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LWR NUCLEAR FUEL BUNDLE DATA FOR USE IN FUEL BUNDLE HANDLING

TOPICAL REPORT

W. B. Weihermiller
G. S. Allison

September 1979

Work Performed Under Contract EY-76-C-06-1830
Form 189 Number 210.1

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PACIFIC NORTHWEST LABORATORY
RICHLAND, WA 99352

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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

Although increasing numbers of spent light water reactor (LWR) fuel bundles are moved into storage, no handling equipment is set up to manipulate all of the various types of fuel bundles. This report summarizes fuel bundle information of interest to the designer of such handling equipment. Dimensional descriptions are included with discussions of assembly procedure and manufacturer provisions for handling equipment. No attempt is made to make a complete compilation of dimensional information; the number of fuel bundle designs and design revisions make it impractical.

Because the fuel bundle designs are so varied, any equipment intended for handling all types of bundles will have to be designed with flexibility in mind. Besides the ability to manipulate fuel bundles in space, handling equipment may be required to locate an external surface or to position a cutting operation to avoid breaking a fuel rod pressure boundary. Even with the most sophisticated and flexible handling equipment, some situations will require use of the manufacturers' as-built descriptions of individual fuel bundles.

Because fuel bundle designs are proprietary information, most of the drawings acquired from the manufacturers could not be reproduced in this report. Where possible, pertinent dimensions were taken from these drawings (with the vendors' permission) and applied to composite diagrams.

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LWR NUCLEAR FUEL BUNDLE DATA FOR USE IN FUEL HANDLING

Light water reactor (LWR) spent fuel is removed from the reactors encased in fuel rods that are held together in rigid fuel bundles. The current U.S. inventory of unreprocessed spent fuel is stored in these bundles. As the number of irradiated nuclear fuel bundles increases, it becomes more important that efficient methods of handling these bundles are developed. This study provides information of interest to designers of handling equipment: LWR fuel rod dimensions, fuel bundle dimensions and details, and the design variations that would affect handling equipment design. This information was gathered by contacting the various fuel bundle vendors, visiting their plants, and observing or discussing the design features and assembly of their fuel bundles. Tables 1 and 2 summarize the U.S. spent fuel discharge inventory for 1962 through 1976 with predicted inventories through 1986.

TABLE 1. Actual and Predicted U.S. Spent Fuel Discharge Inventory - 1962 through 1986[(a)]

	Discharged Fuel Bundles						
Year	PWR	Reprocessed PWR	BWR	Reprocessed BWR	Yearly Total Inventory	Cumulative Inventory PWR	Cumulative Inventory BWR
1962	74	74	190	190			
1963	40	40					
1964	36	36	97	97			
1965	38	38	200	200			
1966	36	36	60	60			
1967	40		136	136	40	40	
1968	36	36	183	183			
1969	76	36	119	33	126	80	86
1970	54	36	178	26	170	98	238
1971	114		402	8	508	212	632
1972	282		748		1,030	494	1,380
1973	165		458		623	659	1,838
1974	499		1,335		1,834	1,158	5,011
1975	935		1,070		2,005	2,093	6,081
1976	1,112		1,565		2,677	3,205	7,646
1977	1,346		3,025		4,370	4,551	10,671
1978	1,973		3,142		5,115	6,524	13,813
1979	2,361		3,117		5,478	8,885	16,930
1980	2,924		3,763		6,687	11,809	20,693
1981	3,028		3,679		6,707	14,837	24,373
1982	3,725		5,161		8,886	18,562	29,533
1983	4,509		5,551		10,060	23,071	35,084
1984	5,108		6,283		11,391	28,179	41,367
1985	5,936		8,489		14,425	34,115	49,856
1986	6,420		9,261		15,681	40,535	59,117

(a) Source: U.S. LWR Spent Fuel Inventory and Projection. Y/OWI/SUB-77/42500, Nuclear Assurance Corporation, June 1977.

TABLE 2. Inventory by Type of Discharged and Unreprocessed LWR Fuel Bundles Through 1987

Vendor-Manufacturer	Fuel Bundle Array Size	Discharged Fuel Bundles
Babcock & Wilcox	15x15	5,866
	17x17	1,671
Combustion Engineering	14x14	4,253
	15x15	545
	16x16	3,039
General Electric	7x7	29,952
	8x8	25,239
Westinghouse	14x14	3,462
	15x15	7,977
	17x17	12,168
Type Unknown		
BWR		3,926
LWR		7,554

FUEL BUNDLE DESCRIPTIONS

The current U.S. inventory of unreprocessed spent fuel is stored in fuel bundles designed and built by several different manufacturers. Besides fuel rods, the bundles consist of fuel rod spacers, end fittings, and various support devices that represent a large part of the fuel bundle volume.

The fuel bundle descriptions in the following discussion identify available details of material composition and mechanical assembly that would be useful in setting up equipment and process parameters for handling the various kinds of LWR fuel bundles. The descriptions cover pressurized water reactor (PWR) and boiling water reactor (BWR) fuel bundles made by:

1) Combustion Engineering (PWR fuel bundle)
2) Exxon Nuclear (PWR and BWR)
3) Westinghouse (PWR)
4) General Electric (BWR)
5) Babcock and Wilcox (PWR).

These descriptions and the subsequent dimensional data represent, at best, descriptions of "typical" fuel bundles. Within each fuel bundle design, many small design variations may have evolved as design and manufacturing experience accumulated.

COMBUSTION ENGINEERING 14x14 AND 16x16 PWR FUEL BUNDLES

Each of Combustion Engineering's 14x14 or 16x16 fuel bundles represented in Figure 1 consists of fuel rods, Zircaloy-4 control element guide tubes, fuel rod spacer grids, upper and lower end fittings, and a hold-down device. The fuel rods in the bundle are initially pressurized with helium and are designed to have a maximum pressure of 2250 psi after irradiation.

The guide tubes, spacer grids, and end fittings form the structural frame of the assembly. The spacer grids are welded to the guide tubes; the end fittings are mechanically joined. The spacer grids are Zircaloy-4 but the bottom retention grid is Inconel 625. The lower end spacer grid is

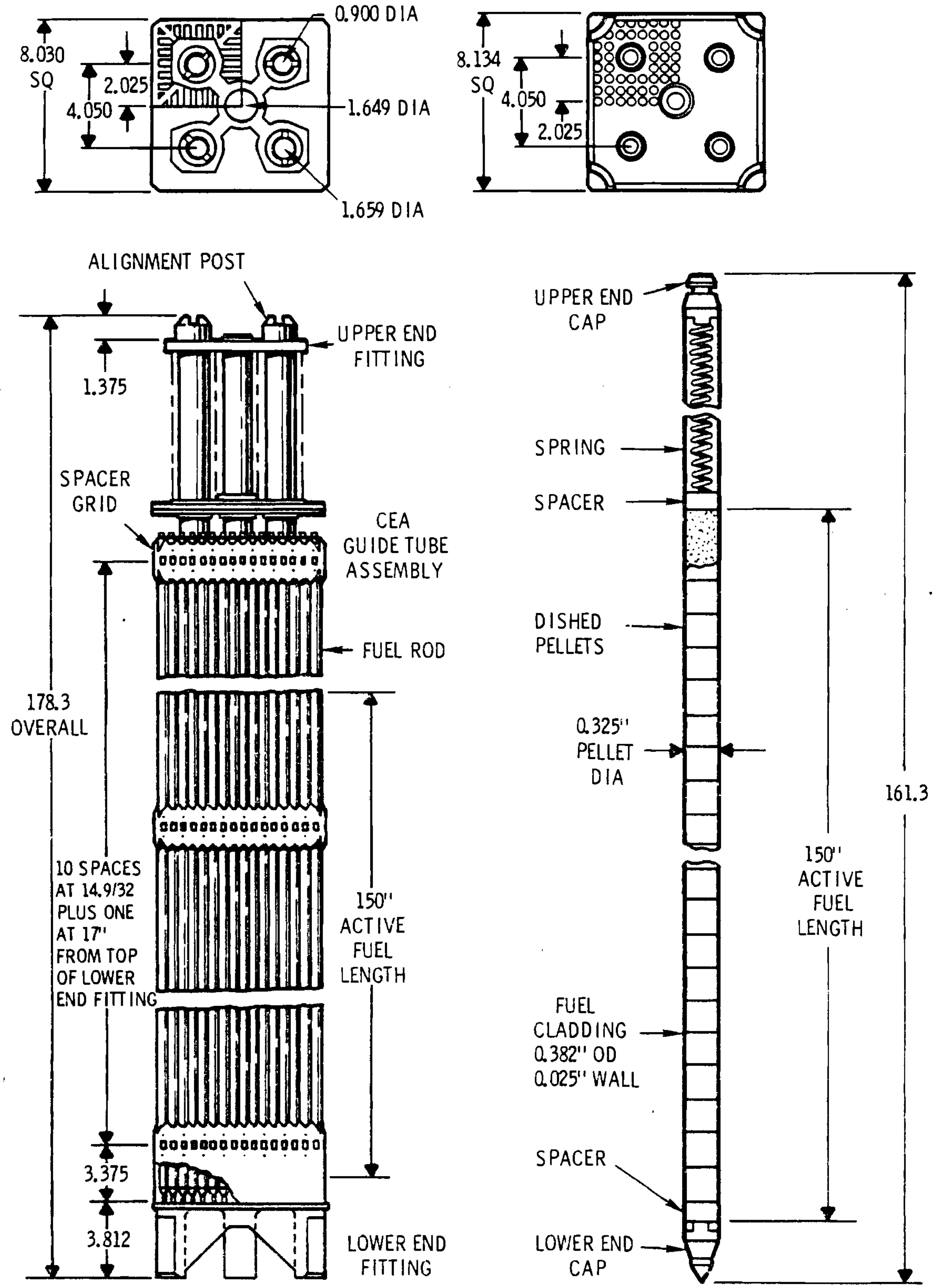

FIGURE 1. Combustion Engineering 16x16 PWR Fuel Bundle and Fuel Rod

supported by Inconel tabs, which are welded directly to the lower end fitting. The spacer grids provide frictional axial restraint to fuel rod motion. The positive axial restraint on the fuel rods is provided by end contact with the upper or lower end fitting. The lower end fitting is cast stainless steel (CF-8). The upper end fitting consists of two cast stainless steel plates and five machined alignment posts of 304 stainless steel.

