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May 1979

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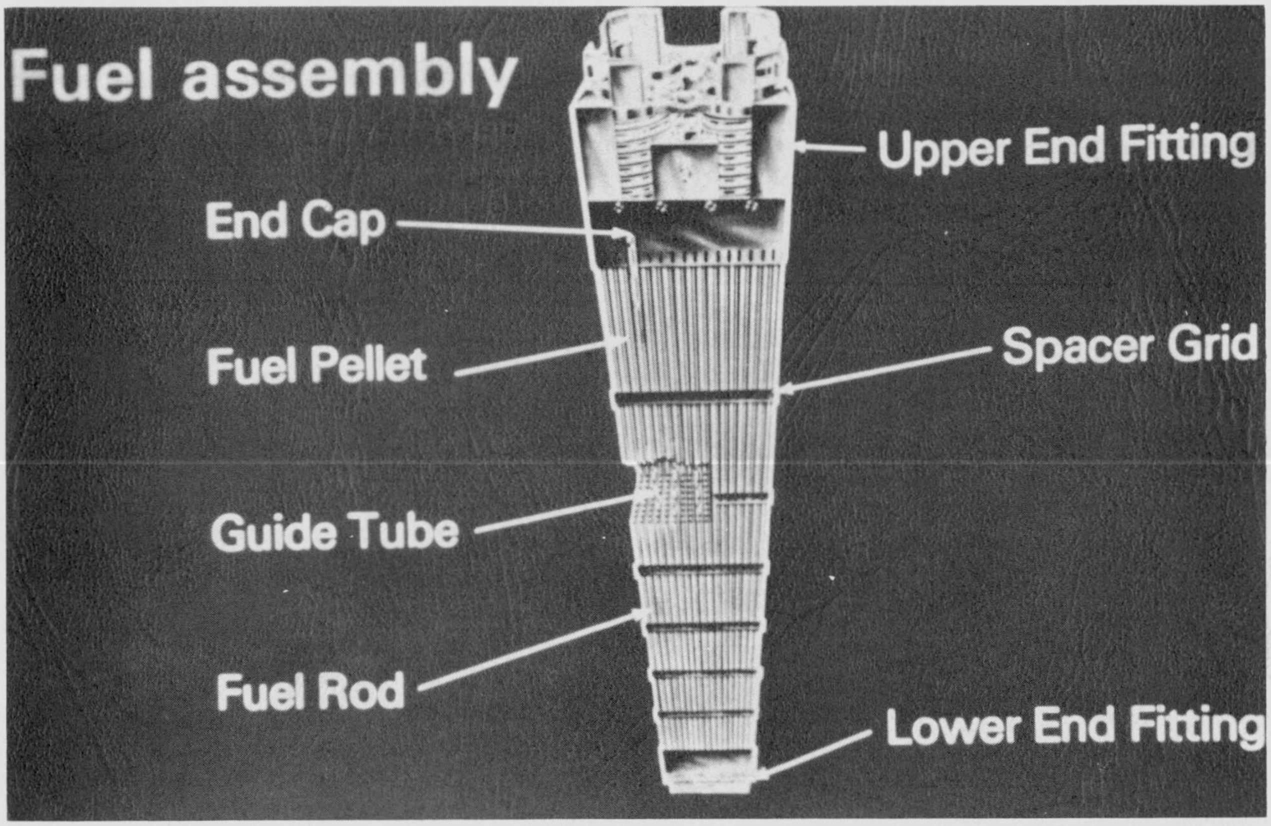
ROD AND BUNDLE ASSEMBLY PROGRAM — FINAL REPORT

Remote Rod and Bundle Assembly and Inspection — Preliminary Design Study



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DOE Contract No. B-64390-A-G Task Order 001

ROD AND BUNDLE ASSEMBLY PROGRAM — FINAL REPORT

Remote Rod and Bundle Assembly and Inspection — Preliminary Design Study

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Date Published — March 13, 1979

Prepared for

Battelle Pacific Northwest Laboratory
B&W Contract No. CRD-1023

ACKNOWLEDGEMENT

The authors express special gratitude to C. R. Woods (NMD-Pa.) for his many constructive comments and advice throughout the conduct of this program. Specific thanks are also due J. M. Kerr (LRC), R. J. Allen and L. A. Coreth (CNFP), and C. Y. Hylton (NPGD) for input and advice on various aspects of this program, and to M. R. Freeman for preparing the manuscript.

Special thanks are expressed to R. E. Schreiber, R. Sharp, and J. R. Carrell (B-PNL) for constructive suggestions and review comments as the work progressed.

SUMMARY

The basic objective of this program was to generate the preliminary design of a remote facility with capabilities to assemble highly radioactive fuel rods and bundles no matter what fuel composition has been specified.

To achieve this objective, a preliminary design study was performed and a final report has been written that describes remote systems facilities to be used for fabricating highly radioactive fuel rods and bundle assemblies. The report contains the following:

- A presentation of the current state-of-the-art for fabricating rods and bundle assemblies
- Block diagrams showing the required flow of components
- Survey of available equipment and recommendations for equipment development needs
- Recommendations for assembly line component scrap and rework
- Inspection plans and recommendations for modifications to current hands-on type inspection plans
- Plans for increasing reliability and minimizing maintenance problems
- In-process storage requirements
- Assessment of possible need to modify fuel assembly designs.

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1. INTRODUCTION

1.1 PROGRAM OBJECTIVES

The overall objective of the Fuels Refabrication and Development (FRAD) Program is to develop a refabrication technology base for proliferation resistant nuclear fuel cycles to such an extent that the choice of preferred nuclear fuel cycles is not limited by refabrication considerations. To achieve this objective, major efforts have been pursued to a) develop conceptual designs for fuel refabrication plants, and b) establish design bases for refabrication plants by providing the required refabrication process technology.

The project to be described here is a part of the FRAD program and focuses on a specific area of the required refabrication process technology. The objective of the present project is to perform a preliminary design study of rod and bundle assembly and inspection of ThO_2-UO_2 Mixed Oxide (ThoMOX) fuels that are mainly gamma emitting. Fully remote operation is assumed due to the high level of radioactivity.

The present preliminary design study specifies a 17 x 17 fuel assembly for a reference design basis. However, the final system will have generic capabilities so that with limited modifications, various other fuel bundle arrays will be able to be assembled.

1.2 PROGRAM CRITERIA

The goal of B&W's program was to develop a comprehensive preliminary design of a facility with maximum flexibility for assembly of fuel rods and bundles where the principal design criteria was the type and level of radioactivity. To achieve the preliminary design, rod and bundle assembly line flow diagrams were developed, major problem areas were identified, and recommendations for solutions to problems have been given.

The preliminary design specifies two parallel rod and bundle assembly lines in a commercial size facility. A primary goal in the design considerations was to maximize the production of the rod and bundle assembly lines to achieve a total throughput rate of $200 \frac{MT}{yr}$ oxide fuel for the parallel line. Future flexibility and maintenance or replacement of failed equipment was carefully considered to mitigate breakdowns and minimize maintenance time. A comprehensive review of the state-of-the-art of remote systems technology and consultations with experts aided in maximizing assembly line availability and throughput.

Fabrication of fuel rods and bundle assemblies in glove boxes represents a significant increase in difficulty when compared to conventional hands-on operation, while fabrication in remote systems assembly involves even more difficulty and expense compared to glove box methods. Thus, the use of computerized data acquisition systems, remote TV cameras, TV monitors, videotape, load cells, position sensors, and large quantities of custom built materials handling and inspection equipment are necessitated in remote assembly facilities.

After conducting a detailed state-of-the-art survey, a block diagram was developed to show the flow of material and operations to be performed in a logical sequence at the various work stations. Subsequently, the following milestones were studied.

- Survey of available equipment and needed equipment
- Study of component scrap and rework
- Inspection plans
- Reliability and maintenance problems
- In-process storage requirements, and
- Evaluation and recommendations for possible modifications to fuel assembly designs.

Commercially available equipment or designs were given first consideration for solutions to defined problem areas. Second priority for mitigating limitations was modification of commercially available equipment and the third choice was to recommend research and development as necessary. Equipment for reprocessing of scrap, isolation of waste, and methods for rework of defective products was identified.

The inspection plan specifies assembly line inspection points, inspection equipment and methods, and computerized acquisition of inspection data. Design alternatives to eliminate maintenance problems in both rod and assembly production lines have been listed, and the basis for choosing the optimum solutions have been discussed in detail. Multiple assembly lines permit production to continue in case repairs may be required in one of the lines, and multiple shifts or overtime in available lines have been designated as fall-back options to help meet production quotas. The computerized data acquisition system will also be used for accountability of fuel materials where in-process storage is required.

For remote fabrication requirements, it may be necessary to modify the fuel assembly design to interface with remote handling methods. Proposed changes in the fuel assembly design concept to facilitate remote fabrication were considered from feasibility and cost standpoints.

The redesign of a fuel assembly was outside the scope of this program. However, it was appropriate to evaluate fuel assembly designs to identify potential fabrication limitations and make recommendations for solutions to what could be a significant problem area.

2. STATE-OF-THE-ART SURVEY

2.1 DESCRIPTION OF THE PROBLEM

Figure 1 is a schematic drawing showing a typical pressurized light water reactor (PWR) fuel rod, while Table 1 lists the design parameters for a fuel rod and a typical 17x17 fuel bundle array. The purpose of Figure 1 is to aid in illustrating the initial operations to be performed in fabricating a fuel rod; i.e., after the lower end cap has been welded and inspected, lower internals (spring and spacer) plus approximately 380 fuel pellets and the upper internals must be loaded into zircaloy tube cladding. Subsequently, the upper end cap is inserted in the open end of the cladding and welded. Fuel rod pressurization, ultrasonic inspection of welds, neutron interrogation, and a variety of inspection operations (as noted in the flow diagrams in Section 3) are required to complete the assembly of fuel rods.

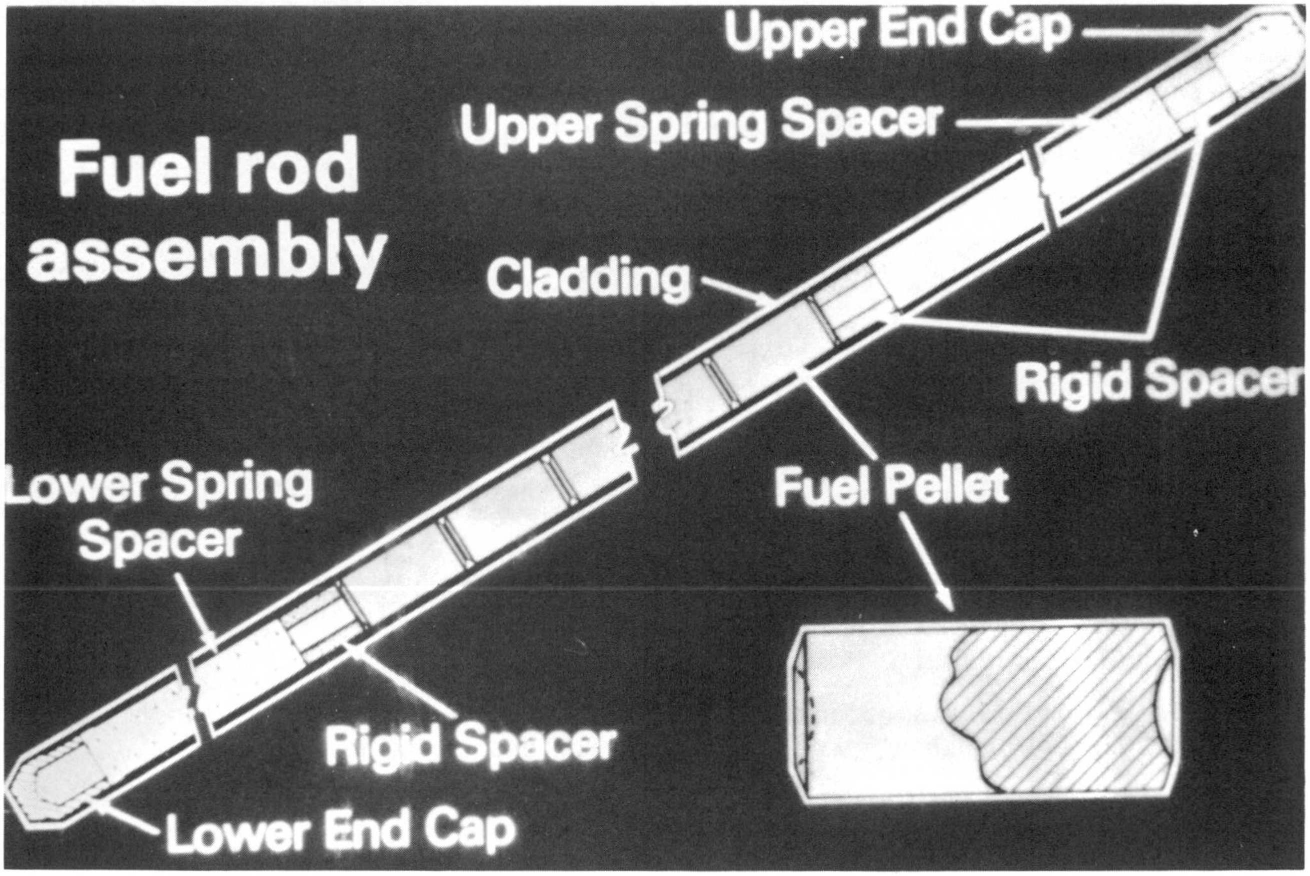


FIGURE 1. TYPICAL PWR FUEL ROD

After a sufficient number of fuel rods (264 for a 17x17 bundle array) have been loaded, welded, and inspected, the rods are grouped into structures called fuel bundles (or assemblies). Figure 2 is a schematic drawing of a fuel bundle showing the six intermaediate spacer grids and two end spacer grids that form the mechanical support of a fuel bundle. Figure 2 also serves to help illustrate the potential difficulty in assembling a fuel bundle, especially under remote conditions.

