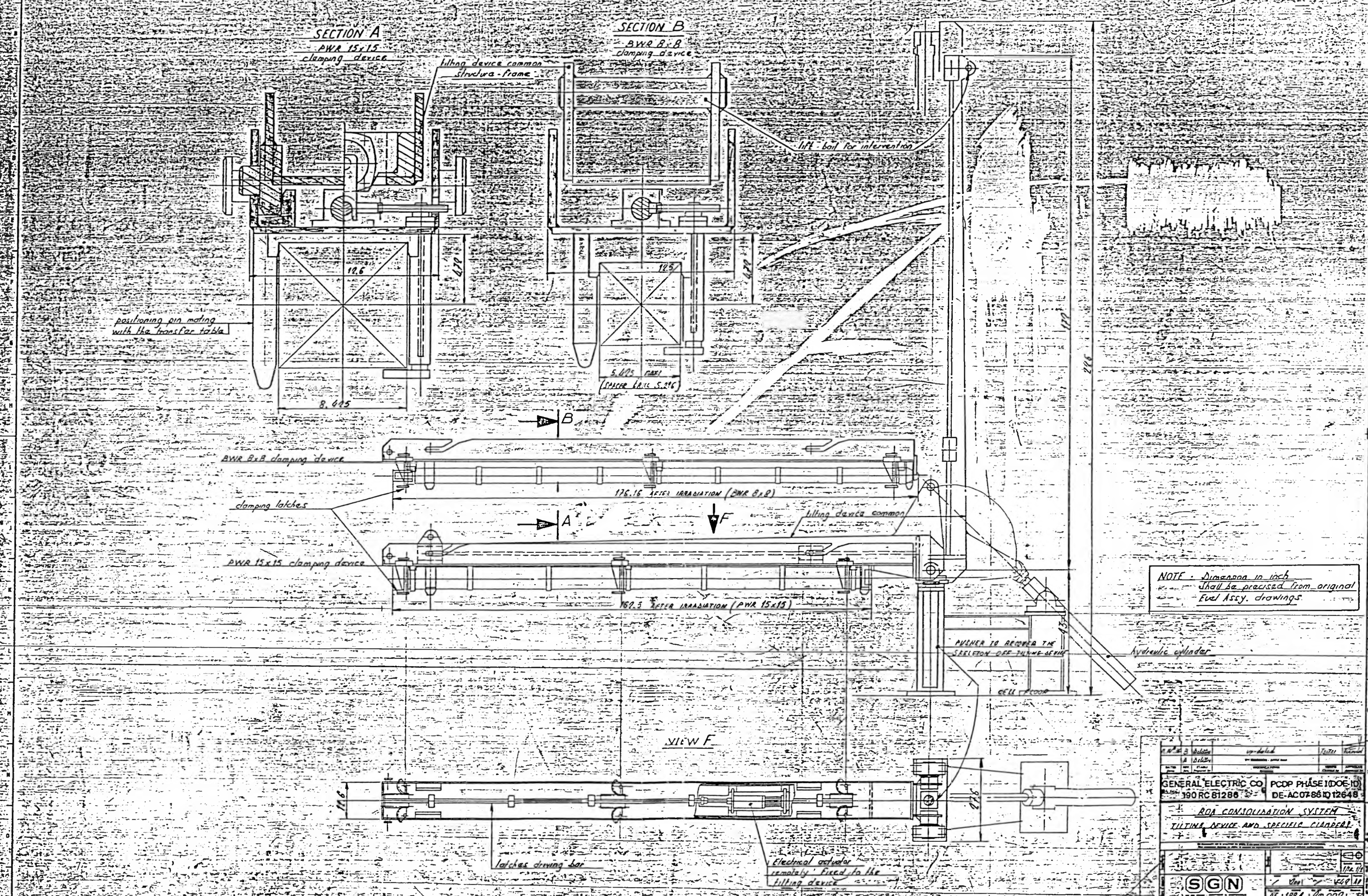
PCDP PHASE I (DOE-ID)
DE-AC07-86ID12648
ROD CONSOLIDATION SYSTEM
crane outline drawing for TAN enclosure
up-dated
SGN
PE 1886 00 001 B
B1



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190 RC 81286

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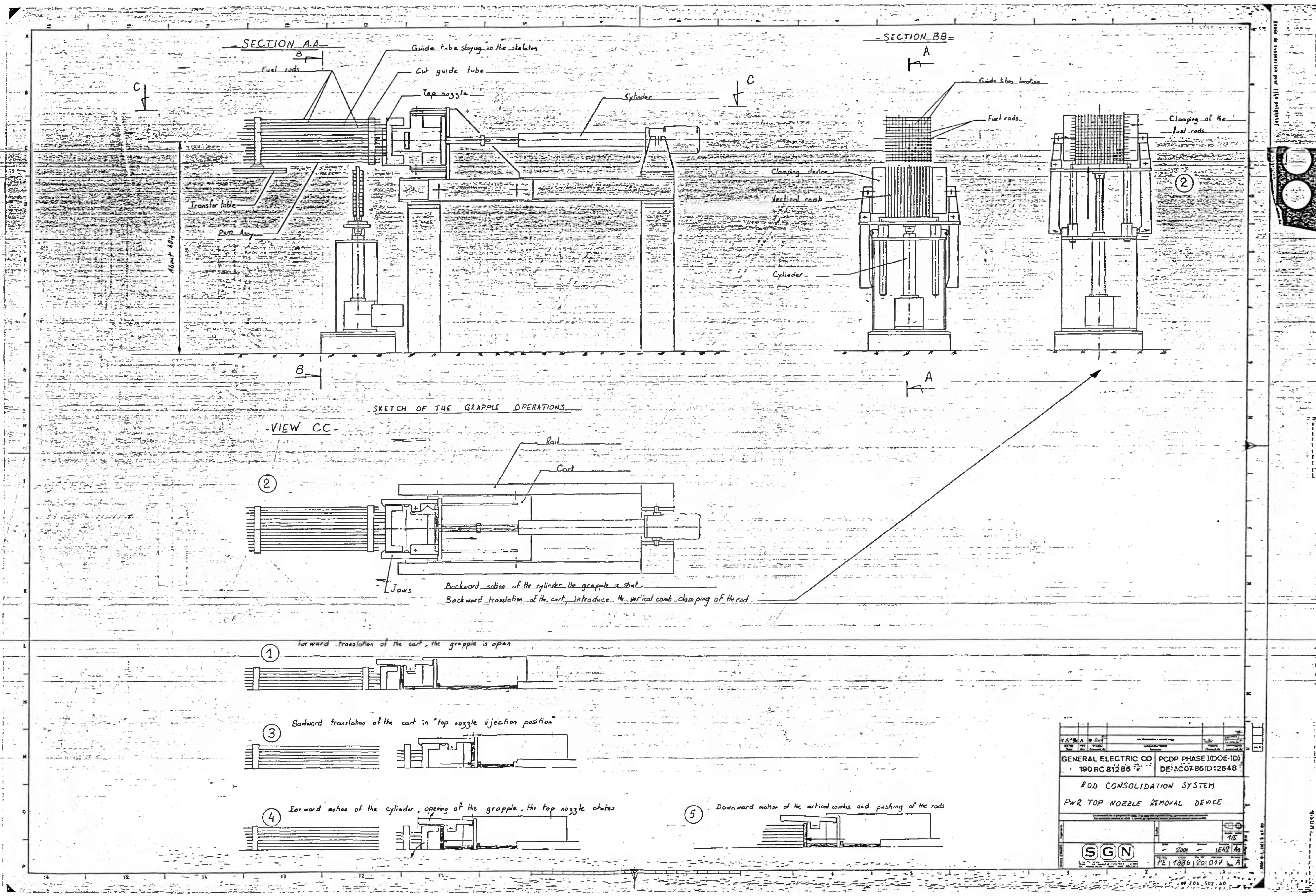
DE-AC07-86ID12648

ROD CONSOLIDATION SYSTEM
TILTING DEVICE AND SPECIFIC CLAMPERS

SGN

B2


SECTION A-A
Guide tube staying in the skeleton
Fuel rods
Cut guide tube
Top nozzle
Cylinder
Transfer table
About 1.80 m
SECTION BB
Guide tubes location
Fuel rods
Clamping of the fuel rods
Clamping device
Vertical comb
Cylinder
SKETCH OF THE GRAPPLE OPERATIONS
VIEW CC
Rail
Cart
Jaws
Backward motion of the cylinder, the grapple is shut.
Backward translation of the cart, introduce the vertical comb clamping of the rod.
Forward translation of the cart, the grapple is open
Backward translation of the cart in "top nozzle ejection position"
Forward motion of the cylinder, opening of the grapple, the top nozzle chutes
Downward motion of the vertical combs and pushing of the rods
GENERAL ELECTRIC CO
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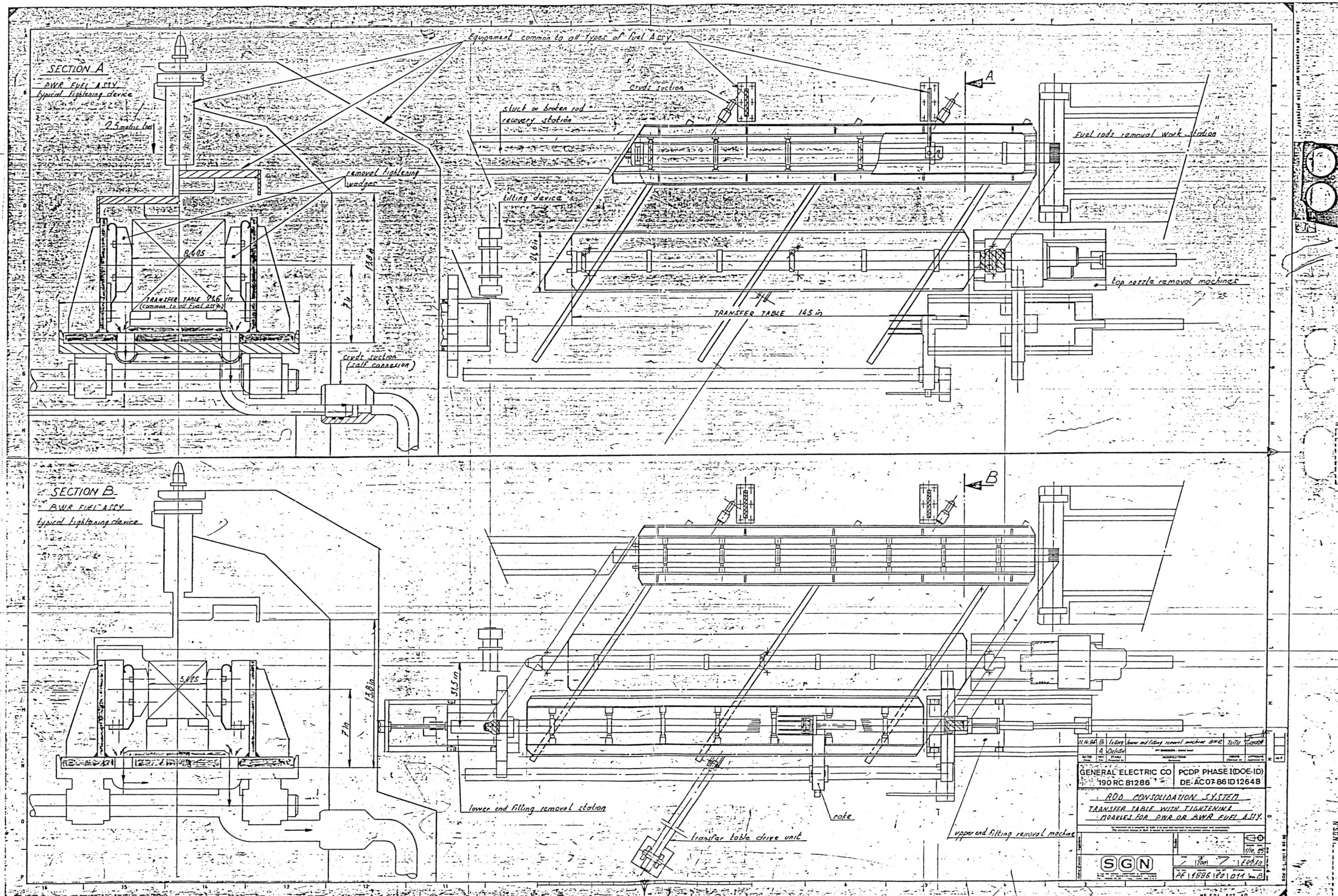
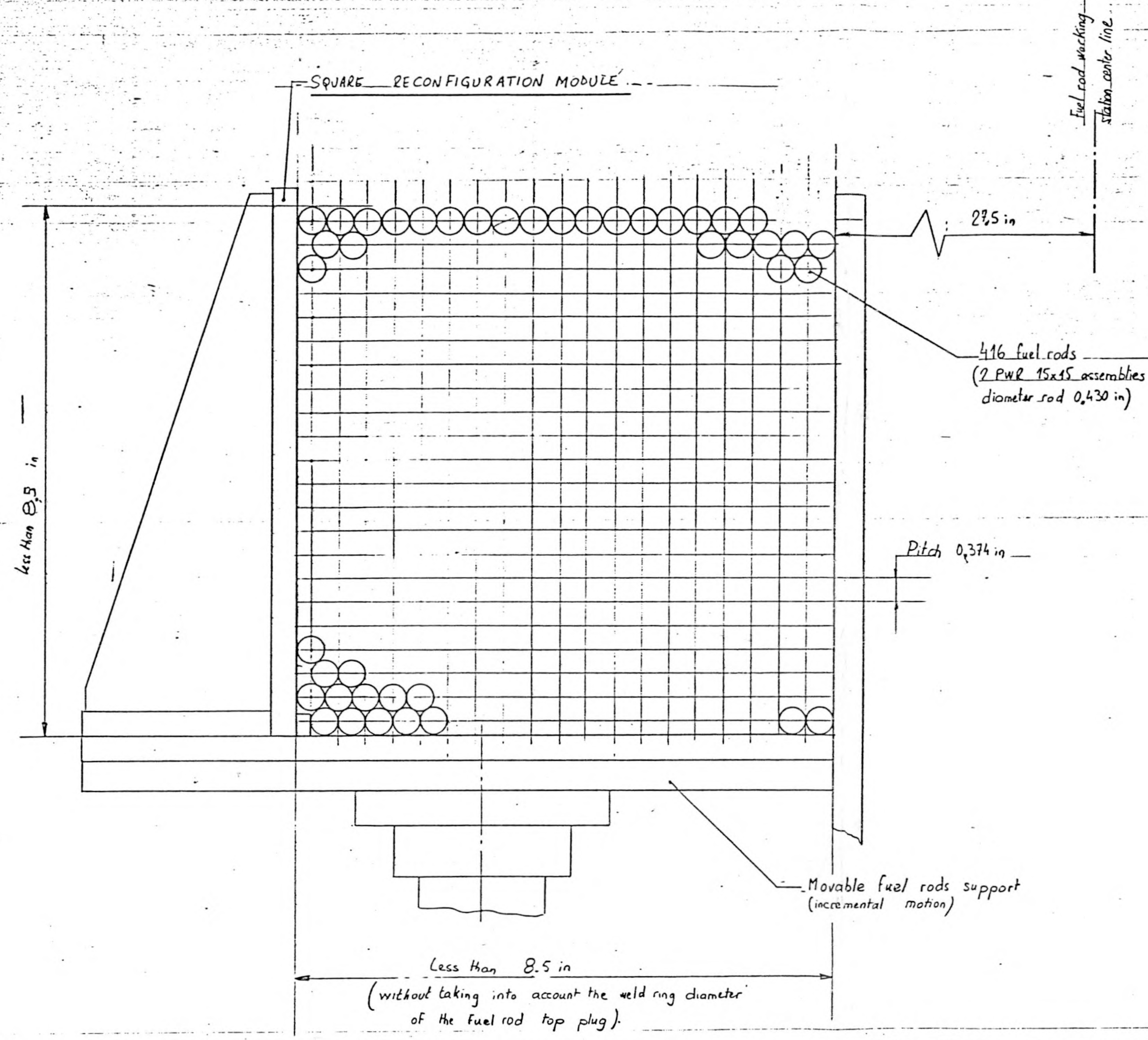
PCDP PHASE I (DOE-ID)
DE-AC07-86ID12648
ROD CONSOLIDATION SYSTEM
PWR TOP NOZZLE REMOVAL DEVICE
SGN
1/5
2001
E42
A0
PE 1886 20 017 A
C 4