At their upper ends, the outer guide tubes each have a widened shoulder that contains an internal thread. Connection with the upper end fitting is made by passing the male-threaded end posts through the upper end fitting and into the guide tubes. There is an additional mechanical connection between the posts and guide tube to ensure that the threaded joint does not become loose during operation. Each guide tube also has a threaded fitting at its lower end. This threaded fitting passes through a hole in the lower end fitting and is secured by a Zircaloy nut that in turn is secured by welding.

The central guide tube inserts into sockets in the upper and lower end fittings. There is no positive axial connection between the central guide tube and the end fittings.

The upper end fittings can easily be removed by unscrewing the four outer alignment posts with a modest torque. The center post is part of the upper end fitting assembly and is removed as part of the assembly.

EXXON NUCLEAR FUEL BUNDLES (PWR 14x14, 15x15 AND BWR 7x7, 8x8)

Exxon Nuclear fuel bundles are designed with mechanically locked upper tie plates to allow removal and replacement of individual fuel rods. The PWR bundles have cap screws that lock the lower tie plate to the guide tubes or guide bars. The BWR bundles are assembled by screwing the threaded lower end cap of the tie rods into the lower tie plate. BWR standard fuel rods are held in position in the lower tie plate by compression springs bearing against the upper tie plate as shown in Figure 15, p. 23. The assembly of these fuel bundles is the same as the assembly of the bundles they replace.

WESTINGHOUSE 14x14, 15x15, AND 17x17 PWR FUEL BUNDLES

Fuel rods are mechanically joined to form a typical Westinghouse fuel bundle. The 15x15 and 17x17 fuel bundles are shown in Figures 2 and 3. The fuel rods (Figures 4 and 5) are supported at intervals along their length by grid assemblies that maintain the lateral spacing between the rods. The grid assembly consists of an "egg-crate" arrangement of interlocking straps. The straps contain spring fingers and dimples for fuel rod support (Figure 6) as well as coolant mixing vanes.

The central instrumentation thimble of each fuel assembly is not attached to either the top or bottom nozzles, but the thimble is constrained by its seating in counterbores of each nozzle.

The guide thimbles are joined to the grids by means of bulge joints (Figure 7). The top end of the guide thimble is fastened to a tubular sleeve by three expansion swages. The sleeve fits into and is welded to the top nozzle adapter plate. The lower end of the guide thimble is fitted with an end plug that is then fastened into the bottom nozzle by a weld-locked screw, which penetrates through the nozzle and mates with an inside fitting in each guide tube (Figure 8). After the fuel rods are loaded, the end plugs are pressed into the ends of the tube and welded. All fuel rods are pressurized with helium, and the fill hole located in the upper end plug is welded closed.

The bottom nozzle is a box-like structure that serves as a bottom structural element of the fuel assembly and directs the coolant flow distribution to the assembly. The square nozzle is fabricated from 304 stainless steel and consists of a perforated plate and four angle legs with bearing plates.

The top nozzle assembly functions as the upper structural element. It consists of an adapter plate, enclosure, top plate, hold-down springs, clamps, and pads. The springs are Inconel 718 and the bolts are Inconel 600; other components are 304 stainless steel.

The fuel rods are laterally restricted by the spring fingers and dimples located in the grids. This spring contact allows axial thermal expansion of the fuel rods resulting in creep from the original assembly location. This