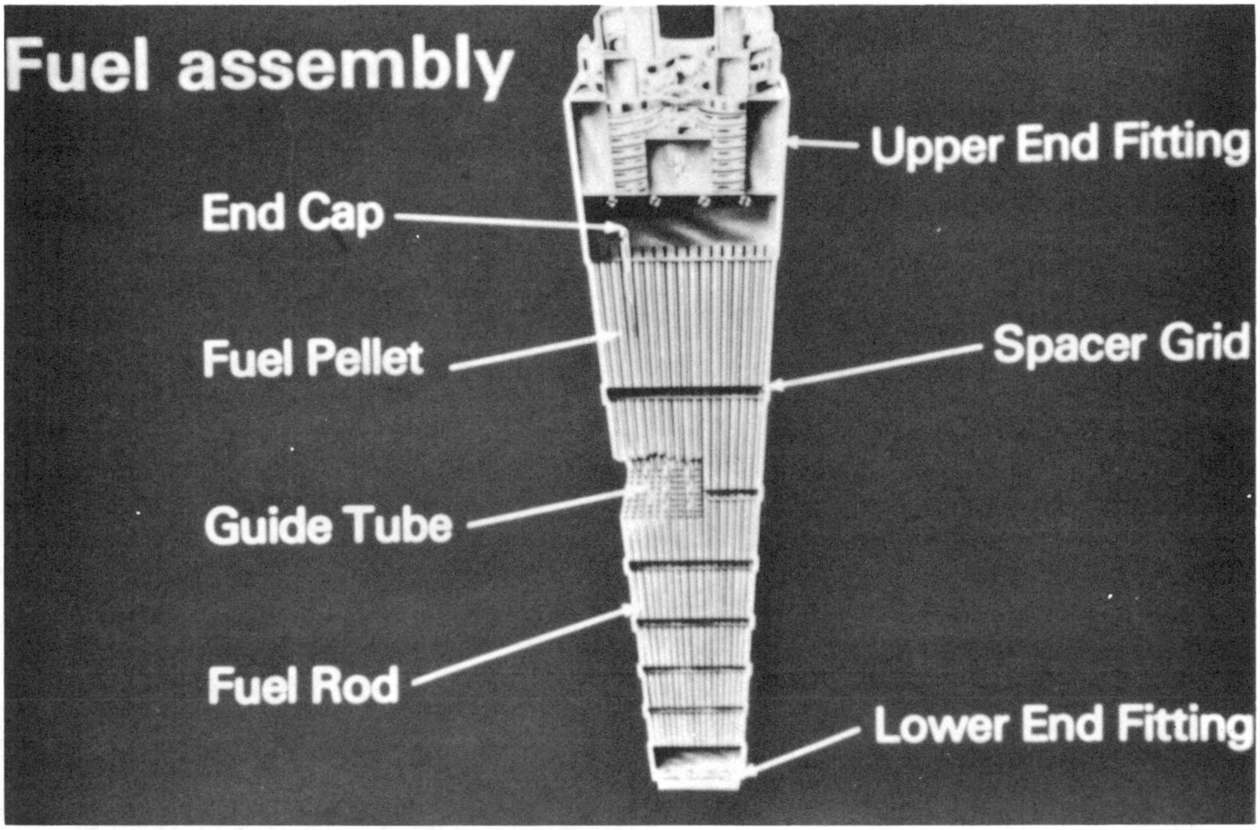


FIGURE 2. SCHEMATIC DRAWING OF FUEL ASSEMBLY

The principal criterion imposed on the fuel rod and bundle assembly line is that the throughput rate be 200 metric tons of oxide fuel per year.

TABLE 1. FUEL ROD AND ASSEMBLY DESIGN PARAMETERS

Fuel Pellet	
Density, % theoretical	95
Diameter, in	0.324
Length, in	0.375
Fuel Rod	
Number per core	54,120
Outside diameter, in	0.374
Cladding thickness, in	0.0235
Active fuel length, in	143
Fuel Assembly	
Number per core	205
Fuel rods per assembly	264
Array	17x17
Weight, lb	1530
Overall length, in	166
Spacer grids	8
Fuel Assembly Materials	
Fuel pellets	UO_2
Cladding	Zircaloy-4
Spacer grids	Inconel 718
End fittings	SS, grade CF3M
Instrumentation tubes	Zircaloy-4
Control rod guide tubes	Zircaloy-4

2.2 ThoMOX ROD AND BUNDLE ASSEMBLY

A literature search has shown that a facility capable of fully remote fabrication of fuel rods and bundles does not exist. However, remote operations are being carried out at numerous national and industrial laboratories[1-21] in the USA and in foreign countries. The most relevant significant advances, from the viewpoint of the rod and bundle assembly program, are being made in the Hot Fuel Examination Facility (HFEF) at Argonne National Laboratory (ANL), Idaho, and at the Hanford Engineering Development Laboratory (HEDL).[22] These advancements have been made primarily in the areas of inspection and characterization; e.g., visual examination, gamma scanning, eddy current examination, profilometry, and bow and length measurements of fuel rods to be removed from such reactors as TREAT, EBRII, and the FFTF. Unfortunately, even the hot cell throughput rates set as a goal for future FFTF examination are extremely slow compared to the throughput rates required for producing LWR fuel rods on an economical basis (see Table 2). However, some of the fuel rod handling and inspection devices appear to be adaptable to production line facilities.

TABLE 2. ThoMOX ROD AND BUNDLE REQUIREMENTS FOR 200 $\frac{MTMO}{YR}$ THROUGHPUT

Product	Throughput			
ThoMOX Fuel	Per Line/ Each Shift	Per Shift (a)	Per Day (b)	Per Year (c)
No. Pellets	42×10^3	84×10^3	168×10^3	41.9×10^6
No. Fuel Rods	110	220	439	109.8×10^3
No. Fuel Assemblies	.5	.9	1.7	416

(a) 2 lines per shift
(b) 2 shifts per day
(c) 5 days per week, 50 weeks per year
(d) Pellet density, 95% T.D.
(e) 17 x 17 fuel assemblies
(f) ThoMOX, 80% ThO_2 - 20% UO_2
(g) Pellet length, .375 in
Pellet diameter, .324 in
Fuel column length, 143 in

In the past few years, significant advances have also been made in applying remote systems technology to the assembly and disassembly of fuel rods and bundles for special experiments. However, while considerable progress has been made in remote assembly of rods and bundles on a small scale, significant advances are still needed before assemblies can be produced with the commercial size capabilities of 200 $\frac{MTMO}{yr}$ shown in Table 2. Some of the important U.S. advances in remote assembly are described below.

At the present time, Argonne National Laboratory's (ANL) Hot Fuel Examination Facility (HFEF) has the capability for remote assembly of both fuel rods and fast test reactor (FTR) subassemblies. Grid spacers for the FTR have been proposed as an alternative to lateral fuel support by wire-wrap spacers, and subassemblies using grid spacers are currently undergoing irradiation in EBR-II. Initial techniques and equipment have been used to remotely disassemble, examine, and reassemble the grid type subassemblies at the HFEF. A unique feature of the grid type subassemblies is the capability for removal of any of the 37 fuel rods for interim examination and replacement without removing or disturbing the other elements in the same subassembly.

Inaccessibility of the fuel rods and bundle assemblies will cause special problems. For example, one of the most basic examinations is visual inspection for cladding surface defects. To accomplish this examination at HFEF, a visual examination machine (VEM) was developed to permit a high volume of visual inspections and to provide safe, automated handling and precise positioning of the fuel rods within a well-lighted and highly magnified periscope field of view. Rather than moving the periscope, the VEM operator moves the fuel rod within the temporarily fixed field of view of the periscope. The element positioning stage provides motion in the X, Y, Z, and rotation directions with digital readouts for each motion. Interchangeable background grids give a suitable background for viewing or photography. The VEM components are designed for future addition of a videotape unit to the periscope and computer controlled operation of the stage.

It can be seen that very sophisticated methods are needed to perform even the most basic examinations, and changes to current commercial inspection points, methods, or sequence of inspection/fabrication steps will be required to implement fully remote operations on the reference production line. In addition, modifications to a normal QA program resulting from such a facility will be needed. Designs for special jigs and inspection fixtures at B&W-LRC, HFEF, and the Hanford Engineering Development Laboratory (HEDL) will be incorporated or modified to suit the purpose of inspecting rod and bundle assemblies. The magazine assembly for positioning during inspection which was previously developed for welding end caps in B&W's FFTF line is especially attractive.

Figure 2 shows a typical B&W fuel assembly. Current 17x17 PWR fuel assembly designs incorporate 264 fuel rods into each assembly. Remote fabrication of such a large number of fuel rods into an assembly may require consideration of alternate assembly design concepts. Any proposed change in fuel assembly design concept to facilitate remote fabrication will be categorized as to degree of feasibility and relative cost. Equipment maintenance in remote operations facilities presents unique problems. These problems have led to special design criteria. Some of the design criteria reported in the literature are as follows:

- Equipment components shall be of modular design to facilitate replacement.
- Where possible, standardized equipment shall be used.
- Equipment shall be maintainable without disturbing adjacent equipment.
- Mockup facilities will be used to test equipment prior to insertion in the remote area.
- Replacement components shall be stored in areas adjacent to components with high mortality rates.
- Equipment will be designed for long life but will be capable of being decontaminated remotely for mainteanance in place or for removal for repair or replacement.
- Remote environment equipment will be maintained by remote replacement of failed components.

2.3 CURRENT COMMERCIAL ROD AND BUNDLE ASSEMBLY

At the present time fuel rods and assemblies are manufactured in the United States by the following companies:

1. Babcock and Wilcox Company in Lynchburg, Virginia
2. Combustion Engineering in Windsor, Connecticut
3. General Electric in Wilmington, North Carolina
4. Exxon in Richland, Washington
5. Westinghouse in Columbia, South Carolina

Current fuel manufacturers use slightly different approaches to rod and bundle assembly. Therefore, the purpose of this section is to present a broad description of the state-of-the-art of the various fuel manufacturers. Fuel elements for modern pressurized and boiling water reactors consist of uranium dioxide fuel, zirconium alloy fuel cladding, spacer grids made from zirconium alloy, stainless steel or nickel alloy, stainless steel end fittings and nickel alloy hold down springs. Manufacturing these components and integrating them into a fuel assembly requires various methods and processes. Most of these methods are conventional except that extraordinary attention is given to processing details to assure reliability and reproducibility. In general, fuel rod loading in present day commercial plants is accomplished in the following manner. Cladding tubes with one end cap welded in place are inserted through a partition (via a sphincter valve) in the fuel loading room and into a loading machine for insertion of the fuel pellets. Some companies handle one rod at a time while others use rotating magazines to handle larger numbers of rods. In any case only the open end of the cladding tube is exposed to possible contamination by the fuel. The fuel pellets needed for one rod are weighed, and their weight is recorded on the quality control document for the fuel rod. Some companies lay out the entire length of fuel pellets plus the fuel rod internal hardware (springs and insulation) and mechanically load the whole fuel stack at one time, while others lay out substacks with varying enrichments and load each substack individually. Pellet quality and fuel stack length tolerance are examined prior to loading. After loading either the individual rods or the magazine of rods, end clearance is checked and the second end cap is inserted and welded. Ultrasonic testing is used to verify the quality of the end cap weld.

At this point some fuel vendors excercise the option to vacuum dry large lots (several hundred at a time) of fuel rods by means of a previously drilled hole in one end cap. Other vendors furnace dry fuel pellets, internal hardware, and the cladding tubes prior to the rod loading operation and do not dry the fuel rods in any later operations. In the vacuum drying operation moisture removal is accelerated by repeated evacuation and purging with inert gas.

Cooled rods are subsequently evacuated, pressurized with helium to the level desired and the hole in the end cap is fused with a laser. The industry then uses a neutron interrogator (called Fat Albert because of its bulk and rotund shape) in a non-destructive examination to verify the absence of gaps between fuel pellets and that all pellets in the rod are of the proper enrichment. Some vendors inspect one rod at a time while others check as many as four rods simultaneously. This operation takes about 15 seconds, compared to ∿6 hours required for autoradiographs used in Pu-bearing fuel pellets for the FFTF. From the interrogator, the rods are transferred to an automatic cleaning device to remove any surface contamination that may have accumulated from the fuel loading and subsequent fabrication operations. The rods are then subjected to alpha counting to assure there is no fissile material contamination on their outside surfaces.

Subsequently a helium leak detector is used to test for leaks and verify the integrity of the final assembled fuel rod.. In the assembly of B&W fuel bundles, a set of six intermediate and two end grids is selected and the cells opened by a unique keying device. The keys hold the individual cells to an open dimension larger than the outside diameter of the fuel rod to prevent scratching of the fuel rod cladding during assembly. The other fuel vendors force fuel rods into tight fitting grid openings and this tends to enhance surface flaws and scratches on the cladding. The keyed grids (or unkeyed grids depending on the manufacturer)are then assembled into a horizontal assembly fixture that holds them in position during assembly fabrication. The assembly fixture is mounted on a granite surface plate. When the manufacturing personnel have satisfied themselves that the grids are in proper position, Quality Control personnel inspect them for alignment using the granite surface plate as a plane of reference.

Assembly personnel insert fuel rods into the grids. Each fuel rod is hand-wiped with acetone as it is inserted into the grids. As the assembly is built up, a central instrument tube is added. Spacer sleeves are affixed to the instrument tube to act as positive separators between grids. After all of the fuel rods (264 in the B&W Mark C-17x17 fuel assemblies) have been inserted, the grid keys are turned and removed to release the cells to grip the fuel rods.

An alternative to manual bundle assembly by technicians is the use of existing semi-mechanized systems that allows insertion of 14, 15, 16, 17, 7 or 8 rods (for CE, W, GE, or B&W assemblies) at one time into a pre-assembled fuel bundle skeleton that may use keyed or non-keyed grids.

The twenty-four control rod guide tubes are inserted into the grids and the end fitting castings affixed to both ends. The guide tubes are mechanically fastened to the end fittings and the fasteners welded. The end fittings are attached to the end grids by welding small insert fasteners in place.

After being released by assembly operations personnel, the fuel assembly is placed on a transfer cart equipped with a hydraulic device for rotating the assembly to the vertical position. Once vertical, the assembly fixture is removed. Subsequent handling is accomplished by lifting the assembly with an overhead crane attached at the upper end fitting as it will be handled for loading into the reactor.

The fuel assembly envelope dimensions are checked in a vertical envelope gauge. Sensors travel over the full length of the assembly in the free standing and restrained positions to check for straightness, twist, bow and envelope. Strain gauges are used to measure water channels at eight locations over the length of the assembly. Signals from the stain gauges are converted by computer to digital values for water channels. These data are then compared to standard values and, if acceptable, the assembly is released for further processing.