Equipement common to all types of Fuel Assy.
SECTION A
PWR FUEL ASSY
typical tightening device
2.5 metric tons
removal tightening wedges
8.405
13.8 in
7 in
TRANSFER TABLE 24.6 in
(common to all Fuel assy)
cruds suction
(salt connexion)
crruds suction
stuck or broken rod recovery station
tilting device
Fuel rods removal work station
top nozzle removal machines
24.6 in
TRANSFER TABLE 145 in
SECTION B
BWR FUEL ASSY
typical tightening device
5.405
13.8 in
7 in
31.5 in
lower end fitting removal station
rake
transfer table drive unit
upper end fitting removal machine
GENERAL ELECTRIC CO
190 RC 81286
PCDP PHASE I (DOE-ID)
DE-AC07-86ID12648
ROD CONSOLIDATION SYSTEM
TRANSFER TABLE WITH TIGHTENING MODULES FOR PWR OR BWR FUEL ASSY.
SGN
PE 1886 80 011
D4



DATES	REV	ETABLI	MODIFICATIONS	VERIFIE	APPROUVE
11.10.86	B	Lecocq	up-dated	Tsitsi	Tuvatot
	A		1re EMISSION		

GENERAL ELECTRIC CO
190 RC 81286

PCDP PHASE I (DOE-ID)
DE-AC07-86ID12648

ROD CONSOLIDATION SYSTEM
TYPICAL SQUARE RECONFIGURATION

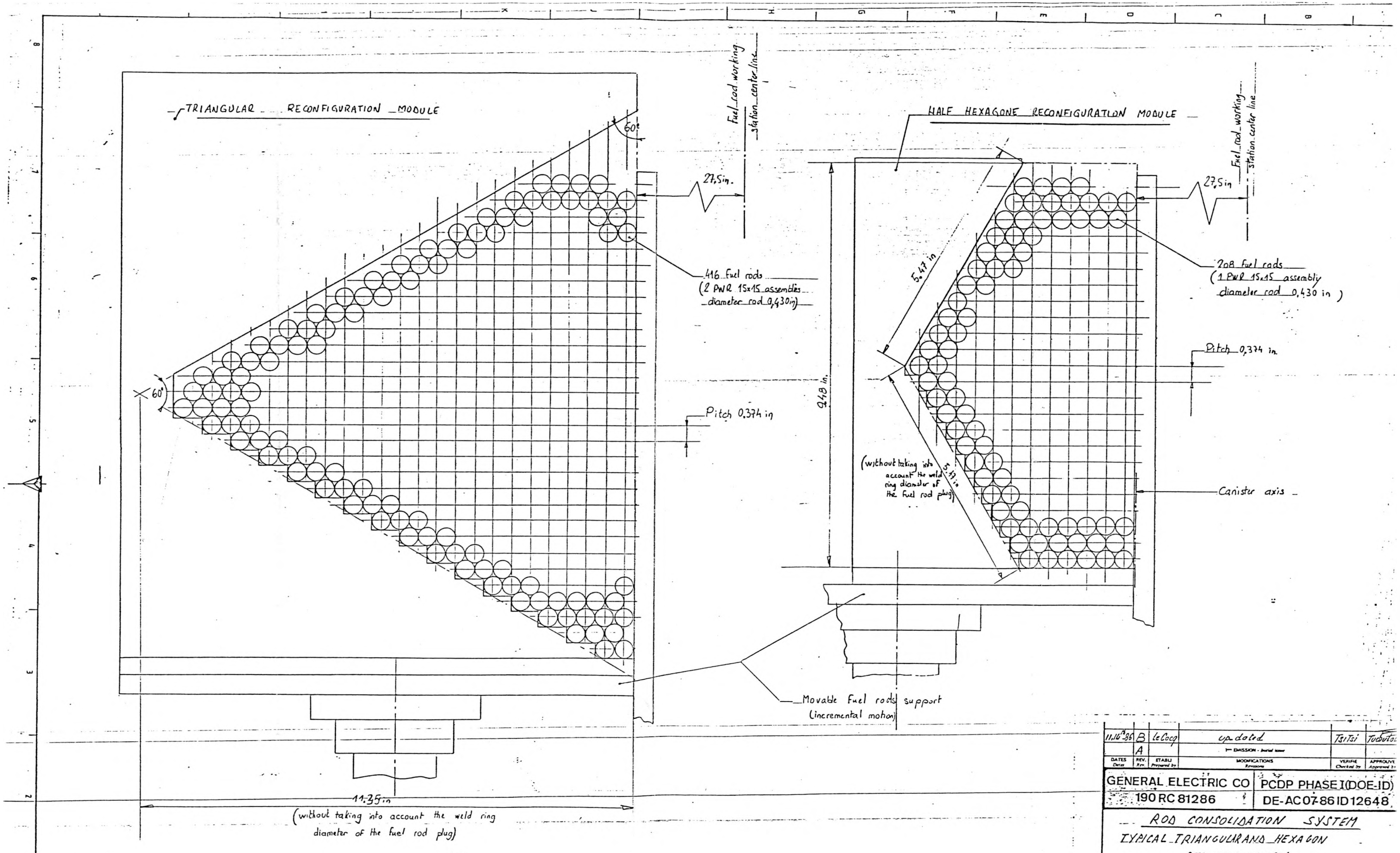
SGN

1/1

E42 A1

PE 1886 120 013 Rev. B

E2



DATES Dates	REV. Rev.	ETABLI Prepared by	MODIFICATIONS Revisions	VERIFIE Checked by	APPROUVE Approved by
11.16.86	B	le Cocq	updated	TsiTsi	Tucbutoc
	A		1re EMISSION - Initial issue		

GENERAL ELECTRIC CO
190 RC 81286

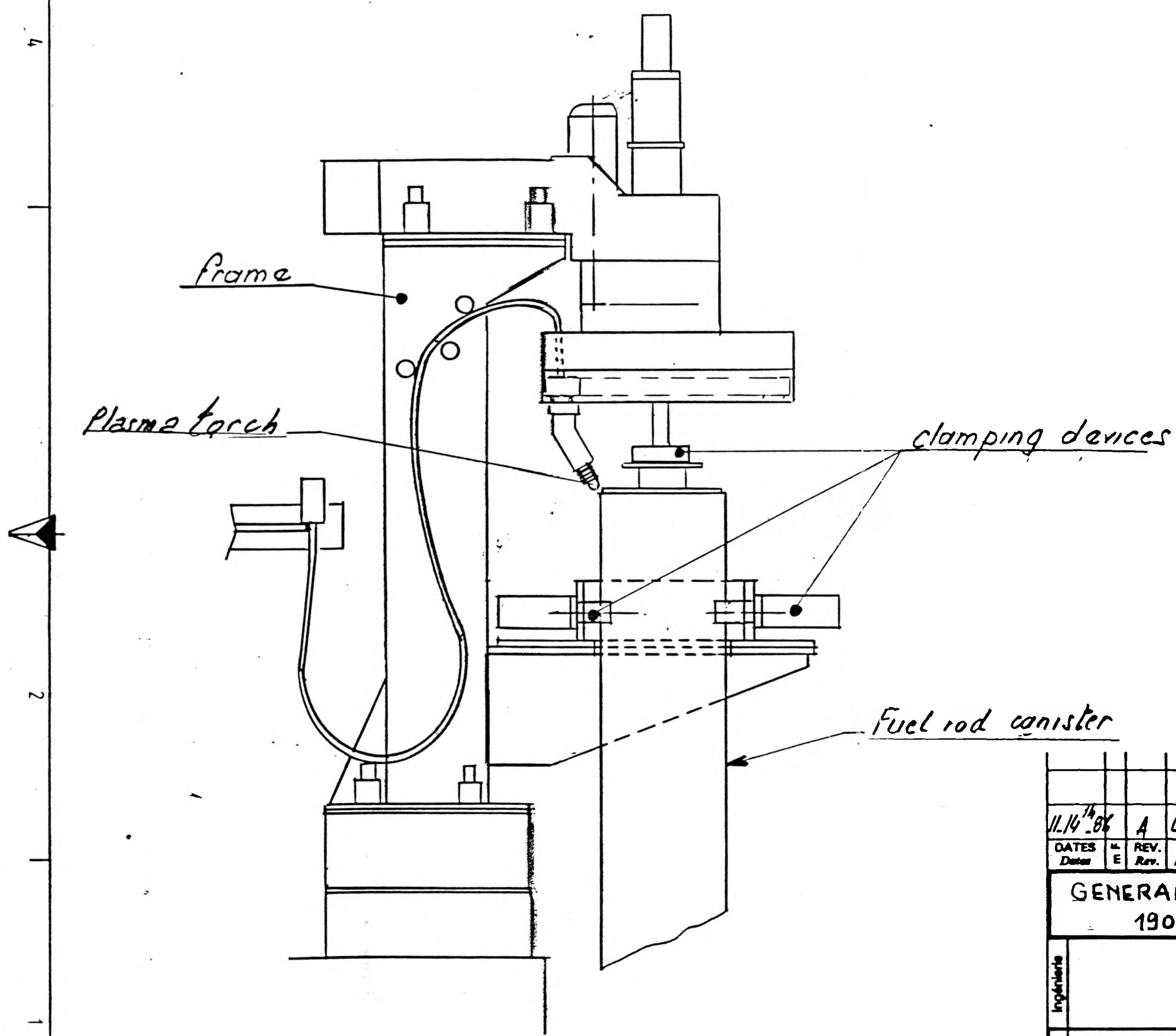
PCDP PHASE I (DOE-ID)
DE-AC07-86ID12648

ROD CONSOLIDATION SYSTEM
TYPICAL TRIANGULAR AND HEXAGON RECONFIGURATION

Etudes PE-1886-20-012
PE-1886-20-012
Echelle Scale 1/1
CMT 200 | E42 | A1

SGN

E3



DATES Dates	E	REV. Rev.	ETABLI Prepared by	MODIFICATIONS Revisions	VERIFIE Checked by	APPROUVE Approved by
11.14th.86		A	Le Cocq	1ère EMISSION - Initial issue	Tsitsi	Tutoutal

GENERAL ELECTRIC CO
190 RC 81286

PCDP PHASE I (DOE-ID)
DE-AC07-86ID 12648

Ingénierie

Maître d'oeuvre
SGN
1, rue des Hérons
MONTIGNY le BRETONNEUX
78184 ST-QUENTIN-YVELINES CEDEX