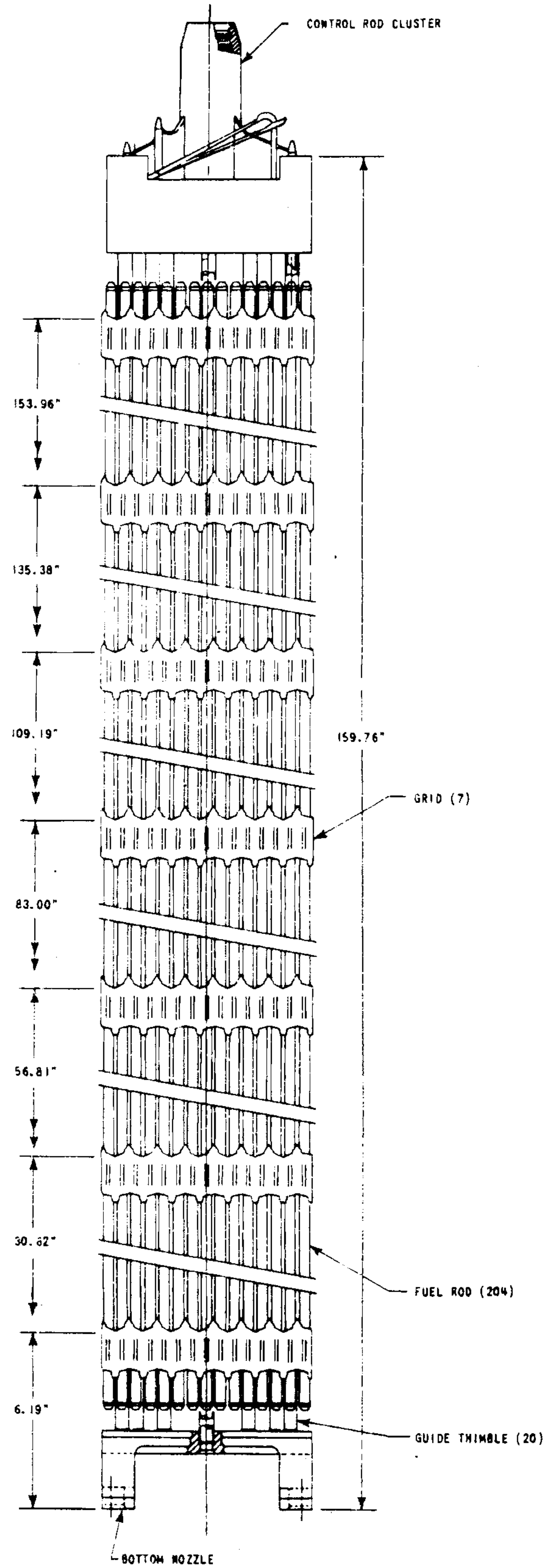

FIGURE 2. Westinghouse 15x15 Fuel Bundle

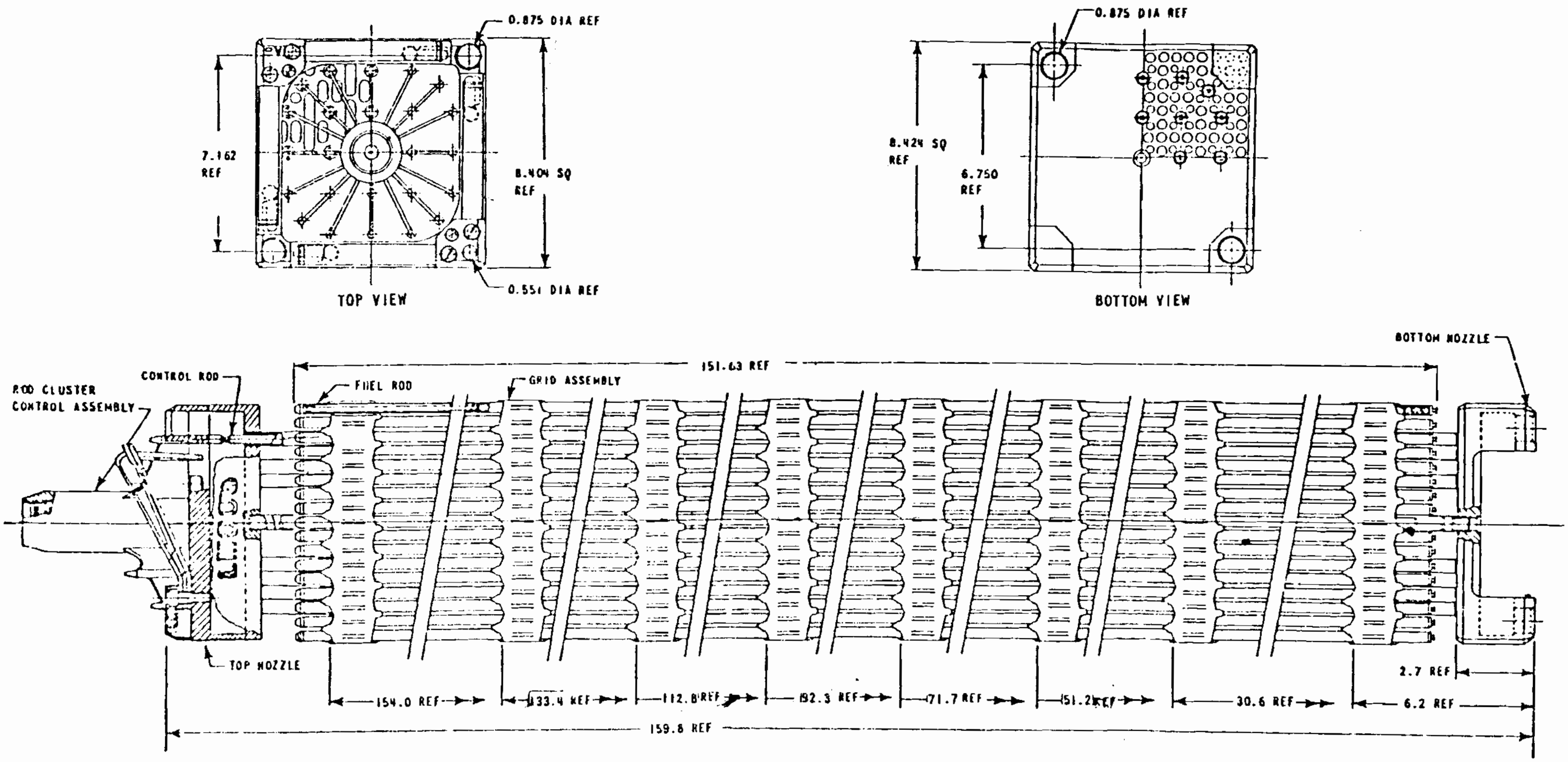

FIGURE 3. Westinghouse 17x17 Fuel Bundle

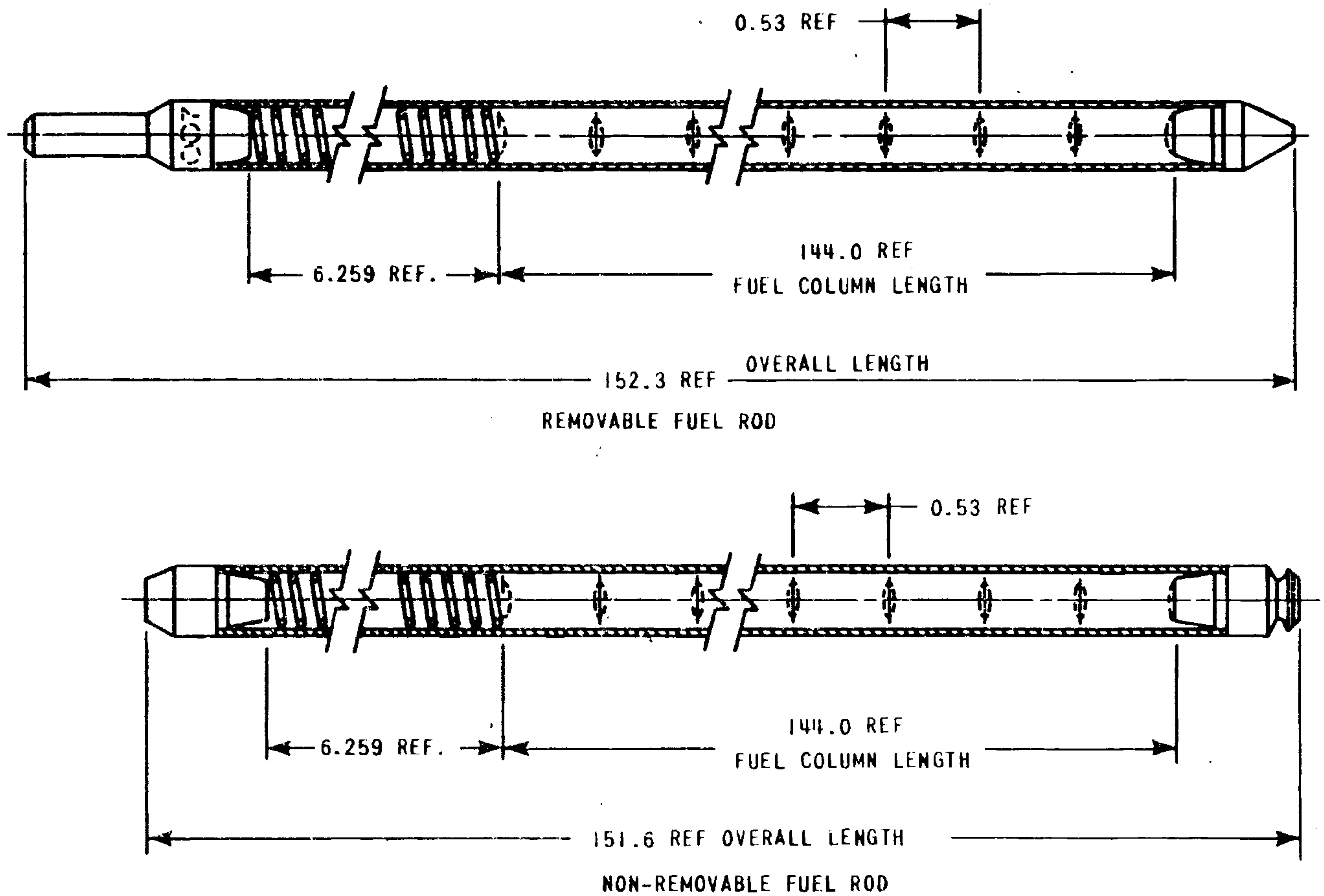

FIGURE 4. Removable and Nonremovable Fuel Rods (Westinghouse 17x17 Fuel Bundle)

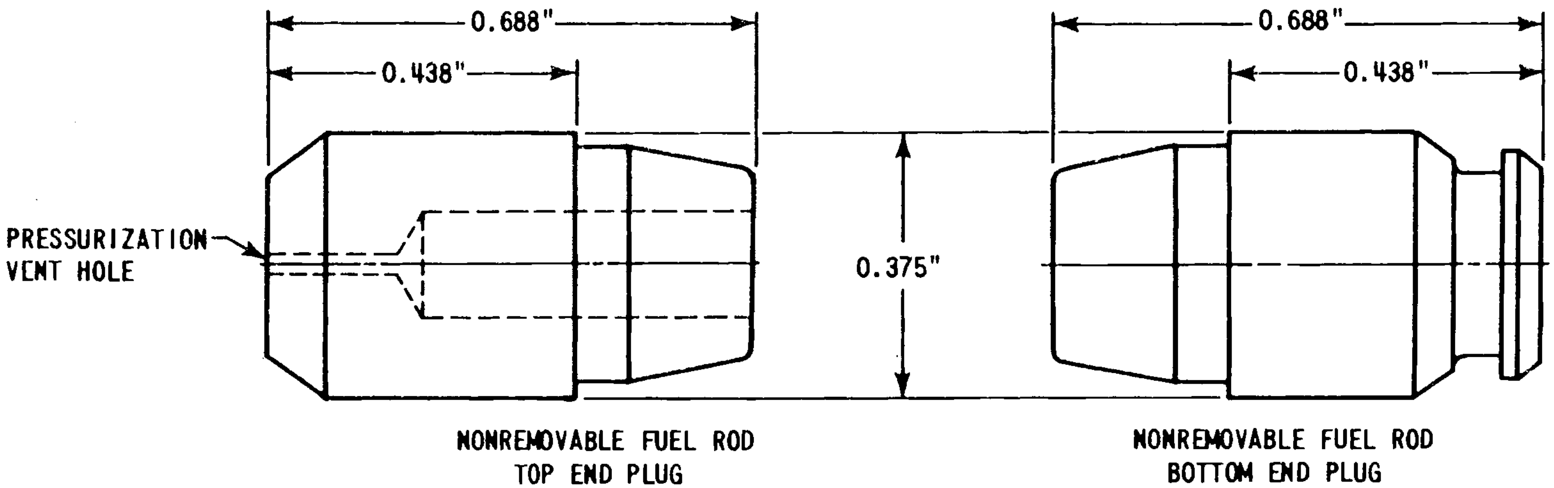

FIGURE 5. End Plugs for Nonremovable Fuel Rods (Westinghouse 17x17 Fuel Bundle)

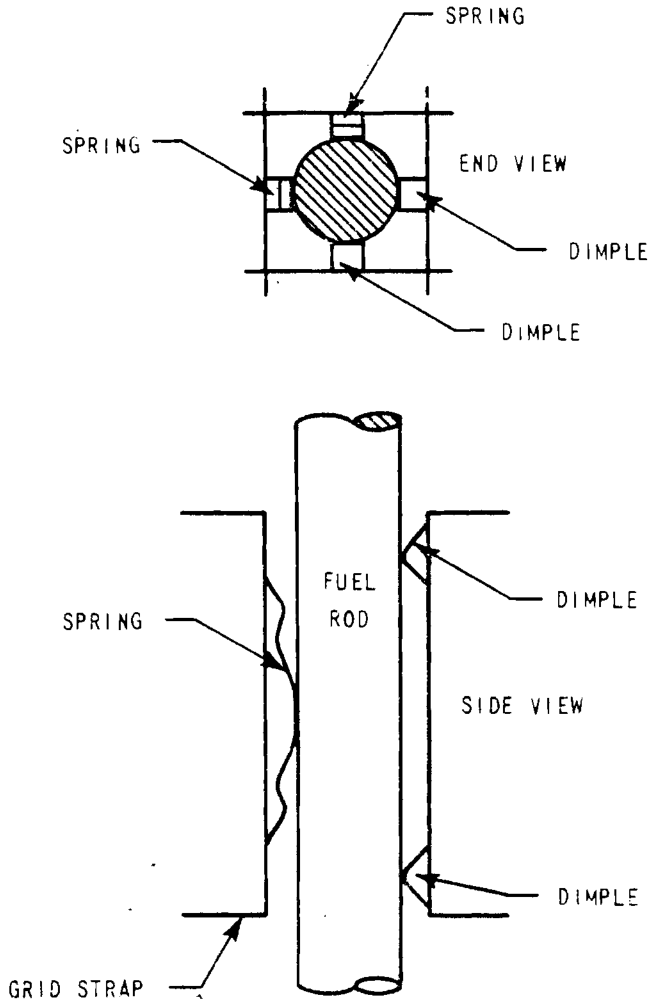

FIGURE 6. Typical Spring and Dimple Support of Fuel Rod in Fuel Assembly Grid (Westinghouse Fuel Bundles)