The hold-down spring and spider are added to the upper end fitting and inserts limiting spider motion are welded in place. The assembly is then transferred to a pit where a control rod with upper tolerance limits is inserted in the fuel assembly guide tubes. This insertion test is to verify guide tube alignment to assure control rod scram time is within tolerance.

Final visual inspection is performed by Quality Control personnel using high intensity lights and magnifying devices where necessary. Cleaning is accomplished by manufacturing personnel using acetone and compressed air. When satisfactorily cleaned, the assembly is sealed in a plastic sheath and either stored (see Figure 3) in the vertical position or placed in a shipping container for shipment to the reactor site.

FIGURE 3. TYPICAL LWR FUEL ASSEMBLY STORAGE

2.4 CONCLUSIONS AND RECOMMENDATIONS

1. Remote facilities to perform rod and bundle assembly of ThoMOX fuel do not exist so that preliminary and detailed design studies are required to produce such a facility.

2. Fuel rod pellet loading operations, performed in commercial nuclear fuel fabrication plants, are highly mechanized and should be adaptable to remote environment conditions. The main problems for rod loading purposes would seem to be adapting present automated processes to a remote facility while maintaining a realistic throughput rate and designing for remote maintenance.

3. Assembly of fuel rods into bundles, in commercial nuclear fabrication plants, may be performed using a combination of manual and mechanized operations. However, due to the significant restraints imposed by remote operation requirements, a high degree of creativity with numerous innovations will be required to assemble fuel bundles in remote automated facilities. The recommended approach is to utilize all presently developed equipment (where possible) and expand or modify present operations and equipment to produce a design for a facility that can assemble fuel bundles at the high production rates required for light water reactors.

3. FLOW DIAGRAM FOR REMOTE ASSEMBLY

3.1 DESIGN ASSUMPTIONS

The following design assumptions have been made to provide a basis for development of the final block flow diagram.

1. The ThO_2-UO_2 Mixed Oxide (ThoMOX) fuels are strong gamma emitters so that fully remote operation will be assumed due to the high level of radioactivity.

2. All processes will be sufficiently mechanized or automated to facilitate control from remote consoles.

3. For purposes of establishing a design reference base, the remote facilities will be designed to fabricate a 17 x 17 LWR bundle with only minor modifications necessary to adapt the facility to fabrication of other LWR assembly arrays (e.g., 14 x 14, 15 x 15, 16 x 16, 7 x 7, and 8 x 8 arrays).

4. Twin processing operations will be employed to minimize the impact of major equipment failures with a combined output of 200 metric tons of metal oxide per year (200 MTMO/yr) for the facility based on a two-shift, 250-working-days-per-year schedule. Three shifts operating seven days a week is not necessary to achieve 200 MTMO/yr throughput because generally the equipment can be sized to produce much higher throughput rates than 200 MTMO/yr without corresponding increases in equipment costs. The two-shift mode of operation will permit surge production in case of a major equipment failure in one line.

5. The option will be provided for material flow to bypass any process station requiring major maintenance so that production of the specific unit operation can be performed in the adjacent parallel assembly line followed by rerouting the product back into the original assembly line for subsequent assembly operations.

6. Certified fuel pellets will be received on trays in packages but not assembled in stacks.

7. Cladding, end caps, pressurizing gas, spacers, spring spacers, and any other hardware will be available to the rod loading operation with necessary QC/QA certification and without a need for further processing of the components. The cladding ends will have been prepared to accept end caps.

8. Fuel rod bundle storage and packaging is not considered.

9. All bundle hardware such as end fittings, guide tubes, spacer grids, etc., will be available as necessary with required QC/QA certification and without a need for further processing as components within the shielded, remote final assembly facility.

10. Packaging and shipping of finished bundles will not be considered.

11. Maintenance of equipment will be a major consideration.

12. Equipment mockup facilities will be used.

13. A work station will be used to process scrap and rework.

3.2 REMOTE FUEL ROD ASSEMBLY

The proposed block flow diagram for fuel rod assembly is presented in Figure 4, and a description of the operations follows.

Before transfer to the hot area, the bottom end cap will be tapped into one end of the cladding tubes and welded in an inert atmosphere. The weld will be ultrasonically and dimensionally inspected, and samples will be removed for weld corrosion testing and metallographic examination. An identification code will then be placed on the end cap for traceability. All cladding and internals will be dried before transfer to the hot assembly facility. A plastic collar will be placed over the open end of each length of cladding to minimize the possibility of contamination in the weld zone area during loading. The cladding will then be transferred to the remote loading area.

In the remote environment, transfer of fuel rods between various unit manufacturing and inspection operations will be mechanized. Simple nylon pulleys and lever arms will be operated by small motors and micro-switches will be utilized to perform the majority of fuel rod transfers.

After removal from storage, certified pellets will be dried and sampled for moisture. The pellets will then be made into stacks of prescribed weight and length and placed on trays. An automatic unloader will push the rows of pellets on the trays into a trough forming a single row at the loading machine for verification of stack length and pellet surface condition to

FIGURE 4. FINAL BLOCK FLOW DIAGRAM FOR FUEL ROD ASSEMBLY

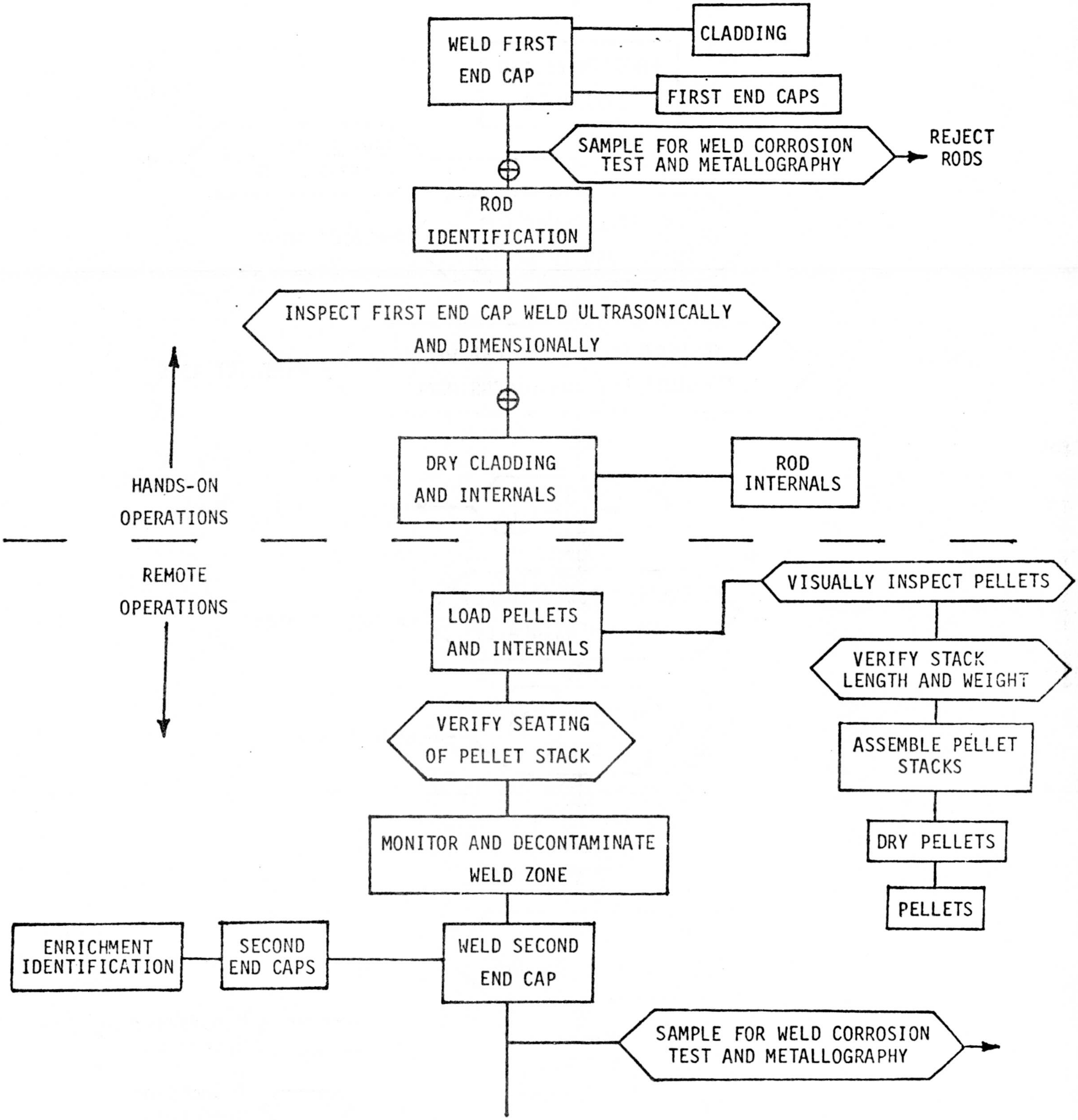
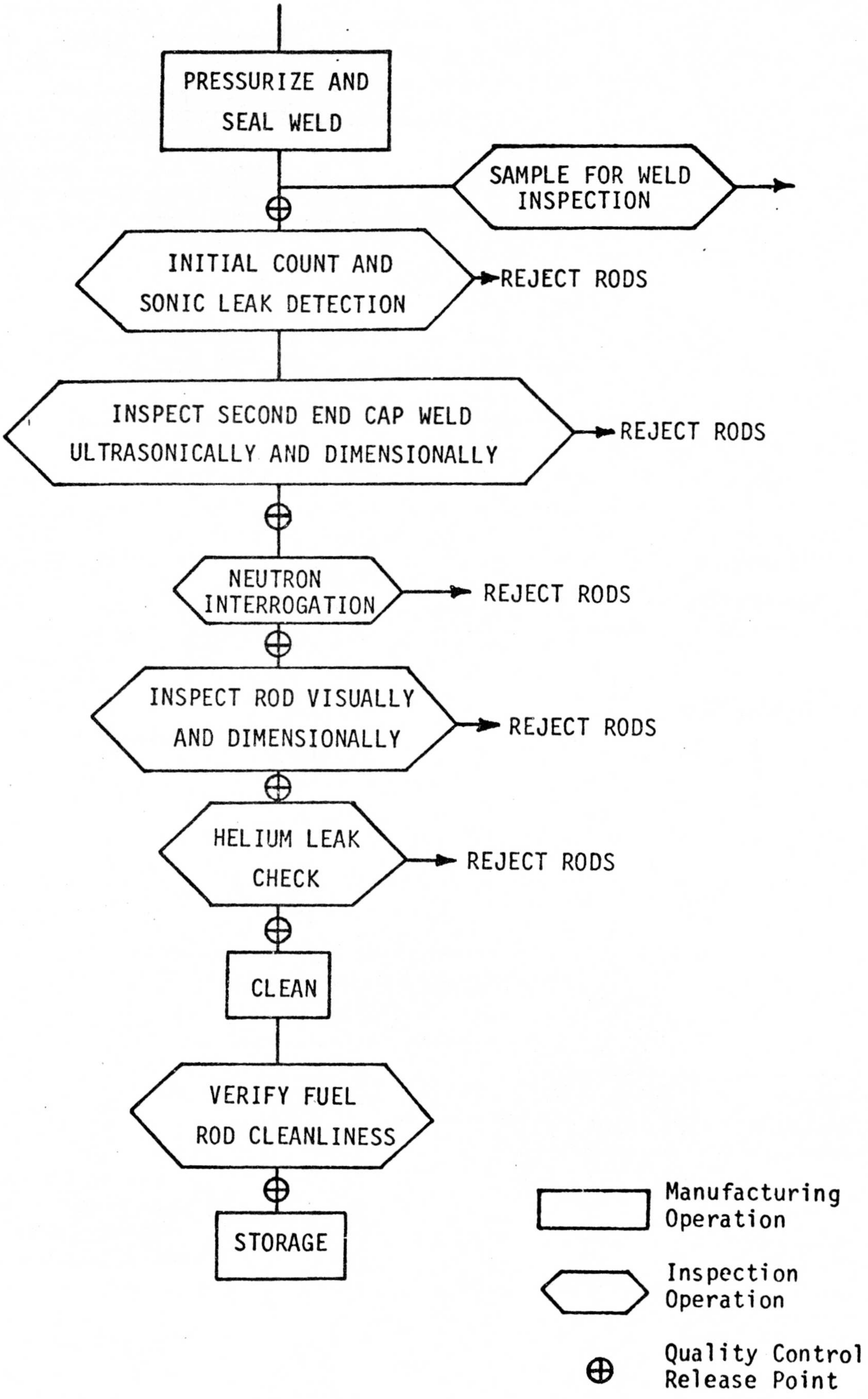


FIGURE 4. (CONT'D)



insure no pellets have been broken. Internals for each end will be added, and the cladding with the first end cap welded will be positioned in the loading machine. The entire pellet stack will be pushed into the cladding at one time. A depth gage will be inserted into the cladding to verify that the column is properly seated. The plastic collar will be removed, the weld area checked for contamination, and cleaned if necessary. The second end cap, which has been marked with the enrichment code, will then be tapped in.

Loaded fuel rods will be transported to the second end cap welding station where each rod will be welded in a manner similar to that used in the cold environment except that a laser welder will be utilized. Samples will be obtained for weld corrosion testing and metallographic examination. Rods will then be moved to the pressurization station where a small hole will be drilled by a laser beam, and the area around the hole will be sealed so that the rod can be pressurized with helium. A defocused laser beam will be used to fuse the hole closed after pressurization. The second end cap weld area will be immediately monitored for a) high frequency sound waves indicating a gas leak, and b) external contamination. Samples of the laser welds will be removed for metallographic examination. Rods will then be transferred to another inspection station where the second end cap welds will be ultrasonically and dimensionally inspected. Neutron interrogation will follow at the next station to detect excessive pellet gaps and to verify enrichment. As the rods exit the scanner, they will be fed through a cleaning device followed by a visual and dimensional inspection. They will then be placed in a helium leak detector to check for defective rods. After release by QC, the rods will be transported to the storage area.