ROD CONSOLIDATION SYSTEM

WELDING MACHINE

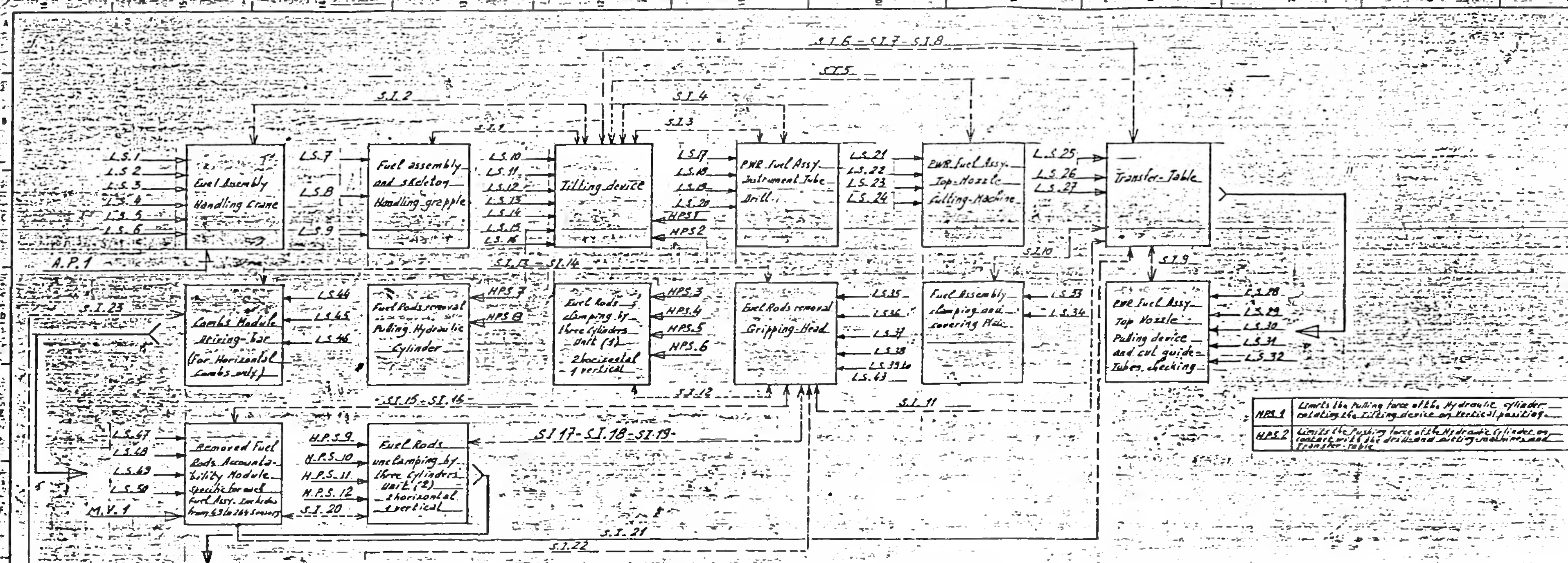
Echelle Scale: –

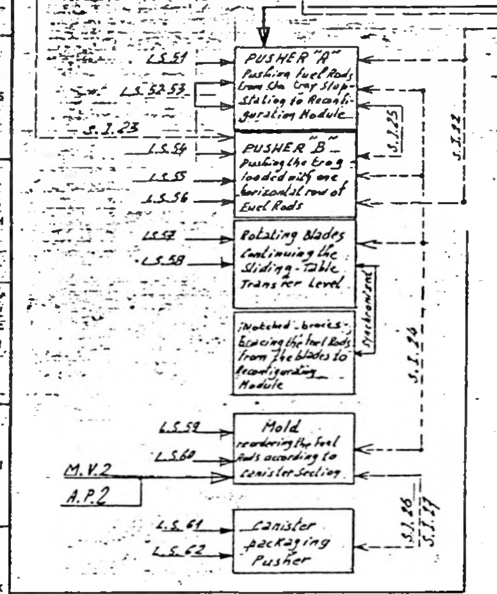
Unité	CMT	Situation	Emetteur	Page
0000	200	0000	E42	1

Typ.doc	Activité	Cat.MT	N°d'ordre	Révision
PE	1886	20	1014	Rév. A

E4

L.S = Limit switch
S.I = Safety interlock
H.P.S = Hydraulic Pressure Switch
A.P. = Automatic programm.
M.V = Memorized Visualisation





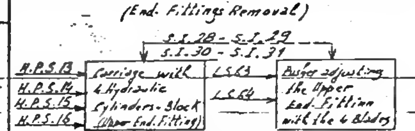
Item N°	Function	Equipment
L.S.1	High position tilting limit	Fuel Assembly Handling Crane
L.S.2	Low position limit	
L.S.3	Travelling motion advancing limit	
L.S.4	" " retracting limit	
L.S.5	Traversing motion one side limit	
L.S.6	" " second side limit	
A.P.1	Controls the Crane on each specific work position.	
L.S.7	Stops the Crane lowering motion when the Grapple is contacting the Fuel Assy. Top-end fitting	Fuel Assembly and skeleton Handling Grapple
L.S.8	Signals the Grapple hooks "open" position	
L.S.9	Signals the Grapple hooks "grasping" position	
L.S.10	Signals the Tilting device on vertical position	Fuel Assembly Tilting-Device
L.S.11	Signals the fuel Assembly standing on the Tilting device	
L.S.12	Signals the clamping shutters on "Open" position	
L.S.13	Signals the clamping shutters on "closed" position	
S.I.1	Authorizes the fuel Assy. Grapple to "ungrasp" on condition that the clamping shutters are "closed" (LS 13)	
S.I.2	Authorises the Tilting device to be rotated on condition that the Crane is on "High position" (LS 1)	
L.S.14	Signals the position of the Tilting device on line with the PWR Fuel Assy. instrument Tube drill-machine (15° from Horizontal)	
L.S.15	Signals the position of the Tilting device on line with the PWR Fuel Assy. Top Nozzle cut-machine (8° from Horizontal	
L.S.16	Signals the horizontal position of the Tilting device	
L.S.17	PWR instrument Tube drill-machine resting on "retracted" position	PWR Fuel Assy. Top Nozzle removal
L.S.18	" " " " " on "advanced position	
L.S.19	Drill-Tool advanced position after drilling	
L.S.20	" " retracted	
S.I.3	Authorizes the tilting device to be rotated to 15° from Horizontal on condition that the drill-machine is on advanced Position (L.S.18)	
L.S.21	Signals the cutting-Machine resting on "retracted" position	
L.S.22	Signals the cutting-Machine on "advanced" position	
S.I.4 S.I.5	Authorizes the tilting device to rotate from 15° to 8° from horizontal on double condition that: the drill-machine is retracted (L.S.17) – the cutting machine is on advanced position (L.S.22) (Limit-switch L.S.14 "off-drives" safety S.I.3.	
L.S.23	Signals the cutting blades disengaged (drive rods advanced)	
L.S.24	" " " " ending cutting (drive rods retracted)	
L.S.25	Signals the position of the table on line with the Tilting device	Transfer-Table
L.S.26	Signals the Position of the Table on specific line for BWR end fittings removal Station (off-drives switches LS 14 and LS 15 -	
S.I.6 S.I.7	Authorizes The Tilting device to be rotated from 8° to horizontal: – on condition the cutting machine is retracted (L.S.21) – (Switch L.S.15 "off drives" safety S.I.5 – on condition the Transfer-Table is on line (L.S.25)	
L.S.27	Signals the Position of the Transfer-Table on line with the Fuel Rods removal station	
L.S.28	Signals the retracted Position of the PWR Top Nozzle pulling device	PWR Fuel Assy. Top Nozzle pulling device and cut guide-Tubes checking.
L.S.29	Signals the advanced Position of the " " " " "	
L.S.30	Signals the intermediate Position of the PWR top nozzle pulling device	
L.S.31	Signals that the PWR Guide-Tubes have been cut by inserting vertical Combs on intermediate position L.S.30	
L.S.32	Signals the retracted Position of the vertical Combs "up"	
S.I.9	Authorizes the transfer Table to be translated on condition that PWR Top Nozzle pulling device is on retracted position "up" (LS 28)	
L.S.33	Signals the clamping and covering Plate on "up" Position	
L.S.34	" " " " " " " low Position	
S.I.10	Authorizes the Transfer-Table to be translated on condition that clamping and covering Plate is on "up" Position (LS.33)	

HPS 1	Limits the pulling force of the Hydraulic cylinder rotating the tilting device on vertical position	
HPS 2	Limits the pushing force of the Hydraulic cylinder on contact with the drill and cutting machine and from [illegible]	

Items N°	Function	Equipment
S.I.16	Authorizes the Gripping head to be advanced from unclamping position LS36 up to contact of fuel rods with the sensors module LS 38, the module beeing on "low" Position (LS.50)	Gripping-head Interfaces
S.I.15	Authorizes the Gripping-head to be moved from extreme back position LS37 to clamping position LS35 on condition that the accountability module is retracted "up" (L.S.47)	
S.I.14	Authorizes the Gripping-head to be advanced from unclamping position (LS.36) up to contact of fuel rods with accountability sensors (LS.38) the horizontal combs beeing closed (LS.44)	
S.I.13	Authorizes the Gripping-head to be moved from extreme retracted position LS.37 up to clamping position LS35, on condition that horizontal combs are opened (LS46)	
S.I.12	Authorizes the gripping-head, to move from back position (LS37) to clamping position (LS.35) on condition that vertical and horizontal cylinders of Unit 1 are retracted (HPS.5 and HPS6) -	
M.V.1	Memorizes and visualizes the initial array of fuel Rods and empty location in the Fuel Assy. structure - Compares with the fuel Rods Array in the Combs lattice - Signals "broken" Rod	Removed Fuel Rods Accountability Module. Specific for each type of fuel Assy. Includes from 49 to 264 Sensors
L.S.50	Signals the "low" position of the module, crossing the L.S.48 and 49 area - Checks all rods are in the Combs array	
L.S.48 + L.S.49	Signal "stuck" fuel Rod in the Fuel Assy. structure as well as in part inserted in the Combs Array. Stop module lowering	
L.S.49	Signals fuel rod removed from Assy. structure but released on late inches of removal stroke – Stops module lowering.	
L.S.48	Signal's "stuck" fuel Rod on top of fuel assy structure laying down the Transfer Table – Stops module lowering	
L.S.47	Signals the retracted "up" position of the module	
L.S.46	Signals the extreme retracted position after all combs have been simultaneously opened	Combs modules driving bar (for horizontal Combs only)
L.S.45	Signals the intermediate position of the drive-bar after having closed one Comb module (Repeated for 5 positions LS.39 to 43)	
L.S.44	Signals the position of the drive-bar after having closed the combs	
H.P.S.8	Limits the pushing force when advancing the Gripping head	Fuel Rods Removal Pulling hydraulic Cylinder
H.P.S.7	Limits the Pulling force when removing the fuel Rods	
H.P.S.6	Limits the force when retracting the vertical cylinder - Maintains the pressure – Signals the Position.	Fuel Rods Clamping by three Cylinders Unit (1)
H.P.S.5	Limits the force when retracting the horizontal cylinders - Maintains the pressure on retracted position - Signals the position	
H.P.S.4	Limits the force of the vertical cylinder driving the locking stirrup Stops the motion on "low position" – Signals the position	
H.P.S.3	Limits the clamping force of horizontal cylinders. Stops the motion	
S.I.11	Authorizes the Transfer-Table to be translated on condition that the Gripping-head is on extreme retracted position (LS 37)	Fuel Rods Removal Gripping-Head
L.S.39 to L.S.43	Signal the 5 positions along the fuel rods removal bench where the horizontal combs have to be rotated.	
L.S.38	Stops the gripping-head advancing the fuel rods on contact with the accountability module sensors.	
L.S.37	Signals the Gripping-head on extreme retracted position (ejecting the fuel Rods)	
L.S.36	Signals the Gripping-head on retracted position (fuel rods unclamping)	
L.S.35	Signals the Gripping head on advanced position (fuel rods clamping)	

Items N°	Function	Equipment
S.I.31	Authorizes the Blades to be retracted on condition: the carriage is retracted (HPS.[illegible])	B.W.R. Fuel Assy. Upper End-Fitting Removal
S.I.30	– The pusher is retracted (L.S.64)	
S.I.28 S.I.29	Authorizes the carriage to be advanced on condition – the Blades are retracted (H.P.S.16) – the pusher is advanced (L.S.63)	
L.S.64	Signals the retracted position of the Pusher (End Fitting [illegible])	
L.S.63	Signals the advanced position of the Pusher.	
H.P.S.16	Limits the 4 Blades retracting force after shearing	
H.P.S.15	Limits the shearing force on the four cylinders	
H.P.S.14	Limits the Pulling force – Signals the retracted Position	
H.P.S.13	Limits the [illegible] force – Signals the Position for shearing	
S.I.27	Authorizes the Mold to be moved on condition that the Pusher is on retracted position (L.S.61)	Fuel Rod Reconfiguration and Canister Packaging
S.I.26	Authorizes the pushing advance motion on condition that the Mold is in line on "lower" position (L.S.60)	
L.S.62	Signals the extreme advanced position of the pusher	
L.S.61	Signals the retracted position of the Pusher	
M.V.2 A.P.2	Memorizes, visualizes and programmes the Mold-loading scenario [illegible]	
S.I.25	Authorizes the Pusher "A" to be retracted [illegible]	
S.I.24	Authorizes Pusher "B" to advance on condition that [illegible]	
S.I.23	Authorizes the horizontal combs opening on condition that the tray [illegible]	
L.S.60	Signals the lower position of the mold on line with the [illegible]	
L.S.59	Signals "up" Position of the mold for receiving the first fuel Rods load	
L.S.58	Signals the retracted position of the 6 blades [illegible]	
L.S.57	Signals the blades [illegible]	
S.I.22	Authorizes the Gripping-head to move in both directions on condition that [illegible]	
L.S.56	Signals the position where the tray slips beneath the sliding table	
L.S.55	Signals the Pusher "B" position when tray [illegible]	
L.S.54	Signals the retracted Position of Pusher "B"	
L.S.53	Stop advancing Pusher A on contact of fuel Rods row against the Mold wall [illegible]	
L.S.52	[illegible]	
L.S.51	Signals the retracted position of Pusher "A"	
S.I.21	Authorizes the Transfer-Table to translate on line with the Tilting device on condition that the Accountability module has crossed the area limited by switches LS.48 and 49	Transfer-Table interface
S.I.20	Authorizes the fuel Rods to be unclamped on condition that the Accountability-Module has crossed the area limited by switches LS48 and 49	Gripping Head interfaces
S.I.19	Authorizes the Gripping-Head to move from unclamping position LS36 to extreme retracted position LS37, on condition that all three cylinders are retracted (HPS.10 and HPS 11)	
S.I.18	Authorizes the Gripping head to be moved from clamping position LS35 to unclamping position LS36 on condition that vertical cylinder of Unit 2 has been repushed (HPS.12)	
S.I.17	Authorizes the Gripping head to be moved from clamping position (LS35) to unclamping position LS.36, on condition that horizontal cylinders of Unit 2 are retracted (HPS.11)	
H.P.S.12	Limits the force when repushing the vertical cylinder. Maintains the pressure – Signals the Position	Fuel Rods unclamping by three Cylinders Unit 2
H.P.S.11	Limits the force when retracting the horizontal cylinders. Maintains the pressure – Signals the position	
H.P.S.10	Limits the force of the vertical cylinder retracting the locking wedges – Stops the motion on "up position" – Signals the Position	
H.P.S.9	Limits the unclamping force of horizontal cylinders – Stops the motion	

