ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

March 3, 1971

Files (Docket No. 50-155)
THRU: D. L. Ziemann, Chief, ORB #2, DRL

EVALUATION OF TWO NEW CENTERMELT FUEL ASSEMBLIES FOR BIG ROCK POINT NUCLEAR REACTOR (CONSUMERS POWER COMPANY)

INTRODUCTION

Consumers Power Company, by letter dated December 21, 1970, requested approval of Proposed Change No. 24 to insert two new centermelt fuel bundles into the Big Rock Point Nuclear Reactor during the February 1971 refueling outage. The Consumers Power Company and the General Electric Company Nuclear Energy Division, have jointly undertaken the continuation of the centermelt irradiation testing program at Big Rock Point, a program that was originally sponsored by EURATOM and the U. S. AEC, and terminated on June 30, 1969. Of the six original centermelt fuel assemblies, five were removed after the first 3-month cycle of irradiation pending destructive evaluation of selected fuel rods. The sixth centermelt subassembly (D-50) was removed in May 1969 when suspected multiple fuel rod failures were confirmed by visual inspection of the bundle. The cause of premature rod failures was tentatively attributed to accelerated corrosion due to clad overheating as a result of excessive crud deposition, predominantly a copper oxide. A supplemental report (6), based on hot cell examination of two fuel rods from the Intermediate Performance Centermelt Assembly that was irradiated for about one year achieving high power rod average exposures of 10,000 MWd/TU, indicates that the cause of severe clad deterioration was accelerated corrosion on the outside surface of the clad driven by local overheating of the clad. Grain growth in the zircaloy structure adjacent to the deterioration indicated temperatures of 1200-1300°F. Failure was attributed to excessive crud deposition and high surface heat fluxes.

DESCRIPTION

The two new centermelt fuel assemblies (D-57, an intermediate performance fuel assembly consisting of an 8 x 8 array of 0.570 inch O.D. fuel rods, 16 of which are hot enough at rated power conditions to have incipient centerline fuel melting; D-56, an advanced performance fuel assembly consisting of a 7 x 7 array of 0.700 inch O.D. fuel rods, 16 of which have definite but moderate center UO_2 melting at rated power conditions) differ from the original centermelt fuel assemblies that were approved by DRL[1] and inserted into the Big Rock Point reactor in March 1968 in that:

8101290347

1. stainless steel tubes with the same dimensions as fuel rod cladding are used:

   a. as corner structural posts for tying the upper and lower frames together,

   b. to hold the five fuel rod spacers in each assembly at the proper elevation, and

   c. to hold dummy rods containing cobalt targets.

2. there are only 16 high power rods in each bundle in contrast to 36 in the original 8 x 8 intermediate performance centermelt assemblies or 29 in the original 7 x 7 advanced performance centermelt assemblies. We have prepared the following table from information provided by Consumers Power Company to identify the most important performance characteristics of the new centermelt fuel assemblies in contrast to fuel assemblies we have already approved[1] for the Big Rock Point core, and in this manner provide the basis for our evaluation.

   For example - line 8 shows that the weight of UO_2 for each bundle type has decreased more than can be accounted for by the omission of fuel in the corner positions, i.e., 7.2% for the 8 x 8 instead of 6% and 10.5% for the 7 x 7 instead of 8%.

   line 9 shows a 16% decrease in U_{235} per bundle.
   line 10 shows 9.5% decrease in fuel enrichment for the 8 x 8 fuel assembly; 7.5% decrease for the 7 x 7 fuel assembly.

   lines 7, 11 and 13 show that 96% of the power was generated in 56% of the fuel (36 rods) in the original 8 x 8 in contrast to 44.5% of the power in the new 8 x 8 which is generated in 26.7% of the fuel (16 rods). Similarly for the 8 x 8, 95.7% of the power was generated in 59.0% of the fuel (29 rods) compared with 55.60% power generated in 35.60% of the fuel (16 rods).

   line 14 shows that the percentage of bundle power generated in the hottest rod of each bundle is about the same or up slightly.

line 18 shows that the ratio of power in adjacent rods is noticeably lower for the new fuel in contrast to the original centermelt assemblies and

line 22 shows that there are fewer low power rods adjacent to the highest power generation rod.

line 21 shows that power generation in the original hot rods was slightly higher than anticipated and

line 20 shows the ratio of old to new fuel rod peaking factors

line 12 shows that the Technical Specifications MCHFR 1.5 is satisfied at the 122% steady-state power level.