3.3 REMOTE FUEL BUNDLE ASSEMBLY

B&W's basic philosophy in the manufacture of highly radioactive fuel bundles is to maximize hands-on bundle assembly operations in a nonradioactive area. Based on this philosophy, B&W proposes a scenario for a 17 x 17 bundle to preassemble (hands-on) one end fitting with 32 inserts welded, 2 end spacer grids, 6 intermediate spacer grids, 24 guide tubes and nuts, 1 instrument tube, and 7 spacer sleeves prior to insertion of the preassembled bundle skeleton into the remote environment. This approach will simplify and minimize the remote bundle assembly operations.

The proposed final block flow diagram for fuel bundle assembly is presented in Figure 5, and a description of the operations follow.

In a non-radioactive area, the assembly fixture used to support components during bundle fabrication will be inspected to insure proper alignment. The lower end fitting and the spacer grids will be inserted and their installation inspected. The instrument tube and spacer sleeves will be inserted, the instrument tube flared, and the entire installation inspected. Guide tubes will be inserted and inspected and the lower guide tube nuts installed, torqued to specification, and checked. The lower spacer grid will be attached to the lower end fitting with welded inserts, and samples will be obtained for metallographic examination. Lower guide tube nuts will be welded, and a visual inspection will be performed.

FIGURE 5. FINAL BLOCK FLOW DIAGRAM FOR FUEL BUNDLE ASSEMBLY

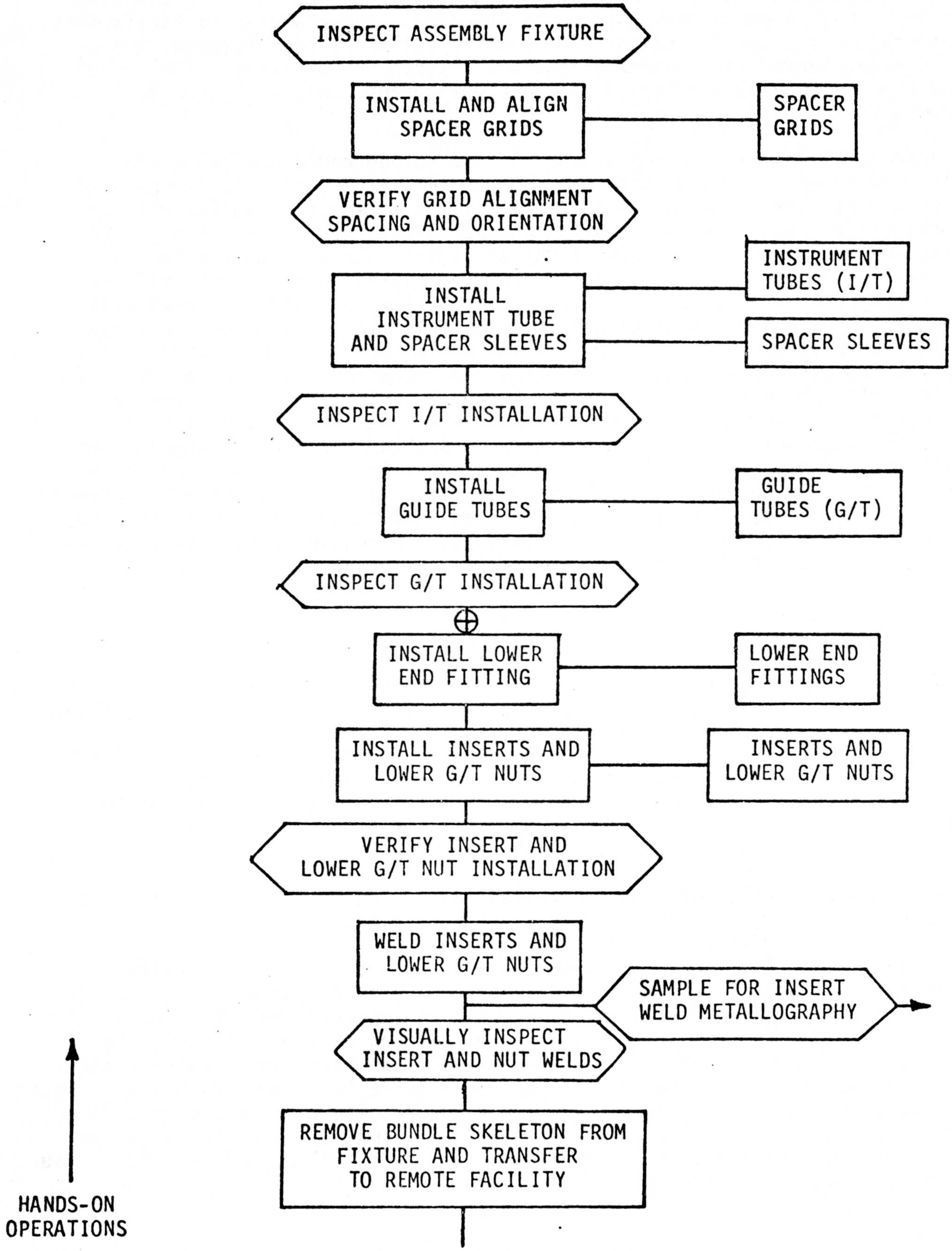


FIGURE 5. (CONT'D)

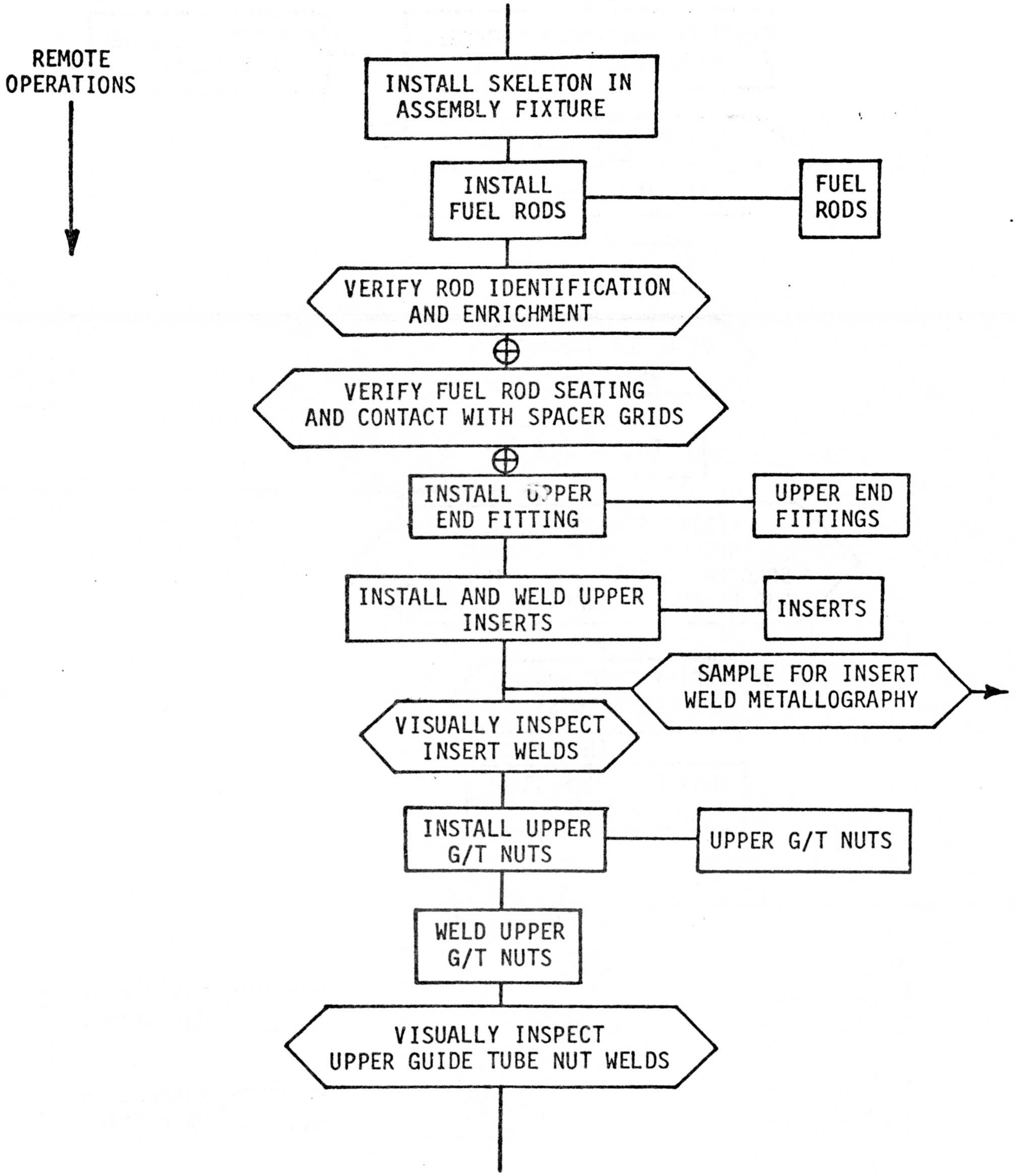
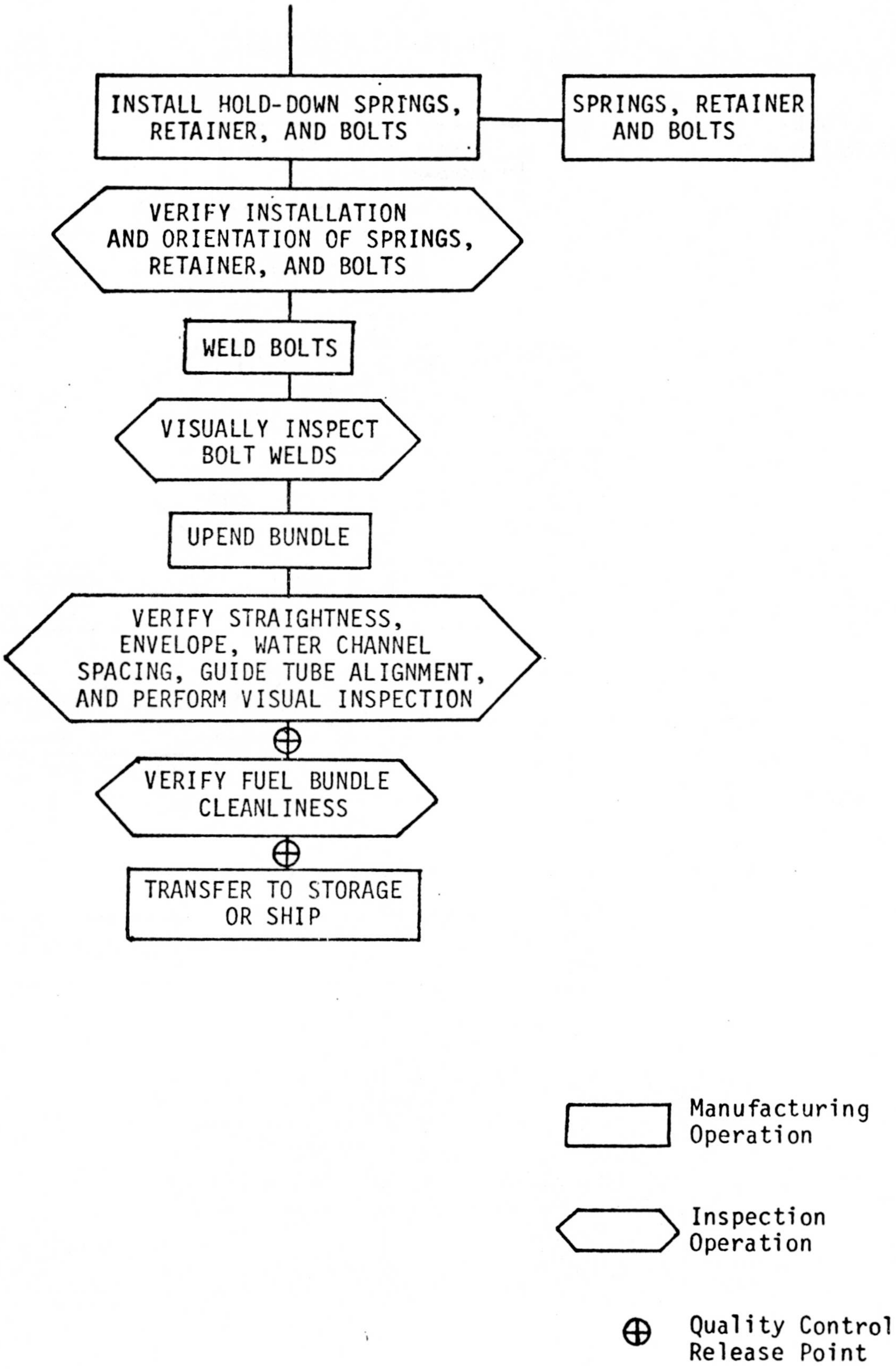


FIGURE 5. (CONT'D FURTHER)



Subsequently, the preassembled bundle skeleton will be removed from the assembly fixture and transferred into the remote environment for installation of the skeleton into another assembly fixture. Fuel rods will then be removed from storage, transported to the fabrication area, and inserted into the grids. Both insertion force and entry into each grid cell will be monitored to detect any problems during loading. After all fuel rods have been installed, their serial numbers, codes, and positions will be checked and recorded for the QC records. Proper rod seating against the end fitting and contact with the spacer grids will be verified. The upper end fitting will be installed and the inserts welded and inspected. Upper guide tube nuts will be installed, torqued to specification, welded, and visually inspected. The holddown springs and retainer will be placed in the upper end fitting and the retainer bolts will be installed and welded. An inspection will be performed on the bolt welds. The bundle will be upended, placed in a vertical fixture to verify straightness, and adjustments will be made as needed followed by another visual inspection. Water channel measurements will be made at selected positions to verify compliance with the specification. Envelope and guide tube alignment will be checked, and final cleaning will be performed with a solvent spray and compressed gas. The bundle will be given a cleanliness inspection before transfer to the storage or shipping areas.

Figure 6 is a schematic drawing showing the preliminary floor plan of the remote rod and bundle assembly facility.