SPECIFIC FOR BWR FUEL ASSEMBLY
(End-Fittings Removal)



Items N°	Function	Equipment
S.I.35	Authorizes "Shearing" on condition all Combs are closed (L.S.66 - L.S.68)	Lower End Fitting Removal
S.I.34 S.I.33	The Carriage is authorized to advance or retract on condition: – the horizontal combs are opened (L.S.65) – the vertical combs are opened (L.S.67)	
S.I.32	The Carriage is authorized to advance on condition that the 4 Blades are retracted (H.P.S.20)	
L.S.68	Signal the vertical combs "closed" Position	
L.S.67	Signals the retracted Position of the vertical Combs	
L.S.66	Signals the Horizontal Combs "closed" Position	
L.S.65	Signals the retracted Position of the Horizontal combs	
H.P.S.20	Limits the 4 Blades retracting force. Signals the position	
H.P.S.19	Limits the shearing force on the 4 Cylinders.	
H.P.S.18	Limits the Carriage retract force. Signals the Position	
H.P.S.17	Limits the Carriage advance force - Signals the position	

GENERAL ELECTRIC CO 190 RC 81286 | PCDP PHASE I (DOE-ID) DE-AC07-86 ID 12648

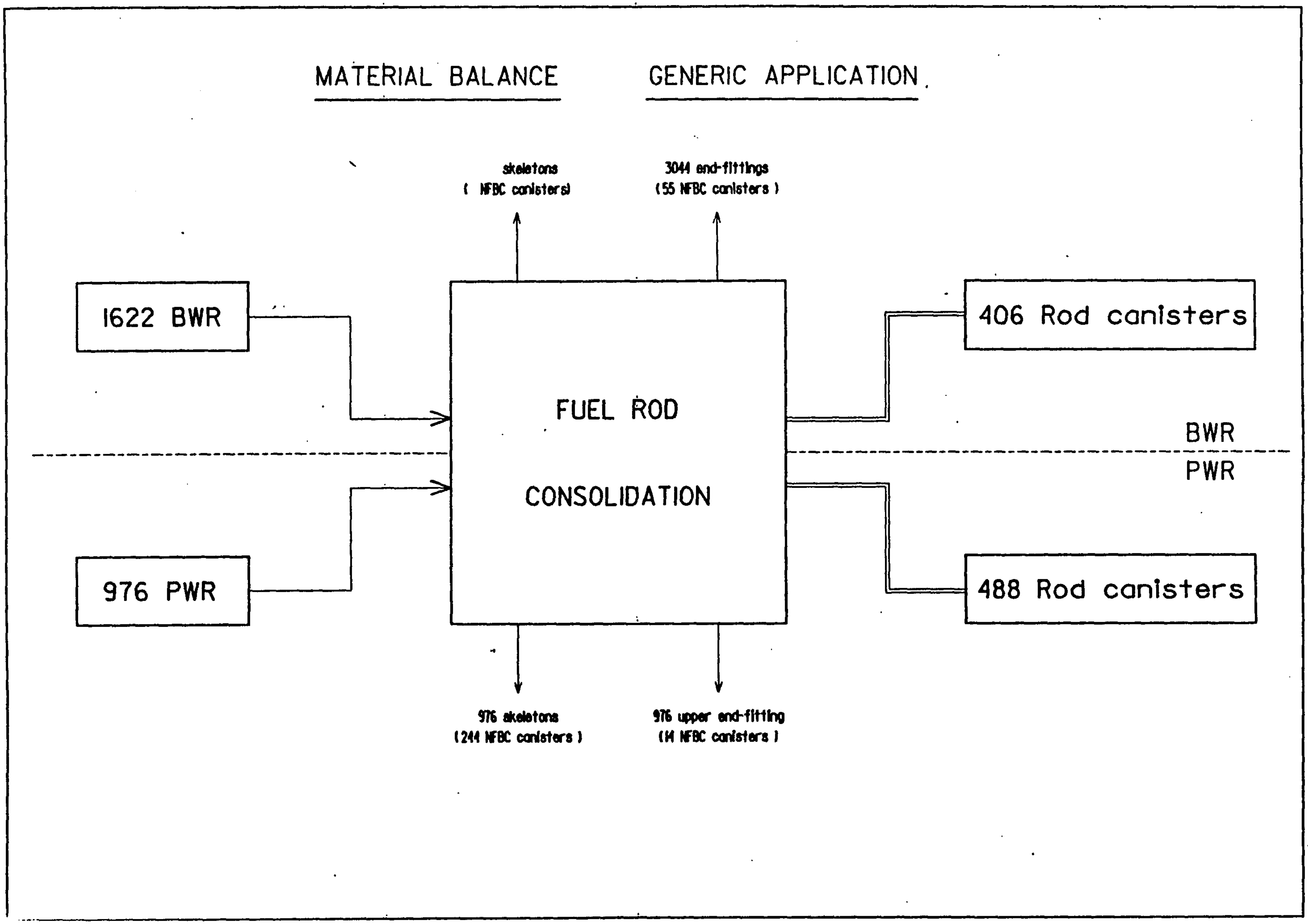
ROD CONSOLIDATION SYSTEM
OPERATIONS SIGNAL-SYSTEM AND SAFETY INTERLOCKS

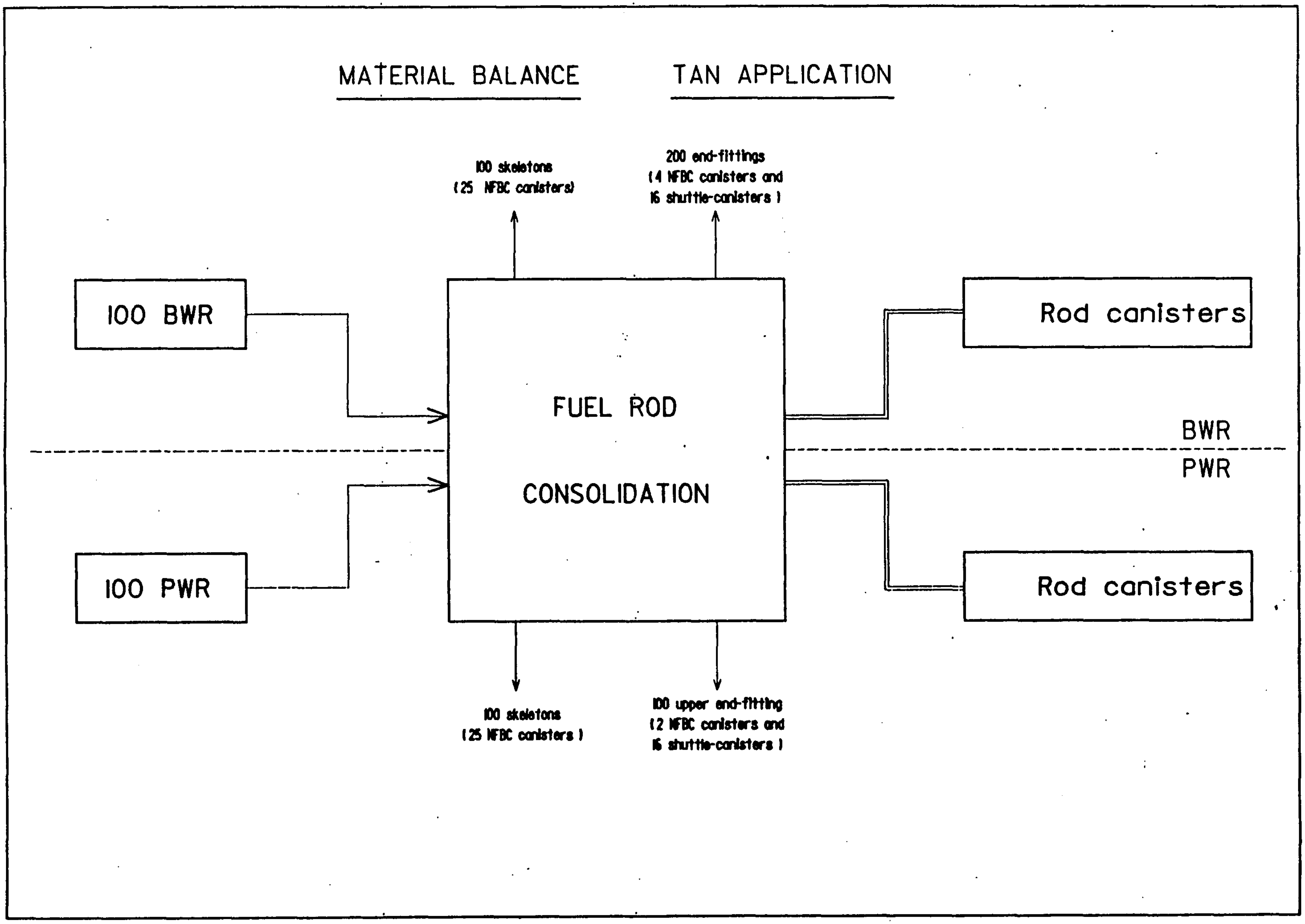
SGN

SH 1886 20 005 A

GI

NF E04-502-A0


MATERIAL BALANCE GENERIC APPLICATION
skeletons
(NFBC canisters)
3044 end-fittings
(55 NFBC canisters)
1622 BWR
976 PWR
FUEL ROD
CONSOLIDATION
406 Rod canisters
488 Rod canisters
BWR
PWR
976 skeletons
(244 NFBC canisters)
976 upper end-fitting
(14 NFBC canisters)


MATERIAL BALANCE
TAN APPLICATION
100 skeletons
(25 NFBC canisters)
200 end-fittings
(4 NFBC canisters and
16 shuttle-canisters)
100 BWR
FUEL ROD
CONSOLIDATION
Rod canisters
BWR
PWR
100 PWR
Rod canisters
100 skeletons
(25 NFBC canisters)
100 upper end-fitting
(2 NFBC canisters and
16 shuttle-canisters)

APPENDIX IV

EQUIPMENT DATA SHEETS

The aim of these data sheets is to describe for the main process equipment the characteristics, functions and the supports necessary to perform these functions.

In that way, the reader has all the main information on each equipment.

ROD CONSOLIDATION CELL CRANE (Modular crane) SHEET 01

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X OPERATING TIME: FOR SUB-SEQUENCE	X OPERATING TIME: PER DAY	SUPPORTS	NOMINAL POWER
Load capacity : 2 metric tons			Electric power	5 KW direct current
Average speed : travelling) variable from "0" to "20" traversing) feet per minute (direct current lifting)				
Functions : A - transfer 14 PWR or 14 BWR fuel elementss from lag-storage to the tilting device	15 mn	x14 = 3h30 mn	Handling grapple . PWR . BWR	
B - transfer 14 PWR or 14 BWR 8 x 8 skeletons from the tilting device to four compartments NFBC canisters	15 mn	x14 = 3h30 mn		
	30 mn	7 h 30 mn		

X : Reserves a margin of 25 % on calculated operating time

END-FITTING REMOVAL STATION

The end-fitting removal station includes :

- 1 tilting device
- 1 BWR lower end-fitting shearing machine
- 1 BWR upper end-fitting shearing machine
- 1 PWR instrument tube drill
- 1 PWR multiple blade cutting machine
- 1 PWR upper end-fitting removal device.

END-FITTING REMOVAL STATION - TILTING DEVICE   SHEET 02-1

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X OPERATING TIME FOR SUB-SEQUENCE	OPERATING TIME PER DAY	SUPPORTS	NOMINAL POWER
Characteristics common to PWR and BWR fuel elements			Hydraulic power unit	1 KW
. Load capacity : 1 metric ton			Control	
. Tilting speed : 1/4 revolution per 2 mn			Clamping device	
. Fitted with clamping device specific to each type of fuel assemblies			PWR 17 x 17 PWR 15 x 15 BWR 8 x 8 BWR 7 x 7	
Functions				
. Specific to PWR fuel elements				
A - Move 70° from vertical position down to alignment with the instrument tube drill	2 mn	x 14 28 mn		
B - After drilling, move down to intermediate position 2 (82°), in line with the cutting machine	0 mn 15 s	x 14 3 mn 30 s		
C - Move down to horizontal position to depose the fuel assembly on the transfer table	0 mn 30 s	x 14 7 mn		
D - Move 90° from horizontal to vertical position	2 mn 30 s	x 14 35 mn		
	5 mn 15 s	73 mn 30 s		

X : Reserves a margin of 25 % on calculated operating time

END-FITTING REMOVAL STATION - TILTING DEVICE SHEET 02-1

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X OPERATING TIME FOR SUB-SEQUENCE	X OPERATING TIME PER DAY	SUPPORTS	NOMINAL POWER
Functions				
. Specific to BWR fuel elements				
A' - Move down from vertical position to horizontal position	2 mn 30 s	x 14 35 mn		
B' - Move 90° from horizontal to vertical position	2 mn 30 s	x 14 35 mn		
	5 mn	70 mn		
. Common to PWR and BWR 8 x 8 fuel elements				
E - Move from vertical position down to horizontal position to clamp the PWR or BWR 8 x 8 skeletons	2 mn 30 s	x 14 35 mn		
F - Move from horizontal up to vertical position to allow the grasping of the skeleton by the handling crane	2 mn 30 s	x 14 35 mn		
	5 mn	70 mn		
TOTAL (PWR elements)	10 mn 15 s	143 mn 30 s		