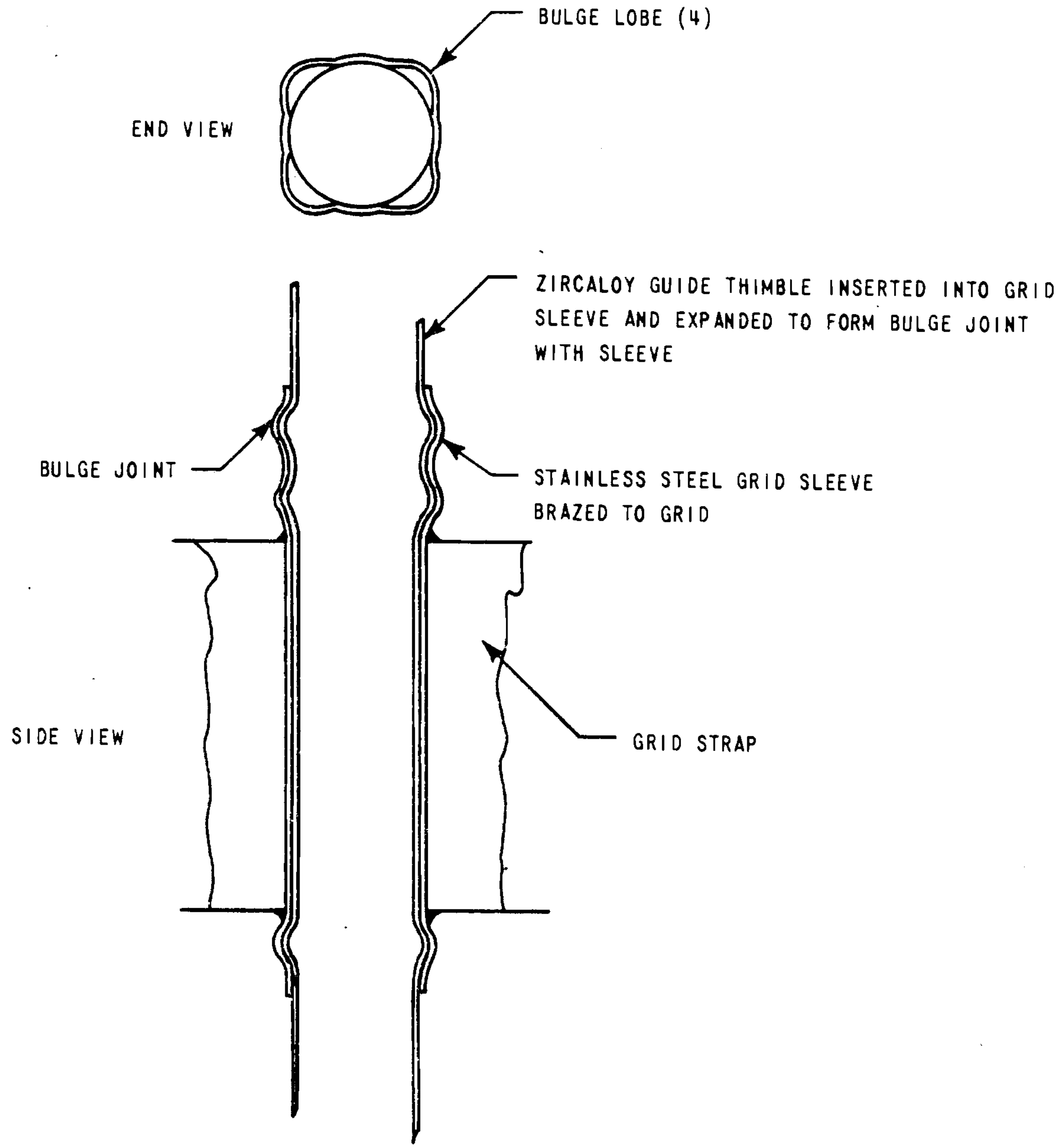

FIGURE 7. Longitudinal Section through Guide Thimble-to-Grid Bulge Joint (Westinghouse Fuel Bundles)

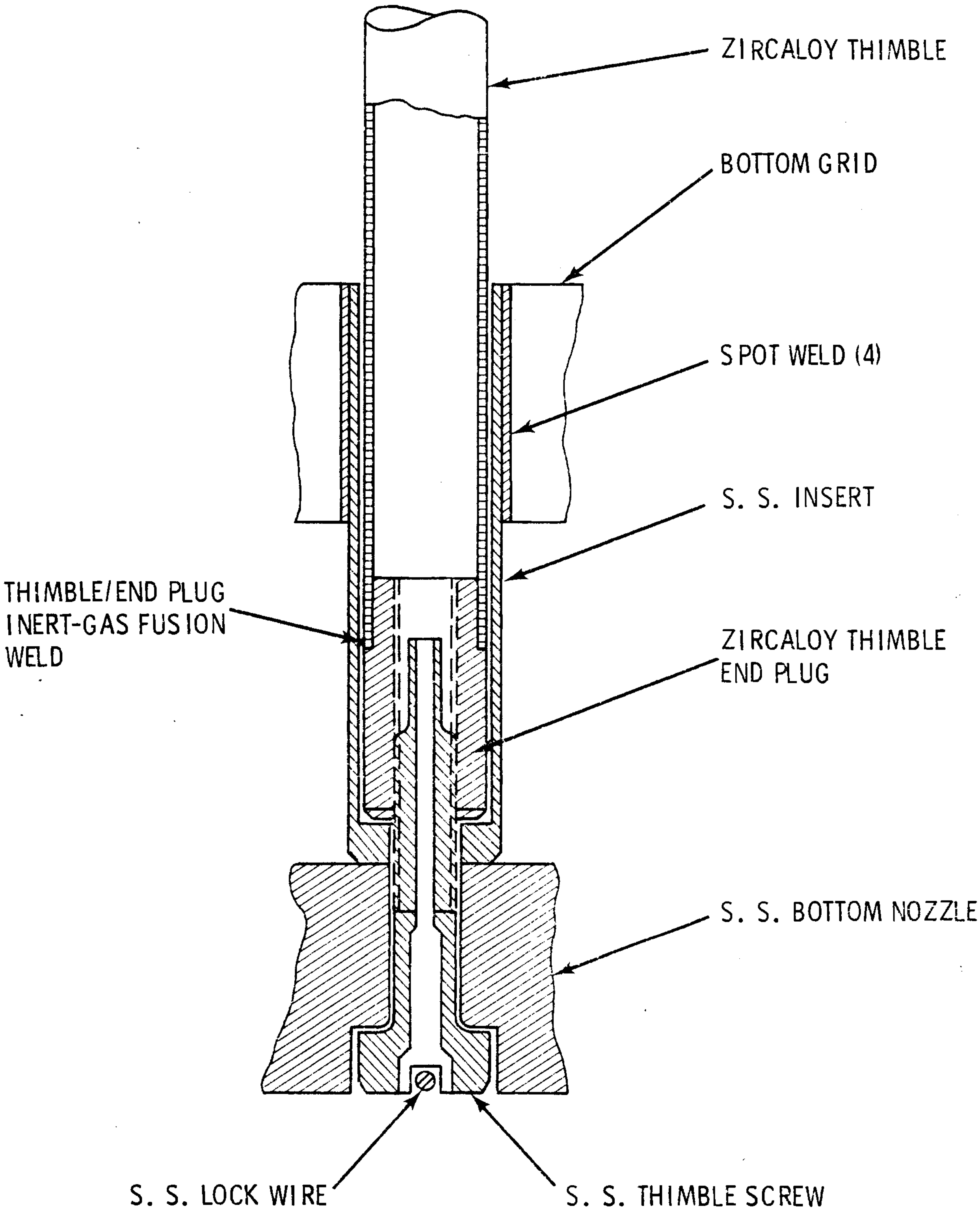

FIGURE 8. Guide Thimble to Bottom Nozzle Joint (Westinghouse Fuel Bundles)

creep is limited by contact with the upper and lower nozzles. Examinations of irradiated fuel bundles indicate a maximum creep of 1/8 inch. Tests also indicated a maximum breakaway force of 100 pounds was required to move the fuel rod through the grids.

Some of these elements could be received from the utility with the control rod cluster in place.

GENERAL ELECTRIC 7x7 AND 8x8 BWR FUEL BUNDLES

The General Electric fuel bundle contains fuel rods (and 1 water rod in the 8x8 bundle only) spaced and supported in a square array by the lower and upper tie plates (Figures 9 and 10). The upper and lower tie plates are 304 stainless steel castings. The lower tie plate has a nose-piece that supports the fuel assembly in the reactor. The upper tie plate has a handle for transferring the fuel bundle from one location to another. An Inconel-X expansion spring on the upper end plug shank of each fuel rod keeps the rods seated in the lower tie plate. The fuel rods themselves have a spring in the upper end plenum chamber as suggested in the composite diagram, Figure 16.

Besides standard fuel rods, two other types of rods are used in the fuel bundle: tie rods and a non-fuel water rod. The eight tie rods in each bundle have lower end plugs that thread into the lower tie plate casting and upper end plugs that extend through the upper tie plate casting. A stainless steel hexagonal nut and locking tab are installed on the upper end plug to hold the assembly together. These tie rods support the weight of the assembly only during fuel handling when the assembly hangs by the handle; during operation the fuel rods are supported by the lower tie plate.

One rod in each fuel bundle is used to position the seven Zr-4 fuel rod spacers. The rod is a hollow Zr-2 tube with welded tabs and a square bottom end plug. The rod is fitted to the spacers by sliding it through the spacer cells with the welded tabs oriented toward the corner of the spacer cell. The rod is then rotated so the tabs fit between the elements of the spacer structure, locking the spacer in the required axial position. The rod is prevented from rotating and unlocking the spacers by the engagement of its

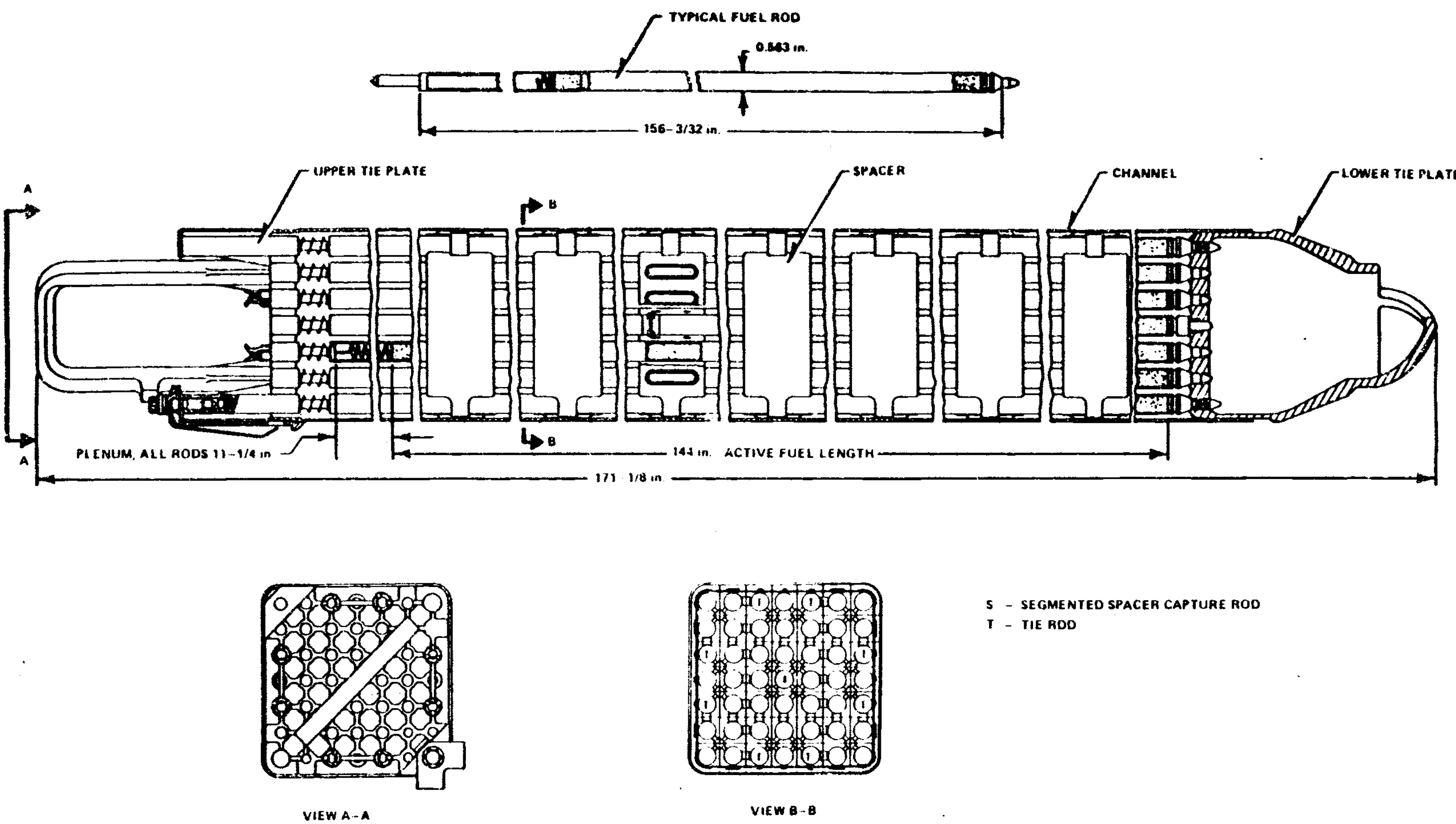

FIGURE 9. General Electric 7x7 Fuel Bundle (Typical Assembly)