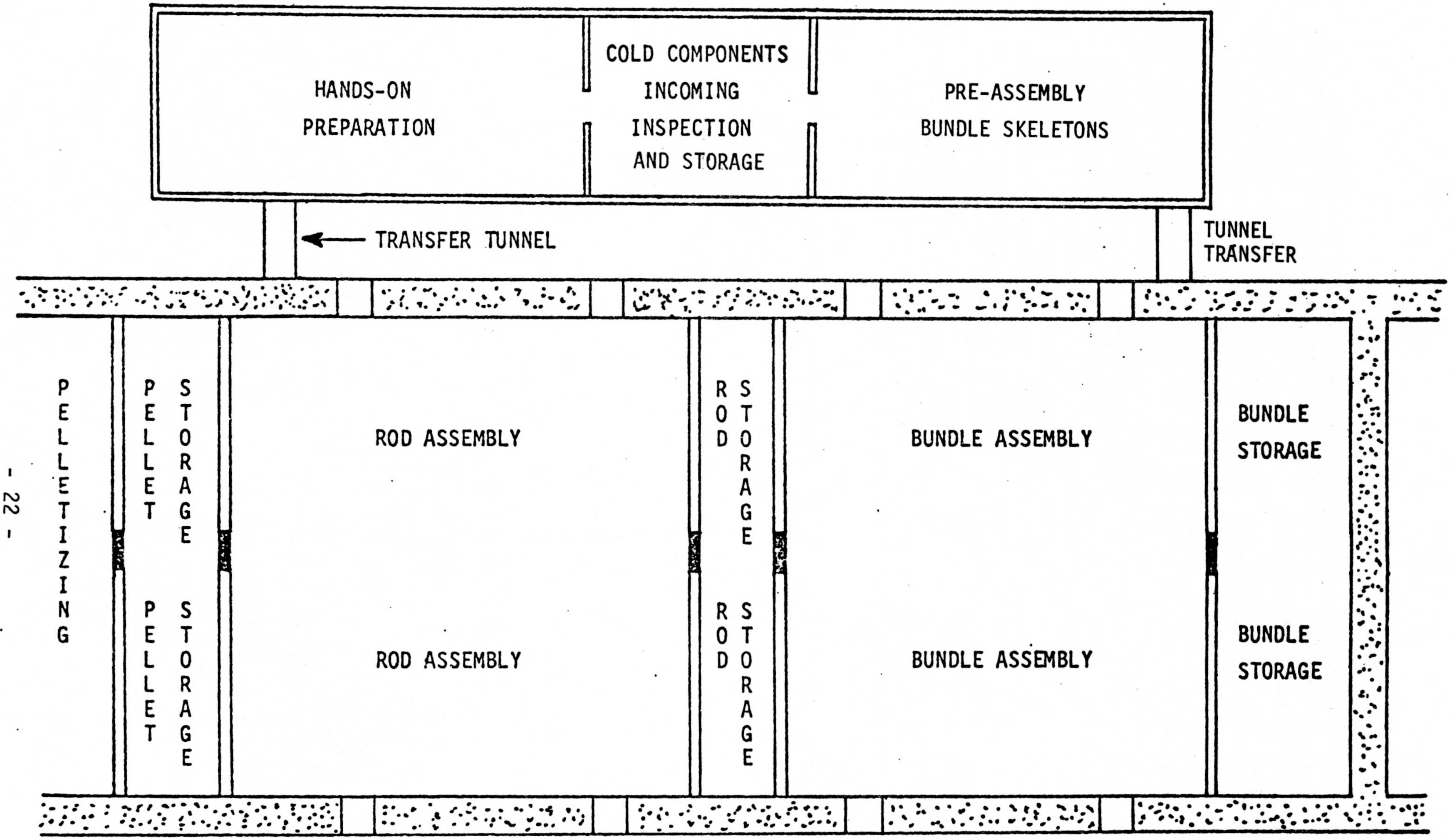


FIGURE 6.

PRELIMINARY FLOOR PLAN OF A REMOTE ROD AND BUNDLE ASSEMBLY FACILITY

4. ASSEMBLY LINE EQUIPMENT NEEDS

4.1 EQUIPMENT PHILOSOPHY

Manufacture of highly radioactive ThO_2-UO_2 mixed oxide (ThoMOX) fuel rods and bundle assemblies assumes all operations will be performed in a remote environment. The objective of this subtask is to select standard, commercially available equipment for as many assembly line operations as is possible. If needed equipment is not commercially available, the next option will be to modify available equipment. The last option will be to recommend the design requirements and functional descriptions for needed equipment. Selection of assembly line equipment will be based on capabilities, ease of operation, flexibility, maintenance, and/or replacement requirements, simplicity, and cost. The definition of equipment in this subtask is meant to include all jigs, fixtures, balances, gauges, electronic equipment, viewing devices, microscopes, and apparatus for performing helium leak checks, X-ray, and neutron interrogation used for manufacture and inspection of fuel rods and the assembled fuel bundles.

Two important possible restrictions are imposed on the equipment by the highly radioactive fuel. First, the equipment (electronic components especially) must be able to withstand the high radiation fields imposed by the fuel without significant deterioration to the equipment properties. For example, gradual deterioration of properties of inspection equipment components could result in erroneous inspection data, although equipment calibration at regularly scheduled intervals should minimize the problem from the standpoint of accuracy.

A second possible restriction on the equipment is that the equipment must function in an atmosphere that contains an extremely low level of moisture. Moisture level must be maintained at a very low level to avoid any moisture pickup by the fuel, cladding, and internal hardware that could ultimately result in hydriding of the cladding during reactor operation.

The basic philosophy used in assessing equipment options are as follows:

- Standardized, modular components will be used where possible.
- Equipment will be highly mechanized or automated.
- Equipment will be custom designed for remote operation and ease of maintenance.
- As many components as possible will be located outside of the highly radioactive environment.
- Hands-on assembly operations (in a non-radioactive area) will be maximized to minimize the amount of equipment needed in the remote environment.

In general, the equipment needed for a remote rod and bundle assembly facility is developed to the following advanced stages, semi-mechanized, mechanized, semi-automated, and automated for manufacture and inspection of both fuel rods and fuel bundles. The principal reasons for maintaining a skeleton crew of people in present commercial nuclear assembly faciliites is to perform routine equipment calibration and maintenance. Therefore, ultimate construction of a remote rod and bundle assembly facility does not require the development of new technology or hardware but rather the application of existing materials handling and diagnostic capabilities and implementation of associated software and sequencing programs.

A definition of the above terms used includes:

- Manual - done by hand with power assists only if part weight demands it
- Semi-Mechanized - performed by machine with human assistance (i.e., loading and unloading)
- Mechanized - performed by machine but requiring a human operator
- Semi-Automated - performed by machine with a human operator at a control board for one or more operations
- Automated - performed by machine with no human operator
- Developed - technology and hardware available but not yet in an integrated system for a specific application
- Applied - in use in similar non-nuclear applications.

Status Categories (Used in following tables)

A. Commercially available equipment suitable

B. Commercially available equipment requires custom modifications

C. Custom equipment, design available

D. Design required

E. Extensive development and design required.

TABLE 3. FUEL ROD ASSEMBLY EQUIPMENT

Block Flow Operation	Equipment	Number Required	Status
1. Weld First End Cap	TIG Weld Box	2	C
	Power Supply and Controls	2	A
	Rod Positioner	2	A
	Vacuum Pump and Gauge	2	A
2. Rod Identification	Roll Embosser	1	A
3. Inspect First End Cap Weld	Ultrasonic Test Tank, Transducer, Associated Electronics	2	A
	Dimensional Gauge	2	A
4. Dry Clad and Internals	Vacuum Oven	2	A

The above operations will be performed hands-on in a non-radioactive area. An entrance area to the cell will be provided through a series of air locks.

Block Flow Operation	Equipment	Number Required	Status
5. Dry Pellets	Pellet Storage and Retrieval System	4	D
	Vacuum Oven	2	C
	Oven Loader and Unloader	2	D
	Moisture Analyzer	2	C
6. Assemble Pellet Stacks	Stack Make-Up Machine	2	C
7. Verify Stack Length and Weight	Stack Length Detector	2	C
	Stack Weighing Station	2	C
8. Visually Inspect Pellets	CCTV System	2	B
	Laser Surface Inspection System	2	D
9. Load Pellets and Internals	Plastic Collar Inserter	2	E
	Pellet & Component Loading Machine	2	B
	Serial Number Reader	2	E
10. Verify Seating of Pellet Stack	Depth Gauge	2	B
11. End Decontamination	Component Insertion Apparatus	2	D
	Rod End Cleaner	2	C
	Alpha Monitor	2	E
12. Weld Second End Cap	Laser Weld Box	3	E
	Laser Power Supply, Optics, and Controls	3	E
	Rod Positioner	3	B
	Vacuum Pump and Gauge	2	A
13. Pressurize and Seal Weld	Laser Optical System	2	B
	Laser Source, Control, Power Supply	2	B
	Evacuation System	2	B
	Pressurization System	2	C
	Pressure Chamber	2	C
	Rod Positioner	2	C
14. Sample for Weld Inspection	Pneumatic Rabbit	2	A
	Microscope	1	A
	Metallographic Preparation System	1	B
15. Initial Count and Sonic Leak Detection	Alpha Monitor	2	E
	Sonic Leak Detector	2	B
16. Inspect Second End Cap Weld Ultrasonically and Dimensionally	Ultrasonic Test Tank, Transducer, Associated Electronics, and Recorder	2	C
	Dimensional Gauge	2	B
17. Neutron Interrogation	Neutron Interrogation System	2	D
	Neutron Source		
	Detector		
	Counting Electronics		
18. Inspect Rod Visually and Dimensionally	CCTV System	2	B
	Laser Gauge	2	D
19. Helium Leak Check	Vacuum Chamber	2	C
	Helium Leak Detector	2	B
	Evacuation System	2	B
20. Clean	Cleaning Tank	4	B
	Air Dryer	4	B
21. Verify Fuel Rod Cleanliness	Alpha Monitor	2	E
22. Storage	Computer Controlled Inventory and Retrieval System	2	D
23. Rod Rework Station	Alpha Monitor	1	E
	Surface Cleaner	1	B
	Surface Grinder	1	C
	Tubing Cutter and Flaring Tool	1	B
	Rod Unloader	1	C
	Pellet Transfer System	1	D
	Pellet Weighing System	1	B
24. Rod Transfers	Integrated Rod Handling System	1	C

NOTE: For completeness, an ultrasonic inspection should be performed on the incoming cladding. In addition, a lathe will be required to machine the cladding to the proper length and prepare the ends to accept the end caps. In the original request for proposal, specific instructions were given to omit these operations.

TABLE 4. FUEL BUNDLE ASSEMBLY EQUIPMENT

Three major work phases will be involved in the fuel bundle assembly operation:

A. Hands-on Assembly of Fuel Bundle Skeleton
B. Horizontal Insertion of Rods in the Remote Environment
C. Remotized Vertical Inspection.

	Number Required	Status
A. Hands-on Assembly of Fuel Bundle Skeleton		
1. Surface Table	2	A
2. Assembly Cradle	2	C
3. Laser gauge	2	C
4. TIG Welder	2	A
5. Metallographic Preparation System	1	A
6. Optical Microscope	1	A
B. Horizontal Insertion of Fuel Rods in the Remote Environment		
1. CCTV System	2	C
2. Retrieval System for Hardware Components	4	C
3. Rod Insertion Machine	4	E
4. TIG Welder	4	B
5. Powered Torque Wrench	4	C
6. Serial Number Reader	4	E
7. Bundle Skeleton Fixture	4	B
8. Hold-Down Spring Compressor System	4	E
9. Apparatus for Upending Bundle	2	C
C. Remotized Vertical Inspection		
1. Straightness and Envelope Gauge	2	D
2. Water Channel Measurement Apparatus	2	C
3. Guide Tube Alignment Gauge	2	C
4. CCTV System	2	B
D. Bundle Rework Station		
1. Electro-Mechanical Manipulator	1	A
2. Master-Slave Manipulators	4	A
3. Grinder	1	B
4. Drill	1	B
5. Welder	1	B
6. Disassembly Fixture with Upender	1	C
7. Hold-down Spring Compressor	1	E
8. Powered Wrench	1	B
9. End Fitting Extractor	1	E
10. Rod Puller	1	E
11. Rod Transfer Mechanism	1	D
12. Shear	1	C

TABLE 5. GENERAL EQUIPMENT NEEDS — ROD AND BUNDLE ASSEMBLY

		Number	Status
1.	Overhead Cranes	10	A
2.	Master-Slave Manipulators	72	A
3.	Electro-Mechanical Manipulators	8	A
4.	Small Parts Transfer System	2	C
5.	Computer a. Accountability b. Inspection and Calibration Data c. Parts Inventory d. Automated Operations Control and Feedback	1	A
6.	Waste Disposal System	1	C
7.	Equipment Decontamination System	2	C

4.3 GENERAL DESCRIPTIONS

The following comments apply to the assembly equipment listed in Tables 3, 4, and 5.

TABLE 3. FUEL ROD ASSEMBLY EQUIPMENT

1. Weld First End Cap. All components are commercially available.

2. Rod Identification. All components are commercially available.

3. Inspect First End Cap Weld. Ultrasonic components are commercially available but will require some modifications including construction of fixtures. Diameter will be checked with a commercially available ring gauge.

4. Dry Clad and Internals. All components are commercially available.

5. Dry Pellets. Pellets will be held in bins of an automatic storage and retrieval system until needed in the rod loading area. When requested, the automatic picker will retrieve the containers and place them on a transporter feeding the vacuum ovens. Containers will be handled by a loading and unloading device at each oven. After completion of the drying cycle, samples will be analyzed by use of a remotely operated moisture analyzer and the drying lots released if satisfactory. While some individual components are available commercially for the steps in these operations, design work will be required to adapt them for a remote application.

6. Assemble Pellet Stacks. Pellets will be pushed off trays used during the storage and drying phases to form fuel rod stacks with some nominal weight determined by a load cell weighing system. Although some commercial designs might be used as a starting point, modification may be necessary to withstand the high level of radioactivity.

7. Verify Stack Length and Weight. The pellet stacks will be formed into a single column, the length checked for specification compliance by use of a mechanical gauge and the weight rechecked on a load cell weighing system. All equipment will be custom designed and built.

8. Visually Inspect Pellets. A combination of closed circuit television and laser surface flaw inspection will be utilized to detect pellets with unacceptable surface conditions (cracks, chips, etc.). The rejects will be removed and acceptable pellets substituted. The pellet column length and weight will then be redetermined. Extensive development is needed before application to commercial operation.