X : Reserves a margin of 25 % on calculated opering time

END-FITTING REMOVAL STATION - UPPER END-FITTING SHEARING-MACHINE (BWR) SHEET 02-3

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X : OPERATING TIME FOR SUB-SEQUENCE	OPERATING TIME PER DAY	SUPPORTS	NOMINAL POWER
Function : cut all the tie rods close to the lower end-fitting			Electric power and control for the cart	10 KW
A - Move the shearing machine forward	0 mn 30 s	x 14 7 mn	Hydraulic cylinder for the blades (oil)	
B - Shear the tie-rods	1 mn 15 s	x 14 17 mn 30 s		
C - Retract the machine	0 mn 30 s	x 14 7 mn		
	2 mn 15 s	x 14 31 mn 30 s		

X : Reserves a 25 % margin on the calculted operating time

END-FITTING REMOVAL STATION - LOWER END-FITTING SHEARING-MACHINE (BWR) **SHEET 02-4**

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X OPERATING TIME: FOR SUB-SEQUENCE	OPERATING TIME: PER DAY	SUPPORTS	NOMINAL POWER
Function : cut all the tie rods close to the lower end-fitting			Electric power and control for the cart	10 KW
A - Move the shearing machine forward	0 mn 30 s	x 14 7 mn	Hydraulic cylinder for the blades (oil	
B - Introduce the combs	1 mn	x 14 14 mn		
C - Shear the tie-rods	1 mn 15 s	x 14 17 mn 30 s		
D - Retract the machine	0 mn 30 s	x 14 7 mn		
	3 mn 15 s	x 14 45 mn 30 s		

X : Reserves a 25 % margin on the calculted operating time

END-FITTING REMOVAL STATION - INSTRUMENT TUBE DRILL (PWR) SHEET 02-5

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X OPERATING TIME: FOR SUB-SEQUENCE	OPERATING TIME: PER DAY	SUPPORTS	NOMINAL POWER
Characteristics			Electric power and control	1 KW
Functions				
A - Move the drill forward during rotation of the tilting device to 70°	0 mn 30 s	x 14 7 mn		
B - Drill the instrument tube	1 mn 15 s	x 14 17 mn 30 s		
C - Retract the drill the enable rotation of the tilting device	0 mn 30 s	x 14 7 mn		
	2 mn 15 s	x 14 31 mn 30 s		

X : Reserves a 25 % margin on the calculated operating time

END-FITTING REMOVAL STATION - INSTRUMENT AND GUIDE TUBES CUTTING MACHINE (PWR) **SHEET 02-4**

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X : OPERATING TIME FOR SUB-SEQUENCE	OPERATING TIME PER DAY	SUPPORTS	NOMINAL POWER
Function : cut all the instrument and guide tubes of the PWR fuel elements			Electric power and control Nitrogen blowing device	1 KW
A - Move the machine forward to penetrate all the tubes	0 mn 30 s	x 14 7 mn		
B - Cut the tubes	1 mn	x 14 14 mn		
C - Retract the machine	0 mn 30 s	x 14 7 mn		
	2 mn	28 mn		

X : Reserves a 25 % margin on the calculted operating time

END-FITTING REMOVAL STATION - TOP NOZZLE REMOVAL DEVICE — SHEET 02-6

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X : OPERATING TIME — FOR SUB-SEQUENCE	X : OPERATING TIME — PER DAY	SUPPORTS	NOMINAL POWER
. Functions : remove the top nozzle when the guide tubes are cut				1 KW
A - Move the top-nozzle removal device forward	20 s	x 14 4 mn 40 s		
B - Move the top-nozzle removal device about 25 millimeters backwards	5 s	x 14 1 mn 10 s		
C - Introduce the comb	15 s	x 14 3 mn 30 s		
D - Move the top-nozzle removal device backward to remove the top-nozzle and dispose of it in the chute.	20 s	x 14 4 mn 40 s		
E - Move the top-nozzle removal device forward to push the fuel rods which could have been pulled when removing the top-nozzle	20 s	x 14 4 mn 40 s		
F - Move the top-nozzle removal device backward	20 s	x 14 4 mn 40 s		
	1 mn 40 s	23 mn 20 s		

X : Reserves a 25 % margin on calculated operating time

ROD REMOVAL STATION **SHEET 03-0**

EQUIPMENT LIST :

03.1 - 1 transfer-table
03.2 - 1 fuel element covering and clamping plate
03.3 - 1 support and gripping head guide structure
03.4 - 1 set of horizontal and vertical combs modules(*)
03.5 - 1 gripping head(*)
03.6 - 1 hydraulic clamping device
03.7 - 1 hydraulic unclamping device
03.8 - 1 rod accountability device(*)

(*) Items 03-4, 03-5 and 03-7 are specific, other items are common to all types of fuel assembly.

SUPPORT : Electric power and control - Hydraulic power unit : 8 KW
Cruds collection system

CALCULATED TIME TO PERFORM THE SEQUENCE : 10 mn 30 sec. Rounded at 11 mn including 25 % margin

The detailed sequence is shown on following SHEETS : 03-1, 03-2, 03-3.

ROD REMOVAL STATION - TRANSFER TABLE ITEM 03-1 SHEET 03-1

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X OPERATING TIME FOR SUB-SEQUENCE	OPERATING TIME PER DAY	SUPPORTS	NOMINAL POWER
Characteristics : common to PWR and BWR fuel element . Load capacity : 1 metric ton . Traversing speed : 6 feet per minute			Electric power and control Cruds collection system	0.5 KW
Functions : continuing function "d" of sheet 02-1				
A - Transfer one fuel element (PWR or BWR) from end-fitting removal station to alignment with the rod removal machine	1 mn	14 mn		
After the rods have been removed :				
B - Return back to initial position with the fuel element skeleton (PWR or BWR 8 x 8 type) spacer grid for BWR 7 x 7. This enables function "e" of sheet 02-2 to be performed	1 mn	14 mn		
TOTAL	2 mn	28 mn		

X : Reserves a 25 % margin calculated operating time

ROD CONSOLIDATION - EQUIPMENT DATA SHEET FUNCTIONAL SEQUENCE "03" **SHEET 03-2**
ROD REMOVAL STATION FUEL ASSEMBLY COVERING AND CLAMPING PLATE - ITEM 03-2

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X	OPERATING TIME FOR SUB-SEQUENCE	OPERATING TIME PER DAY	SUPPORTS	NOMINAL POWER
Characteristics : Common to PWR and BWR fuel element				Electric power and control	0.5 KW
Weight : about 2.5 metric tons				Cruds collection system	
Length : about 15 feet					
Function : After the transfer-table is positioned in line with the rod removal machine :					
A - Move the plate down to fuel element structure In that way, the fuel element is enclosed into a continuous channel		0 mn 30 s	7 mn		
B - After the rods have been removed :		0 mn 30 s	7 mn		
Lift the plate to release the transfer table and enable the return on initial position in line with the tilting device (function "b" of sheet 03-1					
TOTAL :		1 mn	14 mn		

See following sheet 03-3

ROD REMOVAL STATION - ROD REMOVAL MACHINE SHEET 03-3

ITEM : 03-3 - Support and gripping guide structure
03-4 - Horizontal and vertical combs modules
03-5 - Gripping head
03-6 - 03-7 - Hydraulic clamping device on each top of the support structure
03-8 - Rod accountability device

NOTE : Items 03-3 and 03-6 are common to all types of fuel assembly
Items 03-4, 03-5, 03-7 and 03-8 are specific

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X OPERATING TIME FOR SUB-SEQUENCE	OPERATING TIME PER DAY	SUPPORTS	NOMINAL POWER
Characteristics :			Electric power and control	7 KW
- Pulling force limited to 8.5 metric tons			Cruds collection system	
- Speed : 6 feet per minute (gripping head)				
- Stroke : 15 feet (gripping head)				
Functions : continuing function "a" of sheet 03-2				
A - Move the gripping head forward, to swallow the fuel rods	0 mn 30 s	7 mn		
B - Clamp and lock the gripping jaws (Item 03-6) (clamping and locking are automatical)	0 mn 30 s	7 mn	Hydraulic power unit	
C - Pull all fuel rods simultaneously - Stop (about 14.5 feet stroke)	3 mn	42 mn	Common to items 03-7 and 8	
D - Check all rods have been removed and proceed to accountability (advance item 03-8)	2 mn	28 mn		
E - Unclamp the fuel rods (item 03-7)	0 mn 30 s	7 mn		
F - Retract the gripping head, ejecting the rods	0 mn 30 s	7 mn		
G - Retract item 03-8	0 mn 30 s	7 mn		
H - Move the transfer-table back to initial position in line with the tilting-device (operating time included in transfer table function "b" of sheet 03-1				
SUB-TOTAL :	7 mn 30 s	105 mn		

ROD REMOVAL RECONFIGURATION STATION SHEET 04-0

EQUIPMENT LIST : Item 04-1 - Fuel rod tray transfer mechanism - Pusher "B"
04-2 - Fuel rod pusher "A"
04-3 - Transition canister structural frame
04-4 - Reconfiguration Molds with incremental drive mechanism

. The quantity of fuel rod trays is depending on the fuel rod pitch and outside diameter in the initial fuel assembly array.

.. The quantity of reconfiguration molds is depending on :

- the geometry of the canister
- the fuel rod outside diamter

SUPPORTS : Electric power and control - Specific automatic programs

GLOBAL POWER FOR THE STATION : 2 KW

CALCULATED TIME TO PERFORM THE SEQUENCE : 31 mn 30 sec. for one fuel assembly

REFERENCE TIME TAKEN INTO ACCOUNT FOR THE TIME DIAGRAM : 40 mn

(Including a margin more than 25 %)

The detailed sequence is shown on following sheets 04-1 to 04-4 included.

ROD RECONFIGURATION STATION SHEET 04-1

RECONFIGURATION DEVICE

ITEMS : 04-1 - Fuel rods tray transfer mechanism
04-2 - Fuel rods pusher

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X	OPERATING TIME FOR SUB-SEQUENCE	OPERATING TIME PER DAY	SUPPORTS	NOMINAL POWER
Characteristics :					0.5 KW
. Trays carriage and mechanism common to all types of fuel assembly . Tray capacity from 7 to 17 fuel rods specific to fuel rod pitch and diameter from 7 x 7 BWR to 17 x 17 PWR fuel element . Pusher common to all types of fuel element . Pushing force about 0.2 metric ton . Stroke about 3 feet - Speed 6 feet/minute					
Functions : Reconfigure the fuel rod initial array to to an array close to the inside section of the canister. This reconfiguration can be a square, rectangular, triangular, round or trapezoidal section. As the quantity of fuel rods is variable from the BWR 7 x 7 fuel assembly, the sequence is based on processing 2 PWR 15 x 15 fuel element to reconfigure one canister square: section. i.e. : 416 fuel rods (22 x 19 horizontal rows including 2 empty locations)					
Sub-sequence functions are detailed on following sheets 04-1 - 04-2					

RECONFIGURATION STATION SHEET 04-2

RECONFIGURATION DEVICE
ITEMS : 04-1 - Fuel rods tray transfer mechanism
04-2 - Fuel rods pusher

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X OPERATING TIME		SUPPORTS	NOMINAL POWER
	FOR SUB-SEQUENCE	PER DAY		
Functions : Continuing function "g" of sheet 03-3			Electric power and control	
A - Open simultaneously all horizontal combs	0 mn 30 s	7 mn	Cruds collection system	
B - Push the tray loaded with one horizontal row of 15 fuel rods (about 2 feet stroke) stop.				
C - Slip the tray beneath the table, laying the fuel rods one the table stop. Operations "b" and "c" have to be repeated 30 times to reconfigure one PWR fuel element: . 15 times to push and eclipse the tray . 15 times to reload the tray				
Total "b" : 30 x 30 sec.-	15 mn	210 mn		
Total "c" : 30 x 10 sec.-	5 mn	70 mn		
D - Push the 15 fuels rods simultaneously to reconfigurate half a square section (one fuel assembly) into reconfiration mold i.e. : 11 horizontal rows of 19 fuel rods stroke about 10 inches				
.. Repeat 11 times function "d" (11 x 10 seconds)	2mn (rounded	28 mn		
SUB-TOTAL :	22 mn 30 s	315 mn		

RECONFIGURATION DEVICE

ITEMS : 04-3 - Transition canister structural frame
04-4 - Reconfiguration molds with incremental drive mechanism

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X	OPERATING TIME FOR SUB-SEQUENCE	OPERATING TIME PER DAY	SUPPORTS	NOMINAL POWER
Characteristics :					
Item 04-3 U Shaped structure common to all reconfiguration patterns includes a movable blade to support the fuel rods				Electric power and control	1.5 KW
Item 04-4 Specific reconfiguration molds moving down incrementally in the structure. Each mold is adapted to the geometric section of the packaging canister and to the characteristics of fuel assembly				Specific automatic programm	
Drive mechanism : 2 metric tons capacity controlled from an automatic programm twenty-two steps has been considered as an average to reconfigure two fuel element in one canister (or 4 BWR) i.e. : 11 steps for one fuel element					
Functions : continuing function "d" of sheet 04-2					
A - Rotate the horizontal blade supporting the fuel rods row					
B - Repeat function "A" 11 times CW and 11 times CCW 22 x 15 sec. = 330 sec.		7mn(rounded)	98 mn		
SUB-TOTAL :		7 mn	98 mn		

RECONFIGURATION DEVICE

ITEMS : 04-3 - Reconfiguration module structural frame
04-4 - Reconfiguration molds with incremental drive mechanism

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X	OPERATING TIME		SUPPORTS	NOMINAL POWER
		FOR SUB-SEQUENCE	PER DAY		
Characteristics :				Electric power and control	
See sheet 04-3					
Functions : Continuing function "a" of sheet 04-3				Specific automatic programm	
A - Move one step down the reconfiguration mold stop					
- Repeat 11 times operation B at one foot per minute speed (one step = 1 inche)					
11 x 5 sec. = 55 sec. + margin		1 mn 30 (rounded)	21 mn		
The rod reconfiguration sequence ends by returning the pusher and the tray on initial position waiting for a second fuel assembly PWR 15 x 15		0 mn 30 s	7 mn		
SUB-TOTAL		2 mn	28 mn		

TOTAL TIME FOR ROD RECONFIGURATION SEQUENCE : SHEETS 04-2 to 04-4 = 7 mn + 22 mn 30 s + 2 mn = 31 mn 30 s

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X	OPERATING TIME FOR SUB-SEQUENCE	OPERATING TIME PER DAY	SUPPORTS	NOMINAL POWER
Characteristics : includes				Pushing heads specific to canister secion	
Item 05-1 : Consolidation fuel rods pushing device					
Force :0.5 metric ton				Electric power and control	
Speed : 6 feet per minute					
Stroke : about 16 feet					

MAIN CHARACTERISTICS AND FUNCTIONS IN THE DAILY PROCESS SEQUENCE	X OPERATING TIME FOR SUB-SEQUENCE	OPERATING TIME PER DAY	SUPPORTS	NOMINAL POWER
Characteristics : See sheet 05-1				
Functions : Continuing "B" of sheet 05-1				
C - Push all the fuel rods from two PWR or four BWR fuel elements from transition canister into packaging canister	3 mn 30 s	24 mn 30 s		
D - Return the pusher back to initial position	3 mn 30 s	24 mn 30 s		
TOTAL FOR THE SEQUENCE : (X including 25 % margin)	7 mn	49 mn		

NOTE : Packaging into an hexagonal or round canister is performed in two phases :

- . a-b : identic to sheet 05-1 function
- . c : push all the rods one PWR or two BWR fuel element from transition canister packaging canister
- . c' : rotate the canister by 180°
- . c" : repeat operation "c"
- . d-e : identics to "d" and "e" above

APPENDIX V

RELIABILITY AND AVAILABILITY ANALYSIS

INTRODUCTION

This Appendix describes the Phase I determination of reliability of the Rod Consolidation System as required in the task description of the project activity. The work was carried out to show with 75% confidence that the system can complete consolidation of 750 MTHM of spent fuel (60% BWR - 40% BWR) in a 260-day working year at two 8-hour shifts/day. A simulation model of the key operations was constructed. The model is flexible to allow increasing sophistication as the design details mature. It may be used in Phase II with very little modification.