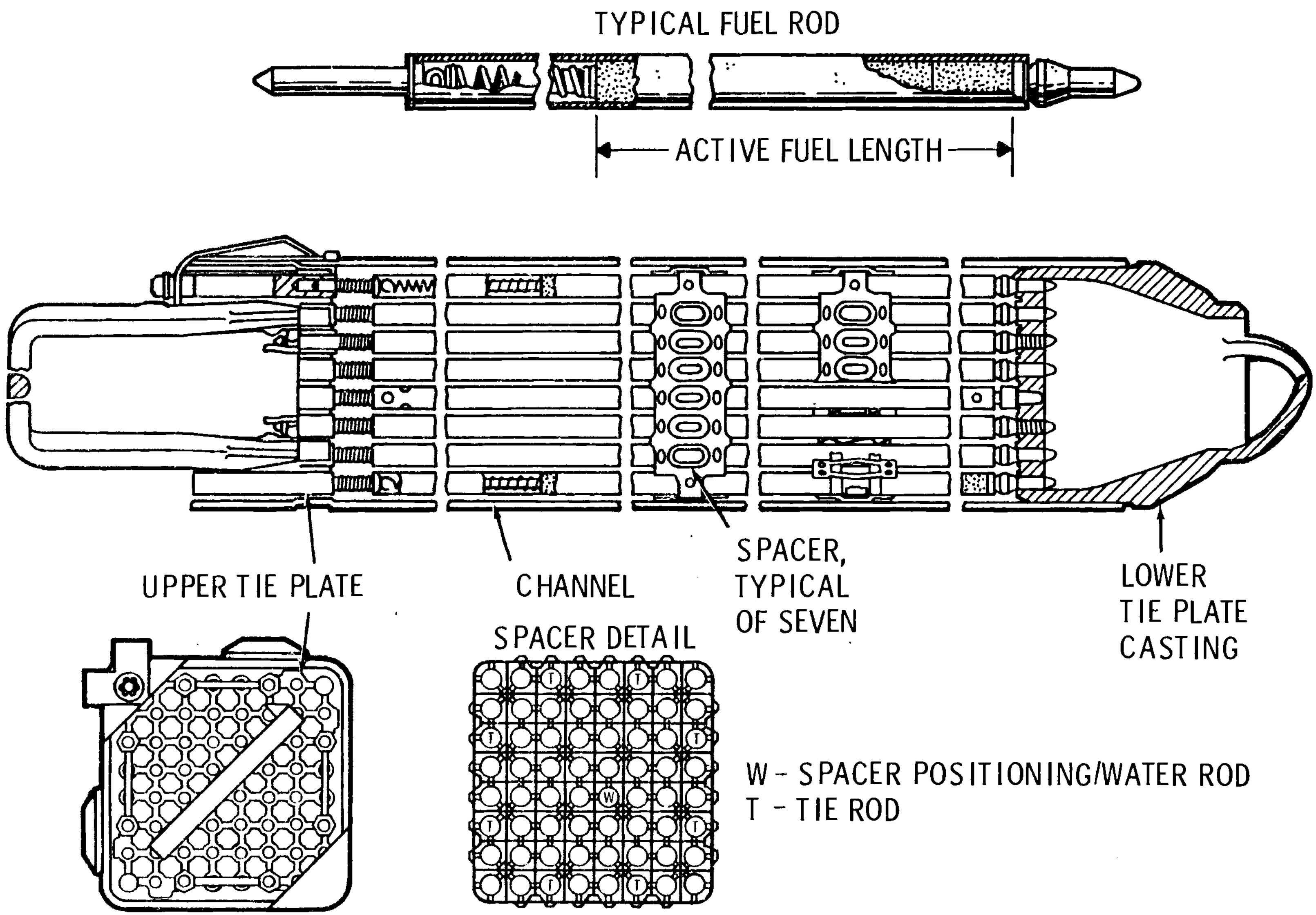

FIGURE 10. General Electric 8x8 Fuel Bundle (Typical Reload Assembly)

square lower end plug with a square end plate hole. The spacers have Inconel-X springs to maintain rod-to-rod spacing. The fuel rods are pressurized with helium and sealed by welding end plugs on each end.

BABCOCK AND WILCOX 15x15 AND 17x17 PWR FUEL BUNDLES

The Babcock and Wilcox assemblies consist of an instrument tube, guide tubes, fuel rods, spacer grids, and upper and lower end fitting assemblies.

The guide tubes are threaded and pass through the upper and lower end fittings. The tubes are secured with a nut that is welded to the end fittings. The end spacer grids, which are wider than the intermediate spacer grids, are also attached to the end fittings. The intermediate spacer grids are held in position by spring contact with the guide tubes but are not locked or welded. The fuel rods are positioned by the spacer grids and rest on the lower end fitting. An instrument tube is secured at the lower end, flared around a retainer sleeve in the lower end fitting.

The fuel rods are pressurized through a hole in the fuel rod lower end cap and sealed by welding. Figures 11, 12, and 13 show the fuel bundle design variations.

FUEL BUNDLE DIMENSIONAL DATA AND MATERIALS INFORMATION

Dimensional data and general information are provided here for the BWR and PWR fuel assemblies from the different suppliers. These data will be useful in designing equipment to handle the fuel bundles. Schematics with lettered dimensions are used to show typical configurations for PWR (Figure 14) and BWR (Figure 15) fuel bundles. Tables 3 and 4 give values for the dimensions indicated in Figure 14 and 15, respectively. Tables 5 and 6 provide detailed dimensional and materials information for PWR and BWR fuel bundles, respectively.

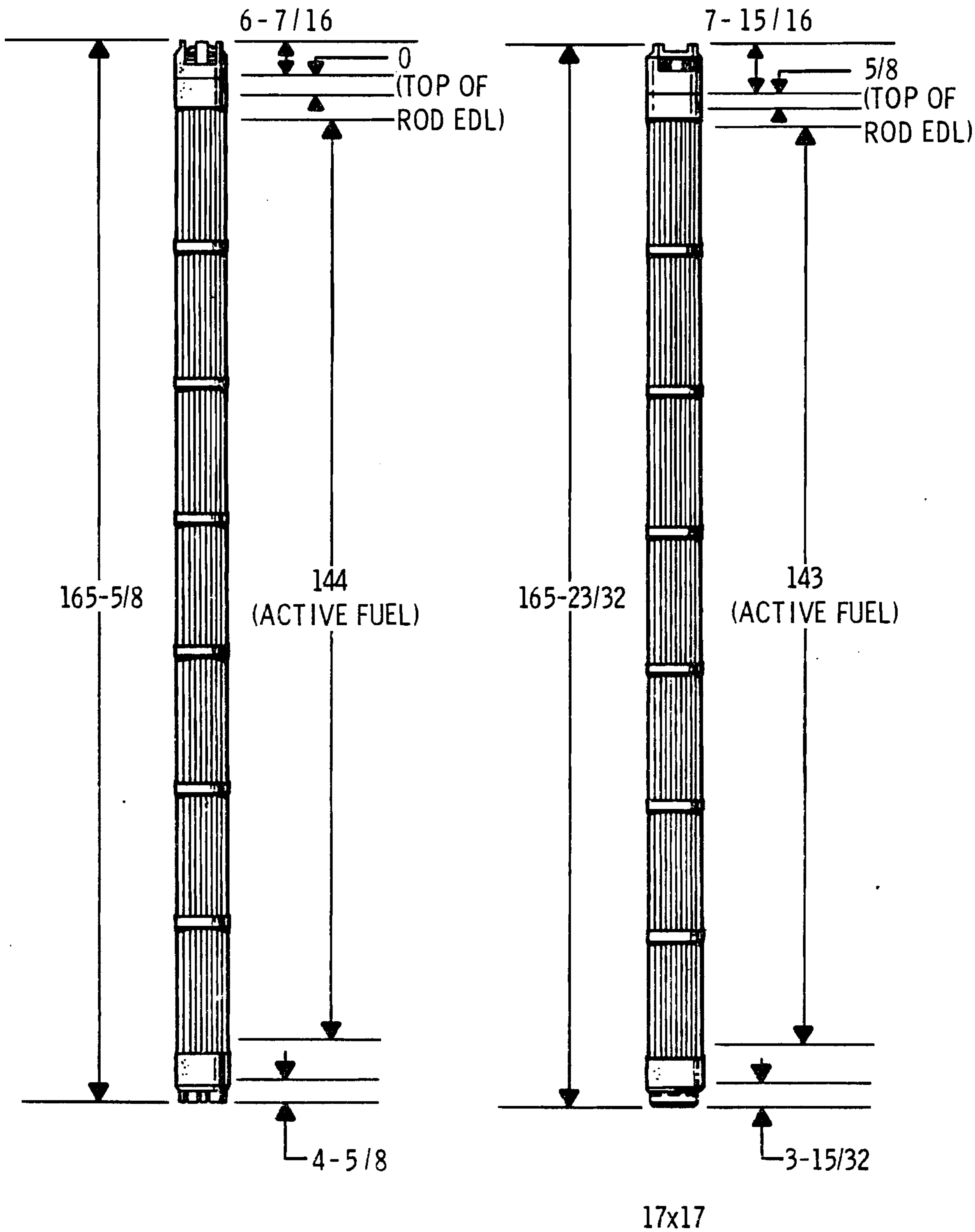

FIGURE 11. Babcock and Wilcox Fuel Bundles of 15x15 (Type 1) and 17x17 Fuel Bundles - Comparison