9. Load Pellets and Internals. The stack consisting of fuel pellets and first end hardware internals will be assembled, aligned with the open end of the cladding, and then inserted. Present fuel assembly fabrication plants have equipment designs which lend themselves to modification for remote operation. A scanning system will detect the rod serial number (SN) embossed on the end cap and match the SN with stack weight and enrichment code. While prototypes of this equipment have been built and demonstrated, more development is needed before application to commercial operation. Scanning heads will

also be installed at other stations for accountability purposes.

10. Verify Seating of Pellet Stack. Custom modifications to a commercially available mechanical depth gauge will be made to verify that the distance between the end of the cladding and fuel stack is within specification.

11. End Decontamination. Extensive development of an alpha monitor is needed to check for contamination at the open end of the cladding after rod loading and removal of the plastic collar. If present, a brush or abrasive type cleaner will be utilized to remove it. Final selection of this equipment will require some evaluation. If satisfactorily clean, the final components (hardware internals and second end cap) will be inserted. A design effort will be needed for equipment to accomplish this task automatically.

12. Weld Second End Cap. A laser system will be installed in the cold area and extensive development is needed to link the weld box by a series of mirrors in a labyrinth to minimize maintenance. The weld chamber, fixturing, evacuation system, and inert atmosphere system will have to be designed for remote application.

13. Pressurize and Seal Weld. After positioning in the rod support, one rod end cap will be inserted into the pressurization cell. A laser will drill a small hole in the end cap, the rod will be sealed just in the area of that end cap, and the pressurization gas applied. When the rod is filled, the laser will be defocused to weld the hold closed. A remote installation of the laser in a cold area such as used in the previous step will facilitate maintenance. All equipment will require either modification of commercially available equipment or custom designs.

14. Sample for Weld Inspection. A pneumatic tube transfer system will be used to remove weld samples from the fabrication area. The samples will be mounted and polished on standard metallographic equipment. The examination will be performed on a commercially available metallograph. Corrosion testing will be accomplished in an autoclave.

15. Initial Count and Sonic Leak Detection. Extensive development of an alpha monitor is required. Some modifications to commercially available sonic leak detection equipment will be required for remote utilization. The system will sense high frequency noise created by the pressurization gas leaking through a hole in the rod. Such a defect could cause contamination to be carried into later processing steps.

16. Inspect Second End Cap Weld Ultrasonically and Dimensionally. Same as 3 except modified for remote application.

17. Neutron Interrogation. Commercially available equipment will have to be modified somewhat to function properly with the high gamma level present.

18. Inspect Rod Visually and Dimensionally. A modified closed circuit television system will allow an operator to perform a visual inspection of the rods. Laser systems will be used to check the rod length, weld undercut, and bow.

19. Helium Leak Check. Rods (numbering one complete assembly) will be loaded into a tray that will be placed into a vacuum chamber. The evacuation and leak detector components will be mounted in the cold area to facilitate maintenance operations with adequate isolation to prevent the spread of any contamination which might be pulled over from the chamber. The required equipment is commercially available with some modifications required.

20. Clean. Stainless steel tanks equipped with rotating brush assemblies will be used to clean the traversing rods. A hot air dryer will remove moisture at the exit. Modified commercially available equipment will be used.

21. Verify Fuel Rod Cleanliness. **Because of high background radioactivity levels, extensive development of an alpha monitor is needed.**

22. Storage. Rods will be stored horizontally on custom cascading table trays. A computer will control material entry and exit as well as maintain accountability records. Provision will also be made for storage of rods requiring rework. Design effort will be required for this facility.

23. Rod Rework Station. Rods which have an unacceptable level of surface contamination will be cleaned with nonflammable organics or abrasives and rechecked with an alpha monitor. Rods which cannot be successfully reworked will be cut open with a tubing cutter, flared to facilitate pellet removal, and unloaded. The pellets will be weighed, transferred to the pellet stack assembly area, and visually inspected by closed circuit television before entering the process streams. All equipment will be modified commercially available designs except for the rod unloader which must be designed **and the alpha monitor which requires extensive development.**

24. Rod Transfers. Rod movement from any station in which a rod is identified as needing rework will be handled by the integrated rod handling system.

TABLE 4. FUEL BUNDLE ASSEMBLY EQUIPMENT

A. HANDS-ON ASSEMBLY OF FUEL BUNDLE SKELETON

A.1 Surface Table. Item is commercially available.

A.2 Assembly Cradle. This unit will be mounted on the surface table (A.1) and will provide support for the spacer grids and lower end fitting during fabrication of the skeleton. Current fuel vendor designs could be used since this will still be a hands-on operation, but the cradle could be customized for the particular fuel assembly configurations that will be fabricated.

A.3 Laser Gauge. To verify proper alignment of all assembly cradle components, a customized laser system will be utilized.

A.4 TIG Welder. For welding guide tube nuts ind inserts, commercially available equipment will be used.

A.5 Metallographic Preparation System. Weld samples will be mounted and polished on commercially available equipment.

A.6 Optical Microscope. Weld samples will be examined on a commercially available microscope or metallograph.

B. HORIZONTAL INSERTION OF FUEL RODS IN THE REMOTE ENVIRONMENT

B.1 CCTV System. A closed circuit television system will be utilized to monitor the bundle fabrication operations and perform visual inspections. Modifications to commercially available equipment will be needed to provide the required capabilities.

B.2 Retrieval System for Hardware Components. In order to provide a supply of the necessary hardware for fabrication, a computer controlled retrieval and transfer system will be needed. The system will have tc be designed for this specific application using commercially available components.

B.3 Rod Insertion Machine. To install fuel rods in the bundle skeleton, a push or push-pull mechanism will be utilized. It will be necessary to modify present designs of fuel vendor equipment for remote operation.

B.4 TIG Welder. Commercially available welding equipment modified for remote application will be employed to weld the inserts, upper guide tube nuts, and retainer bolts.

B.5 Powered Torque Wrench. A powered wrench that is capable of supplying a preset amount of torque for tightening the upper guide nuts and retainer bolts will have to be custom built for remote operation.

B.6 Serial Number Reader. See Table 3, number 9.

B.7 Bundle Skeleton Fixture. This device will hold the skeleton in place horizontally for insertion of fuel rods and final assembly. Current designs for hands-on assembly will have to be modified for the remote environment.

B.8 Hold-down Spring Compressor System. A device to compress the bundle hold-down spring(s) will have to be designed to facilitate installation of the retainer and retainer bolts.

B.9 Apparatus for Upending Bundle. After completing the bundle, it will be oriented vertically for inspection. To prevent distortion during lifting of the bundle with a crane, a support frame will have to be utilized. The design will be similar to equipment used now in commercial fuel assembly production but customized for remote handling.

C. REMOTIZED VERTICAL INSPECTION

C.1 Straightness and Envelope Gauge. Instrumentation and modification of present fixture designs to allow remote measurement of the specified parameters will be required. Individual components are commercially available.

C.2 Water Channel Measurement Apparatus. Modification of mechanical gauges presently utilized will be necessary as well as consideration of radiation effects on calibration.

C.3 Guide Tube Alignment. A dummy control material assembly built to the maximum acceptable dimensions will be inserted into the guide tubes and the force required to withdraw it measured on a gauge. Design of a remote reading gauge will be required.

C.4 Closed Circuit Television System. A CCTV system will be utilized to perform all visual inspections remotely. Only slight modifications to commercially available equipment designed for high radiation environments will be necessary.

D. BUNDLE REWORK STATION

D.1 Electro-Mechanical Manipulator. Flexibility will be needed in the rework station capabilities as the type of operations which must be performed will vary. This manipulator will handle the heavier lifting jobs which cannot be performed with master-slave unit. The equipment is commercially available.

D.2 Master-Slave Manipulators. Same as D.1 except for jobs requiring less lifting capability. The equipment is commercially available.

D.3 Grinder. Applications foreseen for this tool include grinding welds down for bundle disassembly and minor grid repairs. A commercially available unit will be modified for remote operation.

D.4 Drill. If a bundle must be disassembled, the insert welds will have to be drilled out. A commercially available unit modified for remote operation will be utilized.

D.5 Welder. Some welds will have to be performed during rework such as guide tube nuts and retainer bolts. Modified commercially available equipment will be used.

D.6 Disassembly Fixture with Upender. For major rework operations, the bundles will be rotated to a horizontal orientation using a support frame (see B.9) and then placed in a disassembly fixture which will clamp it. The fixture will be similar to the assembly cradel, A.2, and bundle skeleton fixture, B.7.

D.7 Hold-Down Spring Compressor. If the bundle has to be disassembled, the upper end fitting, retainer, and holddown spring(s) will have to be removed. See B.8.

D.8 Powered Wrench. The retainer bolts and guide tube nuts will have to be removed when bundle disassembly is required. See B.5.

D.9 End Fitting Extractor. A design will have to be developed for an apparatus to remove the upper end fitting when fuel rods are pulled.

D.10 Rod Puller. This equipment will be utilized when either individual or complete rod removal is necessary. Single rods which are damaged could be pulled and returned to the rod rework station for opening and recycle of pellets. The bundle would then be returned to the assembly area for insertion of replacement rods and processing in the conventional manner. A design for the puller will have to be developed.

D.11 Rod Transfer Mechanism. Rods which are pulled from rejected assemblies will be transported to the rod rework area by this equipment. A design effort will be necessary.

D.12 Shear. When complete disassembly of a bundle is necessary because of defects in the skeleton components, the entire sleleton will be cut into small pieces by this machine and discarded. Modification of currently available equipment will be required.

GENERAL EQUIPMENT NEEDS – ROD AND BUNDLE ASSEMBLY

1. Overhead Cranes. Cranes will be utilized for the installation, repair, and removal of heavy equipment from the process line. Some will be used for lifting bundles. Commercially available equipment will be satisfactory for this application.

2. Master-Slave Manipulators. These devices will be provided primarily for maintenance activities requiring maximum flexibility with light lifting requirements. They will be used for a limited number of routine manufacturing operations. Commercially available units will be satisfactory.

3. Electro-Mechanical Manipulators. For maintenance activities which exceed the capacity of master-slave manipulators, these units will be necessary. The equipment is commercially available.

4. Small Parts Transfer System. To facilitate the movement of small parts, including those for maintenance, within the remote environment, some type of transfer equipment will be needed. The installation will use custom equipment.

5. Computer. A computer with adequate redundancy will be utilized for special nuclear material accountability, data acquisition, storage, and processing of inspection and calibration data, maintaining parts inventory records, and automated operations control/feedback. Commercially available equipment will be programmed to perform the necessary functions.

6. Waste Disposal System. A significant quantity of waste material from the production and maintenance operations will require disposal. It will be compacted and placed in suitable containers for shipment. Custom equipment will be employed.

7. Equipment Decontamination System. For contact maintenance, it will be necessary to remove loose contamination in order to minimize personnel exposure. Custom scrubbing devices, vacuums, and compressed air nozzles will be utilized.

5. SCRAP AND REWORK PROBLEMS

5.1 SCRAP AND REWORK OPTIONS

Manufacture of highly radioactive ThO_2-UO_2 mixed oxide (ThoMOX) fuel rods and bundle assemblies assumes all processes will be performed in a remote environment. The objective of this subtask is to consider effective methods for handling ThoMOX fuel rods that fail inspection.

Some of the options are:

- Rework of the specific rod defect followed by incorporation of the rod into a fuel bundle
- Opening of the rod, removal of internals, recycling of fuel, and disposal of waste such as contaminated cladding.

Therefore, an initial decision will be required as to what direction to take depending on the nature of the defect.

Current light water reactor (LWR) fabrication facilities operate with very low reject rates in the manufacture of fuel rods and bundles. Mechanization an automation of remote operations in a ThoMOX facility should similarly result in very low reject rates. However, a work station must be provided in the remote facility to handle reject rods even if only very small quantities of rods fail inspection. Furthermore, this work station will provide backup capabilities in case of unexpected higher reject rates for whatever reason.

5.2 SCRAP AND REWORK OPERATIONS

Based on current manufacturing practice, the following types of defects have been categorized as the most likely to occur in a ThoMOX facility: (a) first end cap weld defects, (b) contamination of second end cap weld zone, (c) oversize second end cap weld, and (d) general defects. Following is a set of operations that describe procedures required to process rods that fail inspection.

First End Cap Weld Defects

Welding of the first end cap will be performed in a nonradioactive environment so that first end cap weld defects should be easy to repair. At the present time, standard commercial practice for rods that fail ultrasonic inspection is simply to weld the end cap a second time and reinspect the end cap to verify that the weld defect has been eliminated.

Contamination of Second End Cap Weld Zone

Contamination of the second end cap weld zone has a higher probability of occurring than most other types of defects. Fuel rods showing excess surface contamination will be automatically ejected from the line to the rework station.

After a sufficient number of reject rods have accumulated, decontamination will be performed as follows: While the rod is mechanically rotated, the contaminated weld zone will be (a) wiped with a lint-free pad wetted with an approved cleaner and resurveyed. If the contamination has not been eliminated, the contaminated zone will be cleaned with an abrasive material and resurveyed. If contamination still remains, nitric acid will be used to clean the weld zone. Should any of these procedures decontaminate the weld zone, the fuel rod will automatically be transferred to an adjacent storage area. When a sufficient number of rods are accumulated, the rods will be automatically inserted back into the assembly line. Should all of the decontamination procedures fail, the rod will be handled as described under the procedure entitled General Defects.

Oversize Second End Cap Weld Zone

Fuel rods with an oversize second end cap weld diameter will be automatically ejected from the line to the rework station. The rework operation will be performed after a sufficient number of such rods have accumulated to justify this special operation. While the rod is mechanically rotated, an automated grinder will be employed to reduce the size of the weld diameter to meet specifications. After passing inspection, the rod will automatically be transferred to an adjacent storage area. The rods will automatically be fed into the assembly line after sufficient number of reworked rods have been accumulated.

Rods with General Defects

The phrase "rods with general defects" is defined as rods which fail inspection after rework operations or are rejected for other causes. Rods with general defects that cannot be easily reworked will be cut open with a modified tubing cutter, followed by flaring of the open end to facilitate removal of the pellets and internal hardware. Salvageable metal internal components will be recycled. Pellets will be visually examined and redried before return to the rod loading station.