Approach

The analysis was carried out in two iterations recognizing that many design features were being developed concurrently. A preliminary set of simulation experiments (Series A) was performed after the initial Requirements Analysis meeting on August 25. These results were documented and distributed to the design and evaluation team. Subsequently, after a system design review at SGN (France) was completed in early October, a second set of simulation experiments (Series B) was performed. The model was modified for Series B to reflect primarily changes in the method of introducing spent fuel to the consolidation cell and to more closely mimic the designated time sequences of the various operating equipment. In each series, the simulation parameters were systematically altered to determine their impact on the overall throughput performance.

Series A simulations were performed in 15-minute time intervals. Series B simulations were performed in 5-minute time intervals. Because the PC computer software was limited to 32500-time steps, one year of operating time could not be achieved at the 5-minute intervals. The throughput period was reduced to 6 months of operations and the simulations were replicated up to 10 times to give a cumulative run time of 5 years. The transient period for startup and shutdowns occurs in less than one day; therefore, this method of simulation is adequate.

Methodology

The model used the SIMAN* software system which is designed for the IBM PC. A typical simulation run required approximately five minutes of computer time. The model was structured using the instructions provided in the software manual. Figure 1(a) shows a schematic of the model used for Series A and Figure 1(b) shows a schematic used for Series B. The corresponding rules for Series A and B are shown in Table 1. The parameter settings are listed in Tables 2, 3a and 3b for Series A and B. The operating parameters and results are listed in Tables 4(a) and 4(b) for each series.

Series A begins with a set of experiments where the equipment operates under ideal conditions. Various operating conditions are systematically changed to understand their impact on the annual throughput. Performance is measured as the time it takes to process an assigned tonnage of spent fuel (see last column of Tables 4(a) and 4(b)). In subsequent experiments, the equipment is allowed to encounter delays in a random manner using a probability distribution discussed in more detail later. These delays lengthen the time to process fuel. The objective is to establish availability limits below which the system cannot meet the throughput requirement.

Series B follows the same pattern as Series A, except some experiments were replicated to obtain a good statistical perspective.

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*SIMAN is a product of Systems Modelling Corporation Alden Square, P.O. Box 10074, State College, Pennsylvania 16805-0074, Version 3.0 was used in this study under license to GE.

RESULTS

The results and interpretations for Series A and Series B are discussed separately. Some general conclusions derived from Series A are carried through in the interpretation of results from Series B. The input parameters and the results are listed in Tables 4(a) and 4(b). The input parameters for each experiment are defined in Table 2. Each simulation experiment measured the utilization of the In-Cell Crane, the Table disassembly function and the Canister Closure function. The number of failed assemblies encountered and the residence time of the assembly in the cell were measured also. The principal performance measure was the elapsed time to process a given tonnage of spent fuel.

Series A Results

Experiments 1-5 were run under ideal operating conditions. It was noted that each failure encountered added one day to the process time (Exp. 1 versus Exp. 3). Systematically increasing the failure probability from .001 to .003 (Expts. 2 versus 3 and 4) produced more failures but in a random manner, indicating more replications would be required to achieve the average expected value.

Increasing the campaign length from 20 baskets (Exp. 1) to 40 baskets (Exp. 5) decreased the process time by 10 days as expected. The number of campaigns were reduced from about 21 to 12 and since a one-day of retooling time is required between campaigns, the expected impact would be about nine days.

The use of two in-cell cranes (Exp. 2) instead of one in-cell crane (Exp. 1) reduced the process time by 53.5 days. This results showed the importance of the crane to the operation. One crane was utilized 77% of the time which meant that the other functions were often waiting for the crane. This finding highlighted the need to provide for two in-cell cranes or to reduce the number of crane transfers in-cell. Experiment 15 was run to determine the effect of the release condition on the Table disassembly function. Experiment 15 did not allow the table to be released until the skeleton was delivered by the crane to Station 5. This condition would add a 15-minute delay before release of the table. All other experiments released the table as soon as the crane was available for skeleton removal. The extended release condition (Exp. 15 versus Exp. 2) caused a 41.3-day increase in the process time. It was concluded that the reference design condition would be that the table is available almost immediately after engagement of the skeleton to the crane. The majority of the 15-minute travel time of the crane with the skeleton would be associated with movement and disengagement of Station 5.

Experiment 16 was run to determine if an added delay operation for rod reconfiguration after the rod-pulling function would impact on the process time. The delay was 3/4 hours, but it would be occurring while the table is being reloaded with a second assembly. A second assembly would not need the rod configuration function for 3/4-hour; therefore, no extra time delay was expected under ideal conditions. Comparison of Exp. 16 with Exp. 2 shows no impact. This feature was subsequently incorporated in the design of Series B experiments.

Experiments 6-14 were run under non-ideal conditions. Each of three equipment functions were allowed to have extended delay periods (outage) simulating various breakdown conditions.

In structuring the availability of the equipment, four discrete time periods were selected each with a random probability of occurrence as shown in Table 3(a). The first time period represents the normal operating time of the function. The second time period represents a a low productivity period where the characteristics of the assembly require delays in the function. The third period represents a longer outage delay for minor repairs to the equipment and the last period represents a major outage. The frequency of occurrence is expected to decrease with length of delay or outage. In Table 3(a), the end-cutting and rod-pulling functions are assumed to have the same probabilities, the closure function has the same probabilities, but the time periods are almost double the other functions. A set of experiments were run to determine a range of probability distributions which could meet the target process time of 260 days. These distributions are designed in Table 3(a) as the reference (Exps. 8 and 9), degraded Level 1 (Exp. 11) and degraded Level 2

(Exp. 10). These designations changed only the length of outage delay for the fourth time period and ranged from 64-time steps (ref) to 320 (deg 2) for the end-cutting and rod-pulling functions, and similarly from 63 to 640-time steps for the canister closure function.

The overall availability is the quotient of the product of the normal operating time and its probability and the sums of the products of all delay times and their probabilities. The respective availabilities for the reference case (1, 2, 3, 4A) is 68%, the degraded Level 1 case (1, 2, 3, 4B) is 58.7% and the degraded Level 2 case (1, 2, 3, 4C) is 34%. Each of these availabilities is assigned to the three functions shown in Table 3(a).

Experiments 6 and 7 were run at a special set of conditions where the third delay period probability was interchanged with the fourth delay period probability. These conditions are shown in separate columns of Table 3(a). Experiment 6 used the Series 1, 2, 3, 4C and Experiment 7 used 1, 2, 3, 4A. Experiment 6 processed only about 55% of the throughput in the year clearly an inadequate set of conditions. Experiment 7 achieved the designed throughput in 264 days slightly in excess of the 260-day target. Experiment 8 which used the probability series (1, 2, 3, 4A) achieved the desired throughput in 251 days. Hereafter, this run will be referred to the reference experiment and the probability series will be defined as the reference probability set.

The remainder of the experiments were run to trade off the benefit of having two in-cell cranes against various levels of degraded probability distributions. Comparing Experiment 8 (one crane) and 9 (two cranes), for the same reference probability set, the throughput is decreased by 43 days. Invoking the Level 2 degraded probability distribution shown in Table 3 with two in-cell cranes raises the throughput time beyond 260 days to an estimated 276 days. Invoking the Level 1 degraded probability distribution (Experiment 11) reduces the throughput time to 233 days, well within the target. The tolerable level for a degraded distribution is between Level 1 and Level 2.

The results indicate that a major outage can occur at 0.25% probability and last about four days without jeopardizing the throughput target. These findings form the basis for defining the tolerable reliability and recovery procedures for major repairs of the three functions in the rod consolidation system.

Experiments 12, 13 and 14 show the effect of redistributing the outage probability distribution relative to the reference probability set (Experiment 8). The reference probability set has a mean availability of 68%. If the probability is redistributed to include just one time element of the distribution at the same overall availability, then the probability sets shown in Table 5 are generated.

The results from Series A experiments may be summarized as follows:

One in-cell crane is adequate provided the availabilities of the three operating functions are around 68%. With one in-cell crane, the long outage events require careful analysis and judicious use of modularization to keep downtimes below one day. With two in-cell cranes, the availabilities could drop to about 35% where there is less concern about the recovery time for major repairs.

Series B Results

For Series B, the simulation model was updated to the latest design iteration. This model is shown in Figure 1(b). In relation to Series A, the building crane transfer function was assigned to in-cell Crane #1, but transfers from Station 1 to Station 2 would occur only during the third shift. During the first and second shift, in-cell Crane #1 would perform all other station transfers as shown, except for canister transfers from Station 6 to Station 7. In-cell Crane #2 was required to perform this transfer due to an isolation wall to prevent cross-contamination of the canister packaging station from the other stations.

The rod reconfiguration function was added to the model which linked the table function and the canister packaging station. This function, as shown, provides the transitioning to the canister and requires a delay period, which is nominally shorter than time of arrival of the next assembly for reconfiguration.

Station 1 was modified to be an external interface for incoming spent fuel assemblies and outgoing skeleton canisters. In-cell Crane #1 transferred out a skeleton canister every 12 assemblies. The incoming spent fuel was assumed to be as a basket containing four PWR and eight BWR assemblies. For purposes of the simulation, it is immaterial how the assemblies are grouped on arrival since it is assumed that they are always available when the in-cell Crane #1 is available during the third shift. For purposes of this analysis, the transfer media is named a basket.

Station 2 has been redesigned as in-cell storage. This station queves individual assemblies as they arrive from Station 1. Inspection of the simulation experiments showed that the 15 minutes transfer time from Station 1 to Station 2 was sufficient to keep up with the withdrawals from Station 2.

The simulation model was reset to perform transactions on a five-minute time step using a 24-hour day interval instead of a 16-hour day as in Series A. Processing was done during the first two shifts, except for the first and last hour. One year requires 74880 time steps. Since the software system for the PC computer was limited to 32500 time steps, the simulation was performed at one-half the annual throughput (375 MTHM). To establish a statistical base, some experiments were replicated up to ten times producing an equivalent of five years of output. The campaign period was adjusted from 20 baskets in Series A to 16 baskets to match more closely a typical reload quantity (25 - 30 MTHM) coming from a given reactor. Each campaign involves assemblies with about the same history.

The results are shown in Table 4(b). Nine experiments were run. Experiments 4, 8 and 9 were replicated ten times and average of the replications are shown at the bottom. Experiment 3 was replicated three times and is a repeat of Experiment 2. Note that the first replication of Experiment 3 (3.1) reproduces the data from Experiment 2. Each random number is generated from a separate feed. Thus, repeat replications have the same random number sequence (Experiment 2 and Experiment 3.1). The process time for 375 MTHM is shown in the last column. The target throughput requirement than is 130 days. All values shown for Series B are less than 130 days.

Experiments 1-3 were run under ideal conditions. Experiment 1 used shorter recovery times from a failure event and shorter retooling times compared to Experiment 2. The impact on the processing time was 5.0 days as expected (5.5 days for retooling time and -0.5 day for an extra failure event). From these experiments, it is evident that in-cell #1 has the highest utility, and; therefore, will probably control the throughput.

Experiment 4 was replicated using the reference probability delays for the four equipment operations shown in Table 3(b). Table 3(b) has been reformatted from Table 3(a) to show the cumulative probabilities for each of the four time periods for delay instead of the discrete probabilities as shown in Table 3(a). Also shown are the availabilities associated with a given probability set. Also shown is the availability of in-cell Crane #1 which is assumed as unity for Experiment 4. Comparison of Experiment 3 with 4 shows a drop in utilization of Crane #1 due to the increased downtime of the Table function. In-cell Crane #1 remains as the controlling item, however. In addition, Experiments 5, 6 and 7 the availability of the four equipment functions was increased above the reference values of Experiment 4 by 5%. In each case, there was no decrease in processing time relative to Experiment 4. Experiment 5 actually increased by 0.5 days due to an extra failure. This indicates that in-cell Crane #1 is limiting.