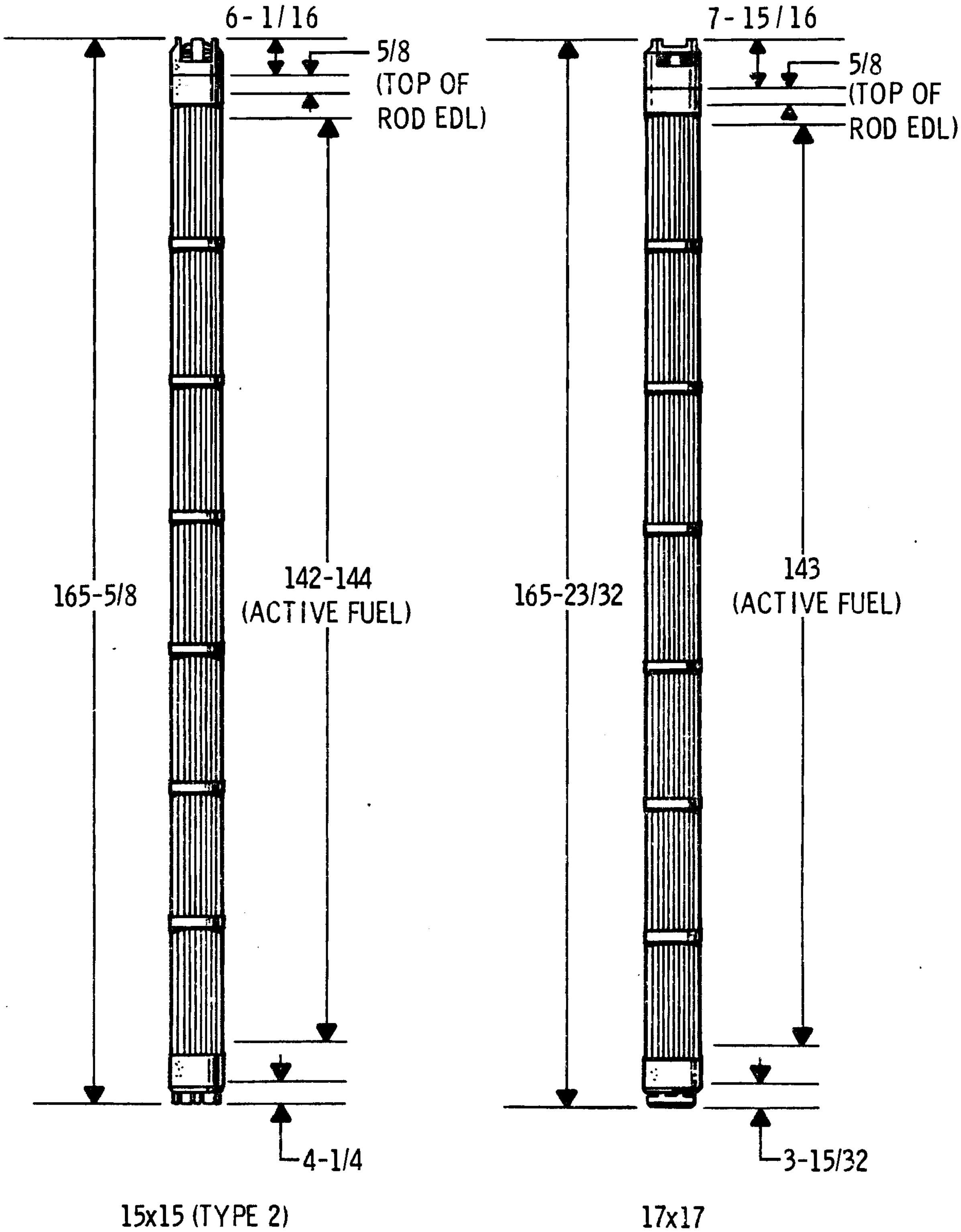

FIGURE 12. Babcock and Wilcox Fuel Bundles of 15x15 (Type 2) and 17x17 Fuel Bundles - Comparison

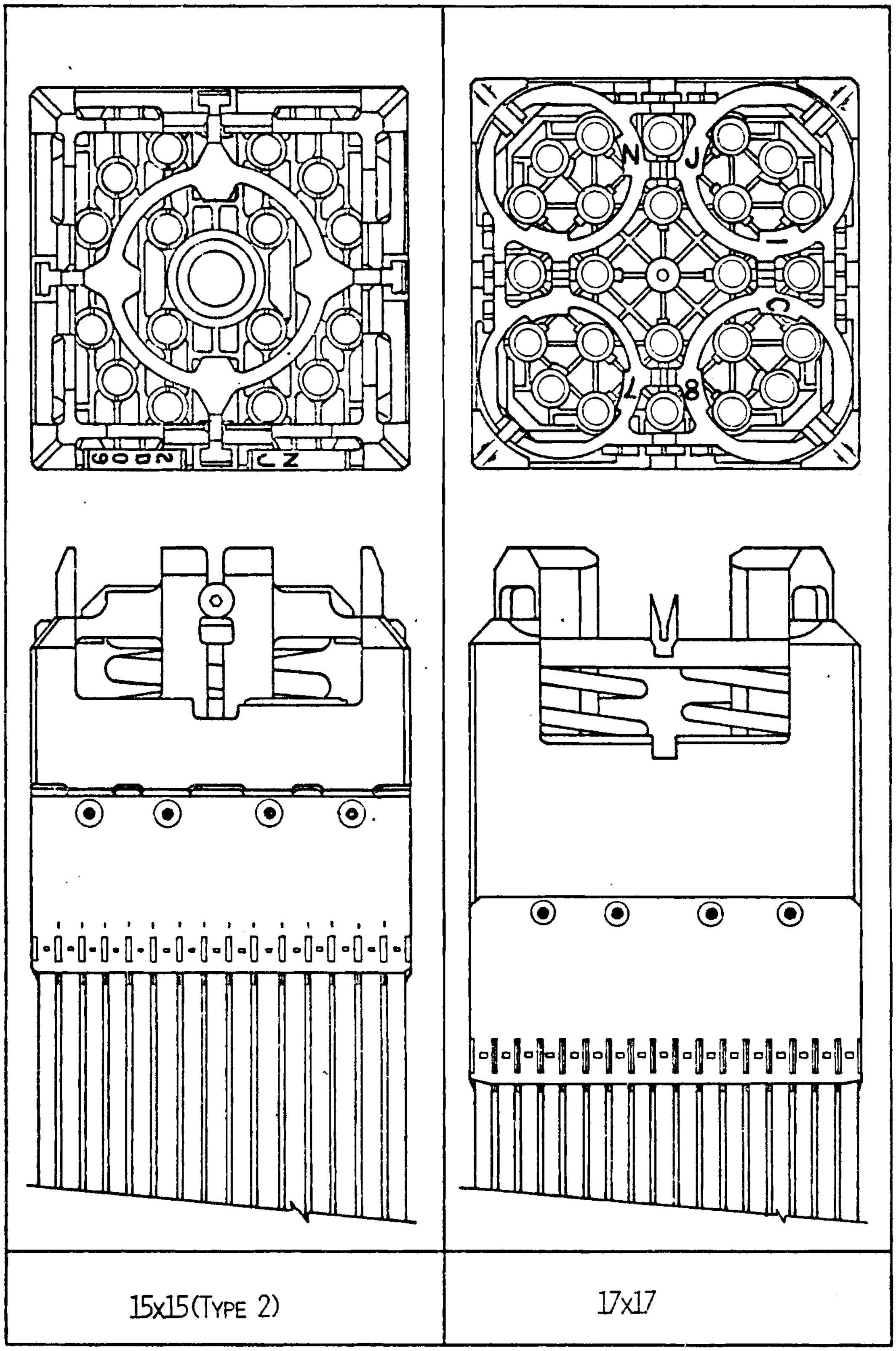

FIGURE 13. Babcock and Wilcox Fuel Bundles of 15x15 (Type 2) and 17x17 Fuel Bundles - Detail Comparison

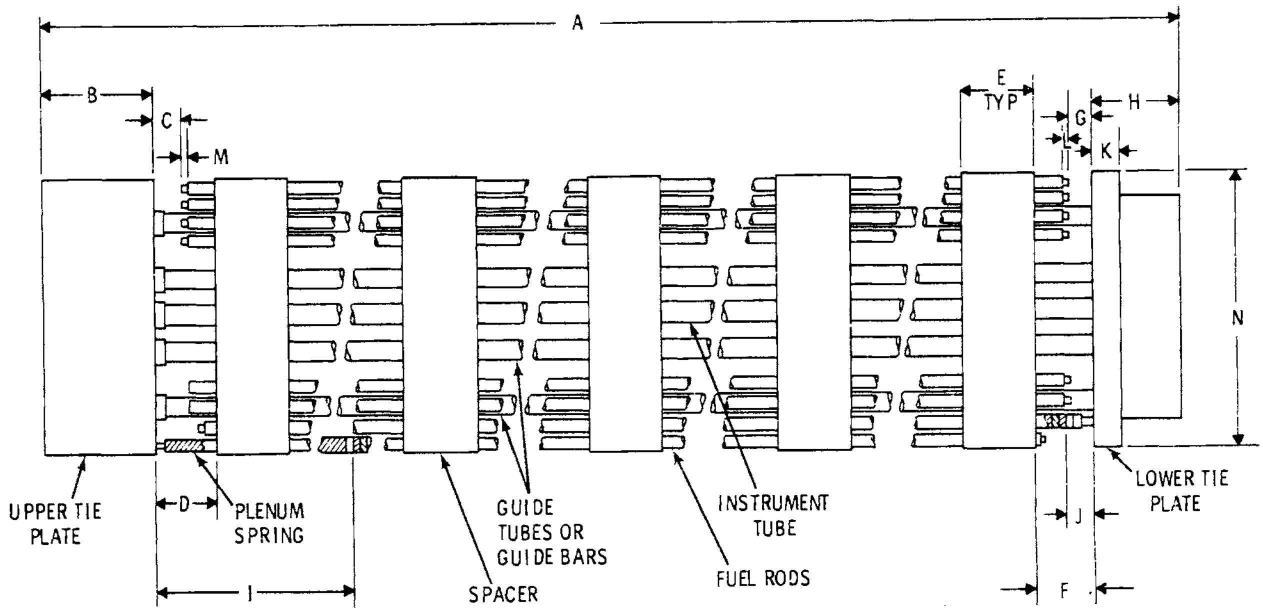

FIGURE 14. PWR Fuel Bundle Schematic

Dimension	Description
A	Overall length of element
B	Overall length of upper tie plate
C	Upper tie plate to upper end of fuel pin after irradiation
D	Upper tie plate to spacer
E	Spacer length (typical)
F	Lower tie plate to spacer
G	Lower tie plate to lower end of fuel pin after irradiation
H	Overall length of lower tie plate
I	Upper end of fuel pin to fuel
J	Lower end of fuel pin to fuel
K	Thickness of lower tie plate grille area
L	Wall thickness, lower end of fuel pin to pressure boundary
M	Wall thickness, upper end of fuel pin to pressure boundary
N	Lower tie plate width