Defective Fuel Bundle Assemblies

Out of tolerance fuel bundle assemblies are very unlikely. Current LWR experience shows defective fuel bundles are probably most likely to occur by handling at the reactor site; e.g., by dropping or bumping a fuel assembly. If very simple repairs cannot be accomplished using remote manipulators, the bundle will be disassembled at the rework station by removing end fitting components, guide and instrument tubes, keying the spacer grids open, and removing the fuel rods. After inspection, acceptable rods will be returned to rod storage or bundle assembly, while reject rods will be handled as described in the previous section on general defects.

6. FUEL ROD & BUNDLE ASSEMBLY INSPECTION PLAN

6.1 GENERAL CONSIDERATIONS

I. It is recognized that the inspection equipment to be utilized must operate in a hostile environment for several years. Because of this, reliability must be stressed in the selection/design of equipment. The reliability requirement implies the following general criteria, all of which must be applied to the selection/design based upon sound engineering practice:

a. No single component failure shall directly or indirectly result in complete inability to perform measurement.

b. Components and subsystems deemed to have a high probability of failure shall be easily removable or accessible for repair.

c. Components with a high probability of failure shall be easily replaceable with available spare parts.

d. Proven technology shall be emphasized.

e. The equipment shall be selected/designed so that, as far as practicable, multiple inspection operations can be conducted.

f. Output data as necessary should be computer compatible and easily available at the time of measurement so that continuous checks on data quality can be performed. Calibration, based upon standards traceable to the NBS, shall be performed on all measurement systems with sufficient regularity to ensure that the accuracy requirements are met.

g. Equipment selection/design shall be accomplished to preclude damage to fuel assemblies and/or components during handling, and inspection operations. Sharp corners, protrusions, etc., should be avoided especially when near any path of fuel assembly movement. All surfaces, fixtures, members, etc., which may come into contact with the fuel assemblies should provide proper safety features (lead in, breakaway members, etc.) to insure no inadvertent damage to the assembly. Mock-up tests shall be performed, simulating working conditions, anticipated accident conditions, component removal for repair/replacement, etc., to ensure reliable continued operation.

II. Sampling frequencies, where specified, are based upon actual practice at a commercial fuel assembly fabrication plant. They were developed from engineering/QC judgment resulting from pilot production runs and subsequent production data. These frequencies should not be considered firm requirements and are given only to illustrage current practice. The selection of sampling frequencies for CoMOX and ThoMOX fabrication must be determined from qualification tests and pilot production runs. Continued production will then verify the adequacy of the sampling plan selected.

This inspection plan identifies those steps necessary to insure that the fabrication of fuel rods and bundle assemblies, containing fuel with a high level of radioactivity, meets adequate quality requirements for safe, economical, efficient fabrication and ultimate operation.

Normal hands-on operation will be utilized wherever possible. In the fuel rod fabrication, the first end cap weld is the only operation that can be performed outside of the hot cell area. In the fabrication of the fuel assembly, hands-on operation will be performed during sub-assembly. This sub-assembly will consist of spacer grids, guide tubes, instrument tube and associated spacer sleeves and a lower end fitting. Rod loading and final assembly will be accomplished within the hot cell area.

Measuring and test equipment used for hot cell application shall be specifically modified, where practical, to permit a minimum of components within the hot cell area.

6.2 INSPECTION STEPS

Key inspection steps are as follows:

FUEL ROD ASSEMBLY/COMPONENT INSPECTION PLAN

COMPONENT/MANUFACTURING STEP	TYPE OF INSPECTION	METHOD
1. First End Cap Weld	1. Flaw Detection	1. Ultrasonic Test
	2. Dimensional Check	2. Ring Gage (accuracy 0.001")
	3. Surface Defect & Weld Coloration	3. Visual @ 6X
	4. Verify Numerical Sequence of Rods	4. Visual
	5. Corrosion - One Sample Weekly Per Weld Station	5. ASTM-G2
	6. Metallographic Exam (One Per Ninety Welds)	6. Standard Specimen Mounting Viewed at 100X for Weld Imperfections
HOT CELL OPERATION		
2. Fuel Pellets - Drying, Preparation for Loading All Visual Inspection Operations Within Shielded Area are Performed Using CCTV Systems	1. Verify Incoming Fuel Pellet Lot and Enrichment Symbol	1. Visual
	2. Pellet Condition	2. Visual Insp. for Chips and Cracks
	3. Moisture Evaluation	3. CEC Analyzer
	4. Verify Stack Weight and Stack Length	4. Electronic Balance (accuracy 0.5 gm Insp. of Length Against Scale (accuracy 1/32")
3. Fuel Rod Loading	1. Identify Fuel Rod S/N to Fuel Stack Information	1. Record on Route Card
	2. Verify Seating of Pellet Stack	2. Length Gage (accuracy 1/32")
	3. Verify Decontamination of Second End Cap Weld Zone	3. Alpha Monitor (accuracy 0.1 DPM/cm^2)
4. Second End Cap Weld	1. Verify Enrichment Identification of End Cap	1. Visual
	2. Alpha Contamination Insp.	2. Alpha Monitor (accuracy 0.1 DPM/cm^2)
	3. Flaw Detection	3. Ultra Sonic Test
	4. Dimensional Insp.	4. Ring Gage - Automated System
	5. Corrosion - One Sample Weekly Per Weld Station	5. ASTM G2
	6. Metallographic Exam - One per Ninety Welds	6. Standard Specimen Mounting - Viewed at 100X for Weld Imperfection

FUEL ASSEMBLY/COMPONENT INSPECTION PLAN

COMPONENT/MANUFACTURING STEP	TYPE OF INSPECTION	METHOD
5. Fuel Rod Pressurization	1. Verification of Pressurization Setup	1. Simulated Fuel Rod With Pressure Gage in One End (accuracy 2 PSIG)
6. Fuel Rod Seal Weld	1. Metallographic Exam One Per Ninety Welds	1. Standard Specimen Mounting Viewed at 100X for Weld Imperfections
7. Fuel Rod Neutron Interrogration (Front End Control of Enrichment Mandatory).	1. Identify Pellet Gaps and Enrichment	1. Simulated Fuel Rod With Pellet Gaps and Various Pellet Enrichments
8. Fuel Rod Inspection	1. Straightness	1. Vertical Scan Using Laser Telemetric System (accuracy 0.001")
	2. Surface Condition	2. Visual - Surface Standards
	3. Length	3. Length Gage of Scale (accuracy 1/64")
	4. Alpha Contamination Insp.	4. Alpha Monitor (accuracy 0.1 DPM/cm^2)
9. Fuel Rod Leak Test	1. Helium Leak Test	1. Mass Spectrometer
10. Fuel Rod Storage	1. Verification of Records	1. All Information of Fuel Rod Traceability Will be Documented on Computer Printout Sheet
	2. Release Fuel Rods for Storage	2. Formal Release Documentation

FUEL ASSEMBLY/COMPONENT INSPECTION PLAN

Note: Quality Control shall issue a release sheet identifying all components by serial number that will comprise a specific fuel assembly. QC will verify all components against this release sheet.

OUTSIDE HOT CELL AREA

COMPONENT/MANUFACTURING STEP	TYPE OF INSPECTION	METHOD
1. Assembly Fixture	1. Verification of Proper Set-Up	1. Verify Against Mfg. Procedure and Eng. Requirements
2. Fabrication of Fuel Assembly Skeleton	1. Inspect Spacer Grids for Proper Set-Up	1. Verify With Eng. Drawing Requirements
	2. Inspect Instrument Tube Flare	2. Dimensional (accuracy 0.010")
	3. Inspect Orientation of Spacer Sleeves & Retainer Sleeve	3. Visual
	4. Inspect Spacer Grid Hard Stops to Assure Damage has not Occurred During Insertion of Guide Tubes and Instrument Tube	4. Visual
	5. Visually Inspect Lower End Fitting to Spacer Grid Insert Welds for Weld Imperfections	5. Visual
	6. Metallographic Examination of Insert Welds - One Per Thirty-Two Welds	6. Standard Specimen Mounting Viewed at 100X
	7. Verify Seating of Shoulders of Guide Tube Plugs to Lower Grillage Surface	7. Visual
	8. Verify Torque of Lower Guide Tube Nuts	8. Torque Gage (accuracy 0.5%)
	9. Visually Inspect Lower Guide Tube Nut Welds for Weld Imperfections	9. Visual

FUEL ASSEMBLY/COMPONENT INSPECTION PLAN

COMPONENT/MANUFACTURING STEP	TYPE OF INSPECTION	METHOD
3. Insertion of Fuel Rods and Final Component Assembly Step 3 is performed inside hot cell area.	1. Verify Proper Installation of Subassembly in Assembly Fixture	1. Visual (Visual Inspections are to Utilize TV or Optical Aids)
	2. Verify Enrichments Symbols and Rod Identification	2. Visual - Record Data
	3. Visually Inspect Spacer Grids and Rods to Ensure no Damage During Fuel Rod Loading	3. Visual
	4. Visually Inspect & Measure Fuel Rod to Lower End Fitting Grillage Clearance	4. Scale or Thickness Gage (accuracy 0.001")
	5. Visually Inspect Upper End Fitting to Spacer Grid Insert Welds for Weld Imperfections	5. Visual
	6. Metallographic Examination of Insert Welds (One Per Thirty Two Welds)	6. Standard Specimen Mounting Viewed at 100X
	7. Verify Torque of Upper Guide Tube Nuts	7. Torque Gage (accuracy 0.5%)
	8. Visually Inspect Upper Guide Tube Nut Welds for Weld Imperfections	8. Visual
	9. Verify Proper Installation of Holddown Springs, Retainer and Retainer Bolts	9. Visual
	10. Visually Inspect Retainer Bolts for Weld Imperfections	10. Visual
	11. Perform Fuel Assembly Envelope Inspection	11. Envelope Inspection - Laser Telemetric Scan System (accuracy 0.001")
	12. Perform Fuel Rod Spacing Inspection	12. Electronic Strain Gage Probing Unit with Computer Readout (accuracy 0.001")
	13. Perform Guide Tube Alignment Inspection	13. Control Rod Assembly Test Gage (accuracy 0.002")
	14. Perform Final Inspection for Defects and Cleanliness	14. Visual
	15. Evaluation of Test and Inspection Results	15. Evaluate Against Specification and Drawing Requirements
	16. Release Fuel Assembly for Storage	16. Formal Release Documentation

7. MAINTENANCE OF ASSEMBLY LINE EQUIPMENT

7.1 EQUIPMENT MAINTENANCE OBJECTIVES

Remote manufacturing operations will necessitate modifications to commercially available equipment as well as custom design of specialized equipment. In addition, the equipment used in a remote environment will require application of unique approaches to installation, maintenance, repair, replacement, and calibration of the specialized equipment. The objective of this subtask is to provide a general approach to maintenance of equipment (that currently has not been designed in detail) for manufacture of fuel bundles in a remote environment while a general design objective is to minimize all maintenance requirements. By necessity, some equipment will require regular maintenance during its life while other equipment will need minimal maintenance if the proper materials of construction and assembly techniques are employed. Equipment that will require higher levels of maintenance will be machines with a number of moving parts and complex electronic control systems. Equipment with few or no moving parts and no wear items such as support racks, magazines, surface tables, etc., will require little or no maintenance.

Equipment requiring replacement of wear parts and anticipated high levels of maintenance will be designed for repair either in-situ or at a repair station in each line. These stations will be equipped with master-slave and electro-mechanical manipulators, cranes, stereo television system, and viewing windows. Low maintenance items will be either repaired in place by use of either master-slave/electro-mechanical manipulators or cell entry. The bundle assembly areas should not present a great problem for contact maintenance since that operation will be relatively "clean" in that all radioactive material will be sealed in the fuel rods. All rods will be removed from the area prior to entry for maintenance purposes. Because the radiation from the fuel will be almost all gamma at an energy level low enough that gamma activation (materials of construction becoming radioactive exposure to high radiation levels) will not occur, contact maintenance of the equipment should pose no radiation problems. An attempt will be made to keep the fuel rod assembly areas as clean as possible in the event an entry is necessary for maintenance. Special attention will be focused on rod loading since the chance for spread of contamination due to particulate matter is high. Early detection of leaky rods will be crucial to prevent carrying contaminated components into later processing steps. The level of radiation at each processing step, after removal of fuel pellets and rods, will be determined by the amount of contamination with the level decreasing continuously from rod loading to final bundle inspection. However, remote maintenance equipment will still be justified in the bundle assembly area for small repair jobs where it would be impractical to remove all fuel or in the event of an accident where rod integrity is breeched and severe contamination results.

7.2 CATEGORIES OF EQUIPMENT

The nature of the equipment significantly affects the methods what will be used in rework and repair. Thus, the equipment will be categorized as follows: 1) fixed peripheral equipment (in a non-radioactive area) designed with the expectation of contact maintenance, 2) in-cell cranes and electromechanical and master-slave manipulators, for which maintenance techniques have been extensively developed, and 3) unit process equipment of varying degrees of complexity which will be designed with emphasis on simplicity and modular replacement components to accomplish repairs in-place within the remote environment (if possible). A list of equipment items falling under categories 2 and 3 has been provided previously in Section 4.0, "Assembly Line Equipment Needs." This section will focus on Category 3; i.e., the unit process equipment needed to manufacture highly radioactive fuel bundles.

7.3 MAINTENANCE PHILOSOPHY AND CRITERIA

There are three basic techniques for the maintenance of process equipment in a remote facility: 1) zero maintenance, 2) remote maintenance, and 3) contact maintenance. These techniques vary in initial cost, time required for returning the line to service, and method of service. A combination of all of these techniques will be applied in the rod and bundle assembly line to accomplish the desired maintenance function. The application of any maintenance technique must take into account the limitations, both present and future, imposed on allowable personnel exposure.