In Experiment 8 in-cell Crane #1 was assigned a mean downtime frequency of 0.001/time step requiring 96 (eight-hour) time steps for recovery. The processing time increased from Experiment 4 to 4.5 days, an indication that the in-cell crane is the limiting equipment item.

Experiment 9 was run with modified failure probability. It is recognized that the crud build-up and hypridine are associated with specific reloads and reactors. These occurrences may result in higher failure events during rod consolidation. Instead of the random failure probability used in other experiments, the failure rate was adjusted to identify 20% of the BWR reload campaigns as suspect, having 10 times the failure rate of all other assemblies. This modification in failure rate would about double the number of failure events. The impact on process time was minor as other fluctuations between Experiments 8 and 9 offset the one-day impact expected.

The process time for Experiments 4, 8 and 9 are well below the target of 130 days. The standard deviations are about two days except for a very unusual occurrence in the fourth replication of Experiment 4 when a large number of outages occurred in a cluster. From the results, it can be concluded that if the four equipment operations and the in-cell crane perform at their designated availability, the total system will meet the throughput target of 750 MT in 184.4 + 4.2 days with 83% confidence. The system can tolerate lower equipment availabilities with about a 60-day margin.

The simulation also computed the residence time from the moment a basket was brought to Station 1 until an assembly from that basket was sealed in the canister. The range of times are shown in the next to the last column of Tables 4(a) and 4(b). The minimum times for Series A are about 2.5 hours which represented the residence time from Station 2 to Station 6. The minimum times for Series B are about 12 hours which included at least eight hours wait before the first assembly was processed on the next shift.

CONCLUSIONS

1. Rod Consolidation System Process Time for 750 MTHM is <188.4 days with 83% confidence (includes 1]).

2. The calculated process time is based on the premise that the availability of equipment functions are:

End-Cutting Function	65.2%
Rod-Pull Function	65.2%
Rod Reconfiguration Function	84%
Canister Closure Function	71%
In-Cell Crane #1	90.4%

3. The process time also is based on the premise that the failure probabilities are <.002 of the spent fuel assemblies processed (└5.2/year) and that the spent fuel is always available on demand.

4. The margin of 71.6 days allows for further decreases in availability of four equipment functions and in-cell Crane #1.

5. The principal equipment item pacing the throughput based on the above premise is in-cell Crane #1.

Table 1

Rules Used for Simulation

1. Basket containing PWR/BWR type fuel is brought into the cell to Station 2 storage in third shift only.

2. Assembly cannot be removed from basket in-cell (Station 2) until Table Disassembly (Station 3) is free.

3. Table Disassembly (Station 3) is not released until skeleton is removed. Table is released as soon as in-cell crane arrives (except for Series A Expt. #15).

4. If a failed assembly is encountered, the Table Disassembly is not released until the recovery time from failure has elapsed.

5. The in-cell Crane #1 has the following priorities for transfer.

   1 = Station 3 to Station (Shifts 1 & 2) and Station 1 to 2 (Shift 3)
   2 = Station 2 to Station 3
   3 = Station 5 to Station 1

   The in-cell cranes in use at a priority request complete their transfer before responding to the new request.

6. Processing of a spent fuel assembly cannot begin in the first hour of the first shift and at the last hour of the second shift. Assemblies in process are continued during these time periods.

7. Baskets of one type of fuel are selected until a preset number of baskets have been processed, thereafter the system is retooled for the second type of fuel. A fixed delay time is allowed for retooling.

8. a) The simulation model processes a set number of baskets equivalent to the annual throughput of 750 MTHM and stops after all baskets are processed.

Table 1

Rules Used for Simulation

(Continued)

b) For Series B experiments which used shorter time intervals, the computer capacity was limited to 32500 steps and the equivalent throughput reduced to 375 MTHM. Additional replications were run to obtain a cumulative operating period of several years.

9. a) Each basket contains four PWR or nine BWR assemblies. Each canister contains two PWR or four BWR assemblies. The product of the campaign length (number of baskets) and number of assemblies in a basket must be multiples of the number of assemblies per canister, to prevent partially filled canisters.

b) For Series B, due to computer limit involved in 8b, the BWR basket was reduced to eight assemblies and the number of baskets was increased to maintain the 60%/40% split between PWR and BWR tonnage processed.

Table 2

Parameters Used in the Simulation Model

A. Operating Schedule

1. Two shifts, five day, 52 weeks/year = 260 day/year.

2. Unit time step = 1/4 hour; 16640 time steps/year (Series B Unit time step = 5 minutes, 74880 time steps/year.

3. First hour and last hour of each day, no processing is started.

4. Series B Third Shift is used to fill in-cell storage assemblies to be consolidated.

B. Normal Delay Times

1. Crane travel time between stations is one time step (1/4 hour). If crane is not already at the requesting location, then one time step is added. (Applies to the building crane and the in-cell crane).

2. End-cutting time at Station 3 is one time step 1/4 hour: Series B two time steps (10 minutes).

3. Rod-pulling time at Station 3 is one time step 1/4 hour: Series B two time steps (10 minutes).

4. (Series B) Reconfiguration time is 40 minutes; however, it is not limiting unless delayed.

5. Canister closure at Station 6 is two time steps 1/2 hour: Series B four time steps (20 minutes).

6. Occurrence of a failed assembly at Station 4 requires 64 time steps (one day) [Series B: (16 hours = one processing day)] for recovery. Probability of a failed assembly: 0.001, 0.002 or 0.003.

Table 2

Parameters Used in the Simulation Model

(Continued)

7. Occurrence of a retooling event requires 64 time steps (one day) before processing begins. [Series B: 16 hours = one processing day.]

C. Quantities

	Series A	Series B
1. Number of in-cell cranes:	1 or 2	[Two discrete cranes]
2. Number of building cranes:	1	[None]
3. Number of PWR baskets:	244	122
4. Number of BWR baskets:	180	102
5. Number of PWR assemblies/basket:	4	4
6. Number of BWR assemblies/basket:	9	8
7. Number of PWR assemblies/canister:	2	2
8. Number of BWR assemblies/canister:	4	4
9. Number of skeletons/canisters:	12	12
10. Number of basket/campaign:	20 or 40	16 (one reload qty.)
11. MTHM in a PWR assembly:	0.461	.461
12. MTHM in a BWR assembly:	0.185	.181

D. Probability of Encountering a Process Delay

Series A (see Table 3a)

Series B (see Table 3b0

Table 3(a)

Probability of Delays for Key Function

Series A

Symbol in Table 4	Time Period	End-Cutting or Rod-Pulling Function Outage Time Step	Prob	Special Condition	Canister Closure Function Outage Time Step	Prob	Special Condition
	1	1	.097	(.975)	2	.975	(.975)
	2	4	.015	(.015)	8	0.015	(.015)
	3	32	.0075	(.0025)	64	0.0075	(.0025)
Ref	4A Expts 8,9	64	.0025	(.0075)	64	0.0025	(.0075)
(Deg)(1)	4B Exp 11	160	.0025	(.0075)	320	0.0025	(.0075)
(Deg)(2)	4C Exp 10	320	.0025	(.0075)	640	0.0025	(.0075)
					Expts 6 & 7		

Table 3(b)

PROBABILITY DELAY OF OPERATION LESS THAN INDICATED TIME STEP
SERIES B
(ONE STEP = 5 minutes)

EIP No.	END-CUT & ROD-PULL 2	12	96	192	avail	RECONFIGURATION 8	16	96	192	avail	CANISTER 4	24	96	192	avail	IN-CELL CRANE 01 0	96	-	-	avail	FAILED FUEL ENCOUNTERS prob of occurence	ELAPSED TIME TO PROCESS 375 MTHM days
1	1.0000	1.0000	1.0000	1.0000	1.00	1.0000	1.0000	1.0000	1.0000	1.00	1.0000	1.0000	1.0000	1.0000	1.00	1.0000	1.0000			1.00	0.0010 BWR&PWR	72.4
2	1.0000	1.0000	1.0000	1.0000	1.00	1.0000	1.0000	1.0000	1.0000	1.00	1.0000	1.0000	1.0000	1.0000	1.00	1.0000	1.0000			1.00	0.0010 BWR&PWR	77.4
3	1.0000	1.0000	1.0000	1.0000	1.00	1.0000	1.0000	1.0000	1.0000	1.00	1.0000	1.0000	1.0000	1.0000	1.00	1.0000	1.0000			1.00	0.0010 BWR&PWR	78.0
4	0.9780	0.9930	0.9980	1.0000	0.65	0.9750	0.9900	0.9975	1.0000	0.84	0.9750	0.9900	0.9975	1.0000	0.71	1.0000	1.0000			1.00	0.0010 BWR&PWR	87.7
5	0.9800	0.9950	0.9982	1.0000	0.70	0.9750	0.9900	0.9975	1.0000	0.84	0.9750	0.9900	0.9975	1.0000	0.71	1.0000	1.0000			1.00	0.0010 BWR&PWR	87.4
6	0.9780	0.9930	0.9980	1.0000	0.65	0.9800	0.9950	0.9978	1.0000	0.89	0.9750	0.9900	0.9975	1.0000	0.71	1.0000	1.0000			1.00	0.0010 BWR&PWR	86.9
7	0.9780	0.9930	0.9980	1.0000	0.65	0.9750	0.9900	0.9975	1.0000	0.84	0.9790	0.9940	0.9970	1.0000	0.76	1.0000	1.0000			1.00	0.0010 BWR&PWR	86.9
8	0.9780	0.9930	0.9980	1.0000	0.65	0.9750	0.9900	0.9975	1.0000	0.84	0.9750	0.9900	0.9975	1.0000	0.71	0.9990	1.0000			0.90	0.0010 BWR&PWR	92.2
9	0.9780	0.9930	0.9980	1.0000	0.65	0.9750	0.9900	0.9975	1.0000	0.84	0.9750	0.9900	0.9975	1.0000	0.71	0.9990	1.0000			0.90	BWR:20%=.01,80%=.001 PWR:100%=.001	92.1

TABLE 4(a)

SIMULATION EXPERIMENTS: SUMMARY and RESULTS
SERIES A

EXPMT No.	CAMPAIGN LENGTH No. of BASKETS	IN-CELL CRANE No.	VEL	UTIL	FAILURE EVENTS PROB	DELAY days	No.	TABLE FUNCTIONS END-CUT hrs	ROD-PULL hrs	UTIL frac	CLOSURE FUNCTION hrs	utility frac	RETOOL DELAY days	TIME IN SYSTEM hours min	avg	max	ELAPSED TIME TO PROCESS 750 MTHM days
1	20	1	1.0	0.77	0.001	1	4	0.25	0.25	0.63	0.50	0.13	1	3.00	9.50	46.00	222.2
2	20	2	1.0	0.48	0.001	1	4	0.25	0.25	0.58	0.50	0.17	1	2.50	7.20	43.75	168.7
3	20	1	1.0	0.76	0.002	1	6	0.25	0.25	0.63	0.50	0.12	1	3.00	9.50	46.00	224.2
4	20	1	1.0	0.76	0.003	1	6	0.25	0.25	0.63	0.50	0.12	1	2.50	9.50	46.00	224.2
5	40	1	1.0	0.81	0.001	1	3	0.25	0.25	0.67	0.50	0.13	1	3.00	9.63	37.00	212.7
6	20	1	1.0	0.39	0.001	1	2	spec	spec	0.84	spec	0.10	1	3.00	27.50	172.00	>265.2
7	20	1	1.0	0.66	0.001	1	4	spec	spec	0.72	spec	0.12	1	3.00	12.25	48.00	264.4
8	20	1	1.0	0.69	0.001	1	2	ref	ref	0.71	ref	0.13	1	3.00	11.65	49.25	250.7
9	20	2	1.0	0.39	0.001	1	6	ref	ref	0.66	ref	0.15	1	2.50	9.00	45.75	207.6
10	20	2	1.0	0.29	0.001	1	3	deg2	deg2	0.74	deg2	0.11	1	2.50	12.25	109.75	est'd 282.3
11	20	2	1.0	0.35	0.001	1	4	deg1	deg1	0.69	deg1	0.14	1	2.50	10.25	69.25	232.6
12	20	2	1.0	0.40	0.001	1	2	al14	al14	0.62	al18	0.19	1	2.50	8.33	34.50	191.7
13	20	2	1.0	0.40	0.001	1	2	al132	al132	0.65	al164	0.17	1	2.50	9.00	34.00	199.0
14	20	2	1.0	0.35	0.001	1	4	al320	al320	0.70	al640	0.12	1	2.50	10.00	106.00	232.3
15	20	2	1.0	0.37	0.001	1	3	0.25	0.25	0.64	0.50	0.13	1	2.75	8.50	32.50	210.0
16	20	2	1.0	0.48	0.001	1	4	0.25	0.25	0.58	0.50	0.17	1	2.50	7.25	43.75	168.