TABLE 3. PWR Schematic Dimensions

Designation	Fuel Element Array	PWR Fuel Bundle Schematic Dimensions, Inches													
		A	B	C	D	E	F	G	H	I	J	K	L	M	N
EXXON (Combustion Engineering	14x14	156.7	6.10	0.5	1.52	2.75 (max.)	1.52	0.5	2.68	9.20	0.60	--	--	--	--
EXXON (Westinghouse)	15x15	159.7	5.05	0.5	1.63	2.75 (max.)	1.80	0.5	2.72	7.40	0.60	--	--	--	--
EXXON (Combustion Engineering)	15x15	148.9	3.39	1.0	1.40	2.75 (max.)	1.40	0	4.86	7.06	0.59	--	--	--	--
EXXON (Westinghouse)	17x17	159.7	3.67	0.5	1.60	2.75 (max.)	1.80	0.5	2.74	7.40	0.50	--	--	8.425	--
Combustion Engineering	14x14	157.2	5.8	--	2.3	1.4	2.6	0	3.3	--	0.95	5/8	5/8	3/8	8.4
Combustion Engineering	15x15	149.1	3.5	--	15.7	1.2	15.7	0	5.1	--	0.69	5/8	--	0.49	8.55
Combustion Engineering	16x16	176.8	10.4	--	3.0	1.4	2.7	0	3.8	--	0.90	5/8	1/2	3/8	8.18
Westinghouse	14x14	159.8	3.67	0	--	--	--	0	--	--	--	--	--	--	--
Westinghouse	15x15	159.76	3.67	0	--	--	--	0	--	--	--	--	--	--	8.426
Westinghouse	17x17	159.765 + 1.789 for spring	3.67	0	1.790	2.142	1.793	0	2.738	6.950	0.688	--	--	--	8.426
Babcock & Wilcox	14x14	NO LONGER MANUFACTURED - ALL REPROCESSED													
Babcock & Wilcox	15x15 Mark B2	165.6	6-7/16	0	0	1.5/4.15	0	0	4-5/8	5-9/16	4-1/8	1	--	--	8.54
	Mark B3 & B4	165.6	6-1/16	5/8	0	1.5/4.15	0	0	4-1/4	5-11/32 to 7-11/32	4-11/32	5/8	--	--	8.54
Babcock & Wilcox	17x17 Mark C	165.7	7-15/16	5/8	0	1.5/4.17	0	0	3-15/32	6-11/32	3-11/32	5/8	--	--	8.54

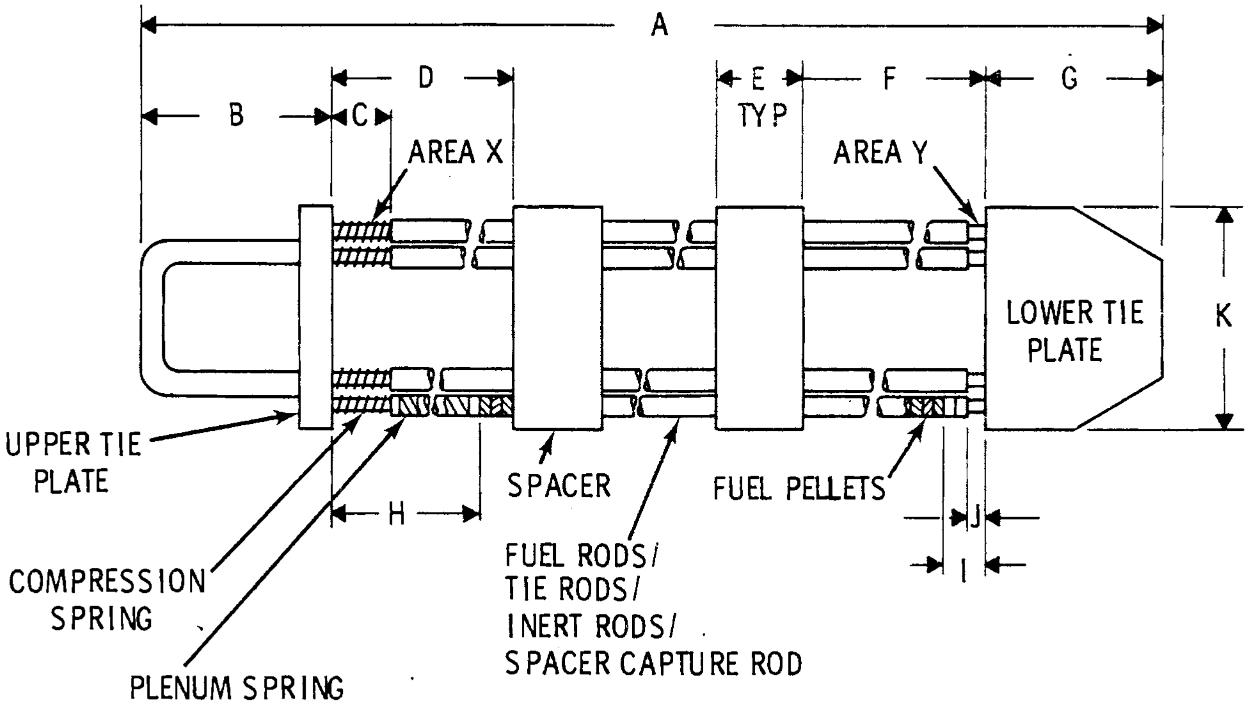

FIGURE 15. BWR Fuel Bundle Schematic

Dimension	Description
A	Overall length of element before irradiation
B	Overall length of upper tie plate
C	Upper tie plate to fuel pin pressure boundary before irradiation
D	Upper tie plate to spacer
E	Length of spacer (typical)
F	Lower tie plate to spacer
G	Overall length of lower tie plate
H	Upper tie plate to fuel before irradiation
I	Lower tie plate to fuel
J	Lower tie plate to pressure boundary
K	Lower tie plate width

TABLE 4. BWR Schematic Dimensions

Fuel Designation		BWR Fuel Bundle Schematic Dimensions, Inches										
		A	B	C	D	E	F	G	H	I	J	K
EXXON (General Electric)	7x7	171.2	6.87	0.84	20.00	2.50 (max.)	17.42	6.75	12.15	0.72	0.23	--
EXXON (General Electric)	8x8 BWR-2	171.2	7.50	0.88	20.00	2.50 (max.)	17.42	6.75	12.20	0.72	0.24	--
EXXON (General Electric)	8x8 BWR-3, 4,5,&6	171.2-178.5	7.50	0.84	20.00	2.50 (max.)	17.42	6.75	12.20-18.2	0.72	0.24	--
General Electric	7x7	171.4	7.5	0.84	19.55	1.625	18.225	6.76	12.315	0.625	0.23	5.263
General Electric	8x8	171.4	7.5	0.84	19.55	1.625	18.145	6.76	12.515	0.625	0.24	5.438
General Electric	8x8	176.16	7.5	0.84	20.63	1.625	18.745	6.76	13.275	0.625	0.24	5.425

		Area X				Area Y	
		Compression Spring		End Cap		End Cap	
Fuel Designation		Wire Dia	Material	Dia	Material	Dia	Material
EXXON (General Electric)	7x7	0.10	Inconel	0.250	Zr-2	0.420	Zr-2
EXXON (General Electric)	8x8 BWR-2	0.10	Inconel	0.250	Zr-2	0.380	Zr-3
EXXON (General Electric)	8x8 BWR-3, 4,5,&6	0.10	Inconel	0.250	Zr-2	0.340	Zr-2

TABLE 5. PWR Fuel Bundle General Information

	Babcock & Wilcox			Combustion Engineering		
	14x14	15x15	17x17	Typical 14x14	Typical 15x15	Typical 16x16
Assembly Weight (kg)	--	689	683	581	621	650
Lower Tie Plate Envelope (in.^{2})	--	8.536	8.536	8.11	8.25	8.14
Spacer Envelope (in.^{2})	--	8.536	8.536	8.13	8.19	8.13
Fuel Rod Pitch (in.)	--	0.568	0.502	0.580	0.55	0.506
Overall Assembly Length as built (in.)	-- --	165.6	165.7	146.3 157.241	149.1	176.8
Fuel Rods						
Number	--	208	264	176	216	236
Length (in.)	--			137-147	140.3 max	161.3
Fueled Length (in.)	100	144	143	128,137	132	150
OD (in.)	--	0.430	0.379	0.440	0.4135	0.382
Wall Thickness (in.)	--	0.0265	0.024	0.026&0.028	0.024	0.025
Material	--	Zr-4	Zr-4	Zr-4	Zr-4	Zr-4
Guide Tubes						
Number	--	16	24	5	--	5
Upper Diameter (in.)	--	0.530 OD	0.430 ID	--	--	--
Wall Thickness (in.)	--	0.016	0.018	--	--	--
Material	--	Zr-4	Zr-4	--	--	Zr-4
Instrument						
Number	--	1	1	--	1	--
Diameter (in.)	--		0.390 ID	--	0.4135 OD	--
Material	--	Zr-4	Zr-4	--	Zr-4	--
Guide Bars		NA	NA			
Number	--			--	8	5
Cross Section (in.)				--	--	--
Tie Plate Material	--	304 SS	304 SS			SS
Spacers						
Number	--	8	8	9:	8	12:
Material	--	Inconel	Inconel	8 Zr-4; 1 Inconel 625	Zr-4	11 Zr-4; 1 Inconel 625
Hold-down spring(s)						
Number	--	1 helical	4 helical	--	--	--
Material	--	Inconel X750	Inconel X750	--	--	--
Plenum Springs						
Working Length (in.)	--	--	--	--	--	--
Wire Diameter (in.)	--	--	--	--	--	--
Material	--	302 SS (top) A286 (bot.)	302 SS (top) A286 (bot.)		--	--

TABLE 5. PWR Fuel Bundle General Information (cont'd)