The criteria upon which the choice of equipment design and maintenance concept will be based are:

- Where possible, standardized equipment will be used to facilitate procurement and minimize spare parts inventory
- Equipment components will be of modular design to facilitate replacement
- Where possible, equipment components will be held in place by toggle clamps or special fasteners to facilitate removal or replacement.
- Remote process equipment will be maintained by remote replacement of failed components
- Equipment will be designed for long life but will be capable of being maintained in place or removed for replacement or repair
- Sufficient access space will be provided to provide for maintenance of equipment modules in-situ or for removal of an entire

- piece of equipment and transfer to the decontamination and maintenance cell(s)
- Replacement components will be stored in areas adjacent to components with high mortality rates
- Equipment will be maintainable without disturbing adjacent equipment and operations. Routine calibration and servicing will be performed from a remote console. Master-slave manipulators will be considered to be a backup in case of emergencies
- If personnel must be used to maintain equipment, then either the equipment will be removed from the process line and decontaminated or else all SNM will be removed from the processing area. In-cell maintenance will be permitted in the rod manufacturing and bundle assembly areas after the fuel has been removed
- Mockup facilities will be used to test equipment and develop maintenance procedures and tools prior to insertion in the remote area
- Construction materials will be selected to minimize decontamination operations
- To provide for flexibility in case of an emergency for repair, material transfer operations will be designed to permit bypass of the breakdown and allow surge production to be performed in the parallel operating line
- Where use of components sensitive to radiation is mandatory, shielding will be used to protect the susceptible equipment
- Ultimately, all equipment and materials used in the remote area will be disposed of as waste which mandates design features that promote decontamination and disposal
- Standard, commercially available small motors will be modified (as per ANL-Idaho) prior to insertion in the remote environment to extend the life of the motors

- Special, commercially available lubricants (as per ANL-Idaho experience) will be used where lubrication is required
- Routine smears will be taken in each manufacturing zone; i.e., the rod loading, rod manufacture, rod storage, bundle assembly, and bundle storage zones to check for radioactive contamination. The data will be computerized for maintenance purposes. Zone supervisors will be responsible for keeping their zones free of loose contamination
- Stereo TV will be used to conduct maintenance requiring depth perception
- Where possible, major equipment will be mounted outside the hot processing area with only the parts that must contact the high activity components inside (i.e., end cap laser welder linked to hot area by mirrors, helium leak detector system connected to chamber in hot area)
- The computer will be utilized to store diagnostic repair information and identify trends for preventive maintenance
- Temperature, vibration, and sound monitors will be used to detect any unusual signs of equipment operation that might indicate the beginnings of a major failure in order to minimize damage
- A small parts transfer system; i.e., an electric shuttle cart mounted on the inner wall of the cell will be used for rapid transfer of minor repair components
- Cranes plus electromechanical manipulators on rails will be used to transfer heavy equipment when major repairs are required

The plant in which the rod and bundle assemblies will be manufactured will include several repair areas. These repair areas will be a remote repair cell, a decontamination cell, and a contact maintenance cell

- The remote repair cell will provide:
  a) specialized maintenance equipment so that equipment can be remotely maintained

b) jigs, fixtures, tools, and services to repair, calibrate, and demonstrate that the equipment is operable before returning to the process cell

c) capability to disassemble equipment into components for future spare parts or be prepared for disposal as scrap

d) additional decontamination of disassembled components required to remove SNM not removable from assembled equipment.

- The decontamination cell will provide:

  a) services required to remove SNM accumulations from assembled process equipment

  b) accountability measurements on decontaminated solutions and residual holdup.

- The contact maintenance cell will provide:

  a) alpha-contained glove box for hands-on maintenance

  b) tunnel-suit entry port for more detailed repair operations on certain components.

8. IN-PROCESS STORAGE REQUIREMENTS

8.1 DEFINITIONS

Manufacture of highly radioactive ThO_2-UO_2 Mixed Oxide (ThoMOX) fuels will necessitate remote processing with requirements for in-process storage of special nuclear materials. The term in-process is defined as goods in manufacture, as distinguished from raw materials or from finished products, while storage is defined as a repository from which accumulated articles may be drawn upon as needed. Fuel rod manufacturing and inspection operations generally require very short term in-process storage (e.g., one hour or less) that is primarily for the purpose of ensuring a ready supply of fuel rods for processing at each station. Therefore, in case a minor breakdown should occur, the flow of rods will continue with a reasonable length of time allowed for minor maintenance problems.

Short-term in-process storage areas will be immediately adjacent to the unit operation stations and will incorporate fuel rod transfer mechanisms. The transfer mechanisms will accept rods from a previous operation, and after performance of the specified operation, the system will transfer the rods to the next station.

Longer term (up to two days) in-process storage will be associated with fuel bundle assembly operations because of the need to accumulate 264 fuel rods necessary to manufacture a single bundle assembly. Furthermore, provision will be made to have a sufficient supply for assembly of several fuel bundles.

It should be emphasized that any long term in-process storage requirements will be kept to a minimum in order to minimize the quantity of special nuclear materials (SNM) resident in the process area. The following discussion will focus on specific means to keep storage as low as reasonably possible.

8.2 IN-PROCESS STORAGE PHILOSOPHY

Assumptions that apply to the in-process storage philosophy for ThoMOX fuel rods and bundle assemblies are as follows:

- Fissile material quantities will be kept as low as reasonably possible in the process area.
- There will be no QC hold points; reject rods will be immediately transferred to the rework area.
- There will be no manufacturing hold points other than the normal backlog of rods required at each unit operation to ensure a continuing flow of material while any minor breakdowns are being repaired.
- A large, main fuel rod storage area will be provided in an area immediately following the station where fuel rod operations are completed, but preceding the fuel bundle assembly stations.

- Reject fuel rods will be processed at regular intervals to minimize SNM residence times.

8.3 STORAGE REQUIREMENTS

The purpose of this section is to categorize the stages of manufacturing that will require storage. The hands-on and remote storage categories are as follows:

- Prepared rods, out-of-cell
- Fuel Bundle skeletons, out-of-cell
- Acceptable, completed fuel bundles, in-cell.

The storage requirements above are listed for completeness; however, they are outside the scope of this program and therefore will not be discussed further. In-cell storage categories listed below will be discussed in more detail in this section.

- Rods prepared for loading
- Loaded, finished rods
- Reject loaded fuel rods for rework
- Fuel bundle skeletons
- Reject fuel bundles for rework

A. Storage Area for Prepared Rods. An in-cell storage capacity of 2,000 rods (with the first end cap welded) is specified for an area immediately adjacent to the fuel rod pellet loading station. This area will provide storage for rods prior to loading with fuel pellets. Use of vertical space will be maximized, and automatic gravity feed of the rods will be utilized to feed empty rods to the pellet loading station.

B. Main Fuel Rod Storage Area. The main fuel rod storage area will have a capacity of 5,000 fuel rods. This number of fuel rods is equivalent to approximately nineteen fuel bundle assemblies. However, the primary purpose of this area is to provide storage for rods prior to assembly of fuel bundles. Therefore, assuming no major outages in both bundle assembly lines, the entire main rod storage area should never be necessary, but the storage will be available in case of some unforeseen emergency.

C. Reject Fuel Rod Storage Area. Storage for 50 fuel rods is specified at the reject fuel rod rework area. Although this number is expected to be excessive, it is as easy to provide storage space for 50 rods as it is for 5 rods. Reject fuel rods will not be permitted access to the main fuel rod storage area until reworking has been performed and the rods pass inspection. This will help to ensure that reject rods are not accidentally used in the assembly of any fuel bundles.

D. Scrap Fuel Rod Storage Area. Storage will be provided for 50 fuel rods that will not pass inspection even after rework operations have been performed. In order to minimize the possibility of loose contamination in the rod and and bundle assembly areas, the scrap storage area will be back upstream in an area prior to the rod loading area. The number selected for storage capacity is arbitrary; i.e., the capacity is large enough to accommodate a generally unrealistic number of scrap rods, but small enough so that only a small area is required.

E. Fuel Bundle Skeleton Storage Area. Storage for 20 fuel bundle skeletons will be required in the bundle assembly area. This area will provide storage for bundle skeletons pre-assembled hands-on in non-radioactive area; i.e., bundle skeletons awaiting completion of final assembly.

F. Reject Fuel Bundle Storage Area. Storage for two fuel bundle assemblies will be required to accommodate fuel bundles that might possibly be damaged in handling. This potential for damage in transfer (although highly improbable) exists for a) the remote manufacturing area, and b) the reactor site. The storage area for damaged bundles will be a small segregated zone of the storage area used for completed fuel bundles that have passed inspection and are awaiting shipping.

9. FUEL ASSEMBLY DESIGN CONSIDERATIONS

9.1 GENERAL

Because ThoMOX fuel pellets are highly radioactive, LWR fuel assemblies containing ThoMOX fuel must be manufactured in a remote environment. Furthermore, remote manufacture of highly radioactive fuel assemblies represents more than an order of magnitude increase in difficulty when compared to conventional, hands-on assembly operations. Therefore, the objective of this subtask was to perform a study of possible fuel assembly design modifications that would enhance the ease of fabrication of fuel bundles under the difficult constraints imposed by the requirements for remote (hands-off) fabrication methods. It should be emphasized that the need for fuel assembly design modifications was significantly reduced by alterations to the block flow diagram so that bundle skeletons could be preassembled hands-on to minimize difficult remote assembly operations.

9.2 FUEL ASSEMBLY DESIGN PHILOSOPHY

Design modifications to LWR fuel assemblies should meet certain design criteria to ensure that practicality and functional requirements do not deteriorate. Some of these design criteria are as follows:

- Any changes to the basic fuel assembly design must be feasible from an economic and manufacturing viewpoint for incorporation into a new design.
- Modifications to fuel assemblies should be generic and be applicable to B&W, CE, GE, and W designs.
- The primary objective of any fuel assembly design modifications will be to facilitate remote bundle assembly operations.
- Where possible, small components may be redesigned to minimize the number of such parts for handling.
- Any possible design modification should not deteriorate operational requirements of the fuel assemblies.
- Where possible, design changes should maximize hands-on bundle assembly operations and minimize remote operations.

9.3 POSSIBLE FUEL ASSEMBLY DESIGN MODIFICATIONS

The general goal of this subtask was to consider ways to modify current fuel assembly designs to minimize difficulties encountered in remote construction of fuel assemblies. Any actual redesign of fuel assemblies is outside the scope of this program.

The most important fuel assembly components that could be modified (from the viewpoint of ease of hands-off fabrication) are the grid spacers and the fuel rods. Grid spacer modifications were considered to enlarge the grid spacer holes to more readily accept fuel rods. Two specific alternative grid spacer designs considered are as follows:

1. Starting with a square Zircaloy or Inconel casting with rough holes precast into the square casting (present configuration), circular holes could be drilled to final dimensions to accept the fuel rods and optimize the water channels.

2. Circular zircaloy tubing could be a) cut into short lengths, b) assembled in a fixture to the present general geometry, and tack welded at the tubing ends to approximately duplicate the present configuration.

Both of the previously suggested grid spacer modifications require a modified fuel rod design to provide mechanical support to the fuel rods. One alternative considered was the use of short leaf springs tack welded parallel to the length of the fuel rod and axially located to make internal contact with a modified grid spacer suggested above. For circular grid spacer holes, three of these leaf springs would be required on the circumference of the cladding. For square grid spacer holes, four leaf springs would be required at each grid spacer. The leaf springs could possibly be tack welded at both ends or at one end only, although a free end may produce sufficient rubbing and wear to cause an occasional loss of fuel rod integrity.

The modifications discussed above were evaluated by members of B&W's Fuel Mechanical Design Department and the following comments were offered. Current spacer grid design requires the grid to provide a certain fuel rod pitch with close tolerancing, fuel rod alignment for controlled rod bow, fuel rod and guide tube rigidity for fuel assembly strength and fuel rod grip to prevent fretting. All of above requirements must be met while keeping the flow restriction and neutron absorption to a minimum. While the suggested modifications are plausible, they would present design problems in meeting the above design requirements. The use of a casting for a grid would be too high on pressure drop, too high on neutron absorption, and would probably be cost prohibitive. The circular tubing suggestion would have the same problems as the casting with the additional ones of difficulty in maintaining close pitch tolerances and possible flow blockage.

The fuel rod modifications that are suggested could cause local distortion in the fuel clad or changes in the clad material properties; either of these could cause severe problems during operation. The rod bow resistance would also be very poor with an all spring design and with all springs being in one plane. A six point contact design, four hard stops, and two springs, would probably be required. A fuel rod anti-rotation feature would also be required for the square cell to prevent loose rods.

The above comments are not to be taken as meaning the suggestions would not work, only that they present several significant design problems which would need resolution before initiation of

Other alternate ideas for fuel assembly modifications involve B&W's keyed grid design. These ideas are not presented here because only modifications that are generic are considered; although B&W's keyed grid design has significant advantages over other fuel assembly fabricators' designs with respect to remote assembly operations.

A definite need for a modification was identified for the purpose of enhancing the ease of handling of fuel rods, especially with respect to possible disassembly of fuel bundles requiring rework. The specific modification would involve having a groove machined (prior to welding) in the fuel rod end caps to permit a latching mechanism to grip the fuel rods so that a pulling force could be exerted on the rods in any emergency situation that might arise, such as bundle disassembly.

10. CONCLUSIONS

1. Remote facilities to perform rod and bundle assembly of highly radioactive fuel do not exist.

2. Commercial nuclear fuel fabrication plants utilize highly mechanized fuel rod pellet loading operations that should be adaptable to remote environment conditions.

3. Current state-of-the-art for assembly of fuel rods into bundles involves a combination of manual and mechanized operations. Due to significant constraints imposed by requirements for remote operation, numerous innovations will be required in the application of presently developed equipment.

4. B&W's basic philosophy is to maximize hands-on fuel bundle assembly operations in a nonradioactive area. Based on this philosophy, B&W proposes to preassemble bundle skeletons prior to insertion into the remote environment. This approach will simplify and minimize the remaining remote bundle assembly operations.

5. Areas identified requiring extensive development are a) plastic collar inserter, b) serial number reader, c) laser weld box, d) alpha monitor, e) rod insertion machine, f) hold-down spring compressor system, g) end fitting extractor, and h) rod puller. In addition, the overall computer system and software will probably require some development effort prior to actual design.

6. The inspection plan described in this report is based on current commercial fuel fabrication practice and the plan is appropriate for a remote operations facility.

7. Equipment maintenance poses a special problem in a remote facility. Where possible, equipment will be simple, standardized, reliable, and modular with special fasteners to facilitate removal.

8. Substantial in-process and surge storage has been allocated in needed areas.

9. The need for fuel assembly design modifications was significantly reduced by alterations to the block flow diagram so that bundle skeletons could be preassembled hands-on to minimize difficult remote assembly operations.

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