TABLE 4(b)

SIMULATION EXPERIMENTS: SUMMARY and RESULTS
SERIES B

EXPMT No.	CAMPAIGN LENGTH No. of BASKETS	IN-CELL CRANES UTIL #1	UTIL #2	TIME vel=1.0 min	FAILURE EVENTS PROB	DELAY hrs	No.	TABLE FUNCTIONS END-CUT min	ROD-PULL min	CON-FIGR min	UTIL frac	CLOSURE FUNCTION min	utility frac	RETOOL DELAY hrs	TIME IN SYSTEM hours min	avg	max	ELAPSED TIME TO PROCESS 375 MTHM days
1	16	0.97	0.13	15	0.001	5	1	10	10	40	0.84	20	0.09	5	11.92	117.58	204.83	72.4
2	16	0.91	0.12	15	0.001	16	0	10	10	40	0.79	20	0.08	16	11.92	116.25	228.17	77.4
3.1	16	0.91	0.12	15	0.001	16	0	10	10	40	0.79	20	0.08	16	11.92	116.25	228.17	77.4
3.2	16	0.89	0.12	15	0.001	16	2	10	10	40	0.75	20	0.08	16	11.92	183.00	308.75	79.2
3.3	16	0.91	0.12	15	0.001	16	2	10	10	40	0.77	20	0.08	16	11.92	128.25	206.42	77.3
R 4.1	16	0.82	0.11	15	0.001	16	0	ref	ref	ref	0.81	ref	0.11	16	11.92	278.25	445.33	86.9
E 4.2	16	0.85	0.11	15	0.001	16	1	ref	ref	ref	0.77	ref	0.11	16	11.92	202.83	353.83	84.7
P 4.3	16	0.85	0.11	15	0.001	16	0	ref	ref	ref	0.80	ref	0.11	16	11.92	259.58	442.17	85.5
L 4.4	16	0.64	0.08	15	0.001	16	0	ref	ref	ref	0.59	ref	0.08	16	11.92	238.50	412.67	111.5
I 4.5	16	0.85	0.11	15	0.001	16	1	ref	ref	ref	0.79	ref	0.12	16	12.08	291.75	472.33	84.8
C 4.6	16	0.87	0.11	15	0.001	16	0	ref	ref	ref	0.78	ref	0.10	16	12.83	226.08	390.17	82.5
A 4.7	16	0.84	0.11	15	0.001	16	2	ref	ref	ref	0.80	ref	0.11	16	12.92	249.00	441.58	85.6
T 4.8	16	0.85	0.11	15	0.001	16	0	ref	ref	ref	0.79	ref	0.08	16	11.92	243.92	412.08	84.3
E 4.9	16	0.84	0.11	15	0.001	16	1	ref	ref	ref	0.79	ref	0.09	16	11.92	210.83	395.25	85.2
S 4.10	16	0.84	0.11	15	0.001	16	2	ref	ref	ref	0.81	ref	0.11	16	12.08	247.75	398.42	85.5
AVG of 4		0.83	0.11				0.70				0.77		0.10		12.14	244.85	416.38	87.7+/-8.0
5	16	0.82	0.11	15	0.001	16	1	ref+5	ref+5	ref	0.82	ref	0.10	16	11.92	277.42	430.00	87.4
6	16	0.82	0.11	15	0.001	16	0	ref	ref	ref+5	0.81	ref	0.11	16	11.92	278.25	439.92	86.9
7	16	0.82	0.11	15	0.001	16	0	ref	ref	ref	0.81	ref+5	0.10	16	11.92	278.17	445.33	86.9
R 8.1	16	0.76	0.10	15	0.001	16	3	ref	ref	ref	0.79	ref	0.10	16	12.58	306.00	480.58	94.4
E 8.2	16	0.78	0.10	15	0.001	16	5	ref	ref	ref	0.79	ref	0.10	16	11.83	270.00	534.08	91.8
P 8.3	16	0.76	0.10	15	0.001	16	2	ref	ref	ref	0.79	ref	0.10	16	12.08	410.08	492.50	94.8
L 8.4	16	0.80	0.10	15	0.001	16	1	ref	ref	ref	0.78	ref	0.10	16	12.08	212.50	396.67	88.8
I 8.5	16	0.78	0.10	15	0.001	16	2	ref	ref	ref	0.77	ref	0.11	16	6.08	394.42	583.67	92.5
C 8.6	16	0.80	0.10	15	0.001	16	2	ref	ref	ref	0.79	ref	0.09	16	12.08	252.50	392.17	89.6
A 8.7	16	0.80	0.10	15	0.001	16	1	ref	ref	ref	0.82	ref	0.10	16	13.08	277.83	428.83	90.4
T 8.8	16	0.77	0.10	15	0.001	16	0	ref	ref	ref	0.79	ref	0.08	16	11.92	280.75	440.92	93.3
E 8.9	16	0.77	0.10	15	0.001	16	3	ref	ref	ref	0.80	ref	0.09	16	11.92	335.08	509.08	93.5
S 8.10	16	0.77	0.10	15	0.001	16	0	ref	ref	ref	0.82	ref	0.10	16	12.08	254.67	475.75	92.5
AVG of 8		0.78	0.10				1.90				0.79		0.10		11.58	299.38	473.43	92.2+/-1.9
R 9.1	16	0.76	0.10	15	0.001	16	3	ref	ref	ref	0.79	ref	0.10	16	12.58	306.00	480.58	94.4
E 9.2	16	0.76	0.10	15	0.001	16	5	ref	ref	ref	0.79	ref	0.10	16	11.83	296.75	534.08	93.9
P 9.3	16	0.78	0.10	15	0.001	16	1	ref	ref	ref	0.80	ref	0.10	16	12.08	299.58	492.50	91.7
L 9.4	16	0.82	0.10	15	0.001	16	1	ref	ref	ref	0.79	ref	0.11	16	12.08	230.67	396.67	87.8
I 9.5	16	0.76	0.10	15	0.001	16	4	ref	ref	ref	0.76	ref	0.10	16	6.50	357.33	583.67	94.7
C 9.6	16	0.80	0.10	15	0.001	16	4	ref	ref	ref	0.83	ref	0.09	16	12.08	239.50	392.17	89.5
A 9.7	16	0.80	0.10	15	0.001	16	3	ref	ref	ref	0.84	ref	0.10	16	13.08	239.33	428.83	90.6
T 9.8	16	0.78	0.10	15	0.001	16	3	ref	ref	ref	0.80	ref	0.08	16	11.92	232.67	440.92	92.4
E 9.9	16	0.77	0.10	15	0.001	16	2	ref	ref	ref	0.79	ref	0.09	16	11.92	[illegible]	509.08	93.2
S 9.10	16	0.78	0.10	15	0.001	16	2	ref	ref	ref	0.83	ref	0.10	16	12.08	291.58	475.75	92.5
S of 9		0.78	0.10				2.80				0.80		0.10		11.62	277.97	473.43	92.1+/-2.1

Table 5

Effect Probability Outage Distributions on

Throughput Time at a Fixed Overall Availability

Series A

Throughput Times (days)		Uptimes - Outage Times 1/2	4/8	32/64	64	320/640	Availability
251	Reference set (Experiment 8)	.975	.015	.0075	.0025	NA	.679
192	All 4 (Experiment 12)	.855	.145	--	--	NA	.679
199	All 32 (Experiment 13)	.9860	--	.014	--	NA	.687
232	All 320 (Experiment 14)	.9986	--	--	--	.0014	.090

SIMULATED ROD CONSOLIDATION SYSTEM
SERIES A

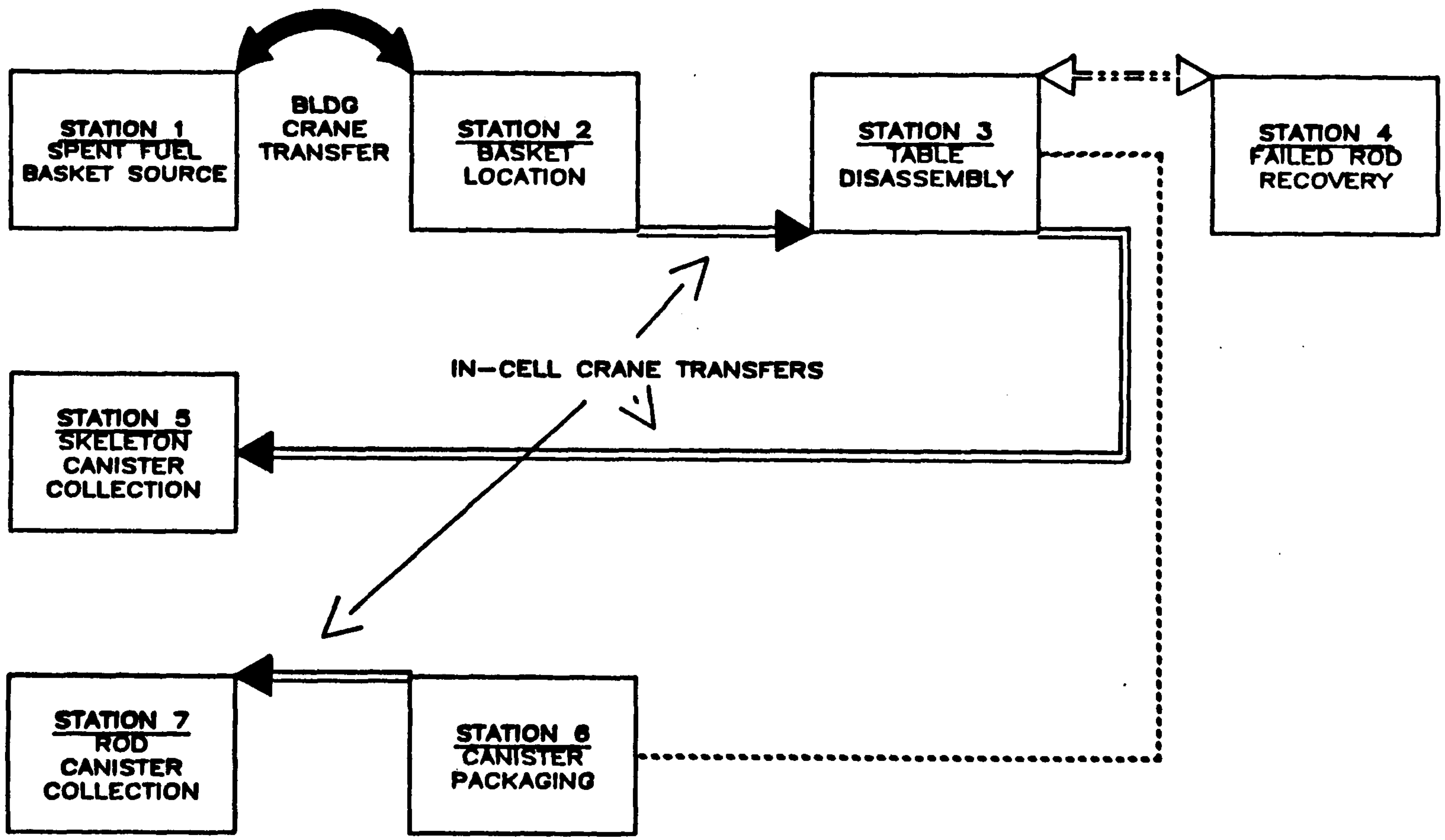

FIGURE 1(a)

Figure 1(a). Simulated Rod Consolidation System (Series A)

SIMULATED
ROD CONSOLIDATION SYSTEM
SERIES B

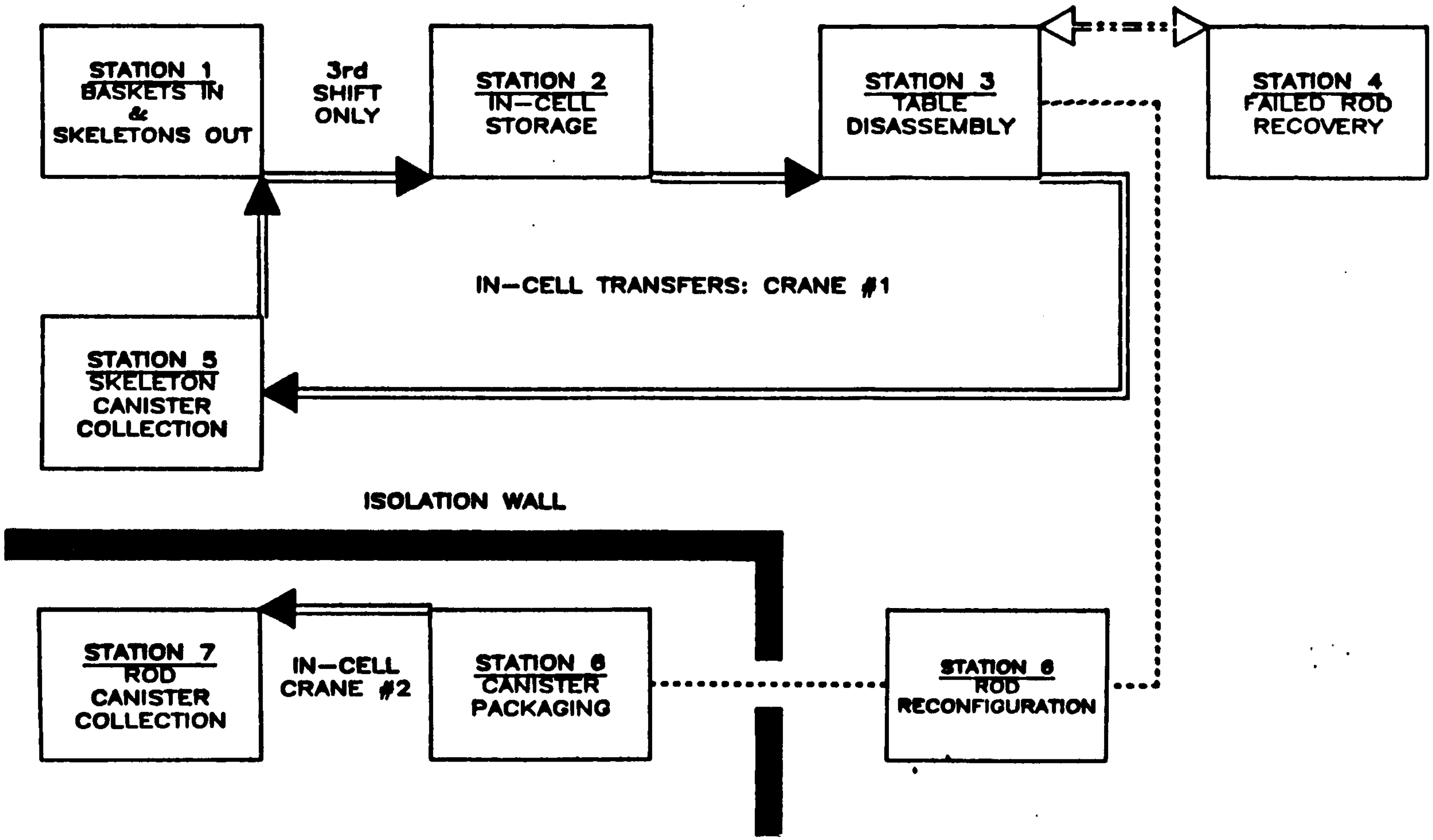

FIGURE 1

Figure 1(b). Simulated Rod Consolidation System (Series B)

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