	Westinghouse 14x14	Westinghouse 15x15	Westinghouse 17x17
Assembly Weight (kg)	--	703	665
Lower Tie Plate Envelope (in.^{2})	7.763	8.424	8.424
Spacer Envelope (in.^{2})	--	--	--
Fuel Rod Pitch (in.)	0.556	0.563	0.496
Overall Assembly Length (in.)		159.76 (+1.75 for spring	159.8 (+1.75 for spring
Fuel Rods			
Number	179	204	264
Length (in.)	152.36	151.8-152.35	151.6-152.3
Fueled Length	144	144	144
OD (in.)	0.422	0.422	0.374
Wall Thickness (in.)	0.0243	0.024	0.0225
Material	Zr-4	Zr-4	Zr-4
Guide Tubes			
Number	--	20	24
Upper OD (in.)	--	--	--
Wall Thickness (in.)	--	--	--
Material	--	Zr-4	--
Instrument Tubes			
Number	--	1	1
OD (in.)	--	--	--
Wall Thickness (in.)	--	--	--
Material	--	Zr-4	--
Tie Plate Material	--	304SS	304SS
Spacers			
Number	7	6 & 7	7 & 9
Material	--	Inconel 718	Inconel 718
Springs	--	Inconel 718	Inconel 718
Plenum Springs			
Working Length (in.)	--	--	--
Wire Diameter (in.)	--	--	--
Material	--	--	--

TABLE 5. PWR Fuel Bundle General Information (cont'd)

	EXXON (Combustion Engineering) 14x14	EXXON (Combustion Engineering) 15x15	EXXON (Westinghouse) 15x15	EXXON (Westinghouse) 17x17
Assembly Weight (kg)	588	612	644	657
Lower Tie Plate Envelope (in.^{2})	8.11	8.25	8.42	8.42
Spacer Envelope (in.^{2})	8.10	8.20	8.43	8.42
Fuel Rod Pitch (in.)	0.58	0.55	0.563	0.496
Overall Assembly Length (in.)	156.7	148.9	161.3	161.3
Fuel Rods				
Number	176	216	204	264
Length (in.)	146.5	139.5	152.0	152.0
Fueled Length (in.)	136.7	131.8	144.0	144.0
OD (in.)	0.440	0.415	0.424	∿0.380
Wall Thickness (in.)	0.031	0.028	0.030	∿0.025
Material	Zr-4	Zr-4	Zr-4	Zr-4
Guide Tubes				
Number	4	0	20	24
Upper OD (in.)	1.115	--	0.544	0.480
Wall Thickness (in.)	0.036	--	0.017	0.016
Material	Zr-4	--	Zr-4	Zr-4
Instrument Tubes				
Number	1	1	1	1
OD (in.)	1.115	0.417	0.544	0.480
Wall Thickness (in.)	0.036	0.027	0.017	0.016
Material	Zr-4	Zr-4	Zr-4	Zr-4
Guide Bars				
Number	0	8	0	0
Cross Section (in.)	--	0.27X 0.40	--	--
Material	--	Zr-4	--	--
Tie Plate Material	304SS	304SS	304SS	304SS
Spacers				
Number	9	10	7	7
Material	Zr-4	Zr-4	Zr-4	Zr-4
Springs	Inconel	Inconel	Inconel	Inconel
Plenum Springs				
Working Length (in.)	8.60	6.48	6.80	6.70
Wire Diameter (in.)	<0.10	<0.10	<0.10	<0.10
Material	Inconel	Inconel	Inconel	Inconel

TABLE 6. BWR Fuel Bundle General Information

	EXXON (General Electric) 7x7	BWR-2 8x8	BWR-3, 4, 5 & 6 8x8
Assembly Weight (kg)	290	312	~322
Lower Tie Plate Envelope (in.^{2})	5.44	5.44	5.44
Spacer Envelope (in.^{2})	5.24	5.24	5.24
Fuel Rod Pitch (in.)	0.738	0.642	0.641
Assembly Length (in.)	171.2	171.2	171.2 to 178.5
Standard Fuel Rods			
Number	40 (2 Gd)	52 (4 Gd)	55
Length (in.)	156.1	156.1	156.1-163.5
Fueled Length (in.)	144.0	144.0	144.0-150.0
OD (in.)	0.570	0.501	0.484
Wall Thickness (in.)	0.035-0.045	0.036	0.035
Material	Zr-2	Zr-2	Zr-2
Tie Rods - Fueled			
Number	8	8	8
OD (in.)	0.570	0.501	0.484
Wall Thickness (in.)	0.035	0.035	0.035
Material	Zr-2	Zr-2	Zr-2
Inert Rods			
Number	0 to 1	1 to 4	1 to 4
OD (in.)	--	0.501	--
Wall Thickness (in.)	--	0.036	--
Material	--	Zr-2	--
Spacer Capture Rods			
Number	1	1	1
OD (in.)	0.570	0.501	0.484
Wall Thickness (in.)	0.035	0.036	0.035
Material	Zr-2	Zr-2	Zr-2
Spacers			
Number	7	7	7
Material	Zr-4	Zr-4	Zr-4
Springs	Inconel	Inconel	Inconel
Tie Plate Material	304SS	304SS	304SS
Plenum Springs			
Working Length (in.)	10.6	10.6	10.6 to 16.0
Wire Diameter (in.)	<0.10	<0.10	<0.10
Material	Inconel	Inconel	Inconel
Compression Springs			
Working Length (in.)	0.84	0.88	0.84
Wire Diameter (in.)	<0.20	<0.10	<0.10
Material	Inconel	Inconel	Inconel

TABLE 6. BWR Fuel Bundle General Information (cont'd)

	General Electric 7x7	General Electric 8x8
Assembly Weight (kg)	∿308	∿278
Lower Tie Plate Envelope (in.)	5.263	5.47
Spacer Envelope (in.)	5.258	5.28
Fuel Rod Pitch (in.)	0.738	0.640
Assembly Length (in.)	171.40	171.40
Standard Fuel Rods		
Number	49	63
Length (in.)		
Fueled Length (in.)	144-146	146-148
OD (in.)	0.563	0.493
Wall Thickness (in.)	0.032-0.037	0.034
Material	Zr-2	Zr-2
Tie Rods - Fueled		
Number	8	8
OD (In.)	0.563	0.493
Wall Thickness (in.)	0.032-0.037	0.034
Material	Zr-2	Zr-2
Inert Rods		
Number	--	--
OD (in.)	--	--
Wall Thickness (in.)	--	--
Material	--	--
Spacer Capture Rods		
Number	1	1
OD (in.)	0.563	0.493
Wall Thickness (in.)		
Material	Zr-2	Zr-2
Spacers		
Number	7	7
Material	Zr	Zr-4
Springs	Inconel X	Inconel X
Tie Plate Material	304SS	304SS
Plenum Springs		
Working Length (in.)	--	--
Wire Diameter (in.)	--	--
Material	--	--
Compression Springs		
Working Length (in.)	--	--
Wire Diameter (in.)	--	--
Material	--	Inconel X

EXPERIENCE WITH HANDLING IRRADIATED SPENT FUEL BUNDLES

Current experience suggests that deterioration of stored fuel is minor. The mechanical state of cladding upon discharge from the reactor is well-known as a function of reactor exposure. Neutron irradiation increases the strength and lowers the ductility of all fuel bundle materials. Hydrogen absorption in metals also tends to lower their ductilities. There is no evidence that these exposures have caused operational problems during fuel handling. The mechanical state of the cladding was fully satisfactory for enduring all phases of handling related to pool storage.

Fuel bundles have been partially disassembled and/or reconstituted in some pools. This generally appears to occur without problems, and reconstituted bundles are returned to the reactor core. However, some fuel rod breakage occurred at Nuclear Fuel Services during attempts to remove rods from fuel bundles by pulling. Pushing was a more satisfactory procedure to avoid fuel rod breakage.

FUEL BUNDLE DESIGN VARIATIONS

The LWR fuel bundles have had no standard designs because designs were continually being modified. Discussions with the vendors of LWR fuel bundles indicated that various design revisions had changed many of the fuel bundle dimensions, including the dimensions of external surfaces that might have been used as references for locating the fuel rods within the bundle. The fuel bundle manufacturers supply the utilities with as-built drawings marked with the fuel bundle serial number. The dimensions needed to locate the fuel rod pressure boundary in relation to an external reference surface at each end of a spent fuel bundle could thus be supplied by the utility. Combustion Engineering personnel suggested designing flexibility into handling equipment to allow for past and future design revisions of fuel bundles. Even with the most sophisticated and flexible handling equipment, some situations will require use of the manufacturers' as-built descriptions of individual fuel bundles.

Combustion Engineering personnel expected that their fuel rods could creep enough during irradiation that the rods could touch either the upper or the lower tie plate. These fuel bundles have upper and lower spacer grids attached to the tie plates, which prevents visual inspection of fuel rod position.

Babcock and Wilcox personnel stated that strong rod-to-grid contact would prevent their fuel rods from creeping during irradiation but that the fuel bundle growth was about 1-1/2 inches (2 inches for the fuel rods themselves).

GRAPPLE DESIGNS FOR MANIPULATION OF FUEL BUNDLES

The vendors of the various LWR fuel bundles have designed provisions for their fuel bundles to accept manipulating grapples. These provisions and the concept of grappling methods are discussed here, but no actual drawings are included because the specific designs are proprietary information.

COMBUSTION ENGINEERING

The Combustion Engineering fuel bundles are lifted by the upper spring plate, which forms a cross. A grapple resembling a notched pipe is lowered to the center of the element and then rotated to hook the connecting webs of the plate. All of the Combustion Engineering bundles use this method for lifting, but some design variations in the fuel bundles would require variations in grapple design.

WESTINGHOUSE

The upper end fittings of the Westinghouse fuel bundles have an outer perimeter ledge. The bundles are lifted by four hooks that are guided into place under the ledge by tapered pins and then forced outward and locked into place.

GENERAL ELECTRIC

General Electric elements are lifted by a bail that is an extension of the upper fitting and diagonal to the fuel bundle. One grapple hook is aligned with the bail by a box-type guide. The hook is then pivoted into place.

BABCOCK AND WILCOX

Babcock and Wilcox fuel bundles are lifted from the outside by inserting L-shaped hooks into windows in the upper end fittings. The Mark C (17x17) grapple has four hooks that are guided into place by four corner posts of the end fittings. The windows for these four hooks are located in these four corner posts at 45^{0} to the sides of the fuel bundle. The Mark B (15x15) grapple has four hooks that are guided into place by the four sides of the end fitting and enter off-center windows that are located on each side.

Grapples have been designed and provided by

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