Comparison of New and Original
Centermelt Fuel

	1	2	3	4
	8 x 8 Intermediate Performance Centermelt		7 x 7 Advanced Performance Centermelt	
	Original (Ref. 1)	New Prop. Ch. 24	Original (Ref. 1)	New Prop. Ch. 24
1) Rod Diameter inches	0.570	0.570	0.700	0.700
2) Fuel Rods/Bundle	64	60	49	45
3) Cobalt Targets in corner positions	0	4	0	4
4) Number Depleted [illegible] rods per bundle (low power)	28	0	20	0
5) Number Natural UO_2 rods per bundle (low power)	0	28	0	12
6) Number Intermediate Power (2% U_{235}) rods per bundle	0	16	0	17
7) Number High Power rods per bundle	36	16	29	16

	1	2	3	4
8) Weight UO_2/Bundle kg	140 136 calc	126 calc	167 161 calc	144 calc
9) Weight $U_{235}O_2$/Bundle-kg	3.89 calc	3.26 calc	4.75 calc	3.98 calc
10) Average bundle enrichment %	$\frac{3.89}{136}$ or 2.86	$\frac{3.26}{126}$ or 2.58	$\frac{4.75}{161}$ or 2.95	$\frac{3.98}{144}$ or 2.76
11) Percent total UO_2 in high power rods	$\frac{36}{64}(100)$ or 56.3	$\frac{16}{60}(100)$ or 26.7	$\frac{29}{49}(100)$ or 59.2	$\frac{16}{45}(100)$ or 35.6
12) MCHFR at 122% Power Multi Channel Model Multi Rod Correlation	 1.56 1.53 (Ref 5 a)	(Ref 4c)*	 1.54 1.58 (Ref 5a)	(Ref 4c)*
13) Percent Power Generated in Low power rods/bundle Intermediate rods/bundle High power rods/bundle	(Ref 2b) 4.0 0 96.0	(Ref 4 a&b) 11.1 44.4 44.5	(Ref 2a) 4.3 0 95.7	(Ref 4 a&b) 15.85 28.55 55.60
14) Percent bundle power generated in highest power rod	2.8	2.8	3.43	3.55

*MCHFRs are reported for the intermediate performance assembly only. New thermal hydraulic correlations have been used to calculate the MCHFRs and therefore a direct comparison of MCHFRs is not valid.

	1	2	3	4
15) Variation of power in high power generation rods within each bundle %	8.5	2.0	7.5	3.0
16) High Power Rods Enrichment - ea bundle	12 @ 4.3% 16 @ 5.0% 8 @ 5.6%	8 @ 4.5% — — 8 @ 6.5%	12 @ 4.3% 12 @ 5.0% 5 @ 5.6%	— 8 @ 5.0% 4 @ 5.6% 4 @ 6.5%
17) Highest rod power factor/bundle	1.81-1.83	1.688	1.71-1.89	1.596
Lowest Rod Power Factor / Bundle	0.10-0.21	0.29	0.09-0.24	0.289
18) Ratio Highest Rod Power / Lowest Adjacent Rod	(Ref 2b) $\frac{1.81}{0.10}$ or 18.1 (Ref 3a) $\frac{1.83}{0.21}$ or 8.7	$\frac{1.688}{0.29}$ or 5.83	(Ref 2a) $\frac{1.71}{0.09}$ or 19.0 (Ref 3a) $\frac{1.89}{0.24}$ or 7.9	$\frac{1.596}{0.289}$ or 5.5
19) Moderator/UO_2 or W/F ratio	2.6		1.98	

	1	2	3	4
20) Ratio Hot Rod Old / Hot Rod New	1.81 or 1.83 / 1.688	or 1.07-1.08	1.71 or 1.89 / 1.596	or 1.07 or 1.18
21) Ratio Design Hot Rod / Actual Hot Rod (Ref 3a) (Ref 2a, 2b)	1.83 / 1.81 or 1.01		1.89 / 1.71 or 1.11	
22) Max. No. low power rods adjacent to hottest rod	6	1 low 3 intermediate	6	4
23) Fuel Depletion av. Bundle MWd/T	15,000	10,000	15,000	10,000
High Power rods	20,000 (Ref 2c)	15,000 calc (Ref 4d)	20,000 (Ref 2c)	15,000 calc (Ref 4d)

EVALUATION

The Intermediate Performance Fuel assembly, D-50 (an 8 x 8 array of fuel rods irradiated for a three-month period with five other centermelt fuel assemblies in the Big Rock Point reactor followed by an additional irradiation period of about eight months after the other five centermelt assemblies had been removed from the reactor to await destructive evaluation of fuel rod performance), will not be re-inserted into the core. This fuel assembly with hot rod average exposures of 10,000 MWd/TU has been permanently removed from the centermelt fuel irradiation program because of failure of many rods. The failures are attributed to severe clad deterioration caused by accelerated corrosion on the clad surface where clad overheating had occurred.(6) Similar failures were observed in normal reload fuel that was irradiated during the same period. Excessive crud deposition and high heat fluxes were reported to be the main factors involved in creating the high temperature condition. Neutrographs of one entire rod with incipient failure showed no hydriding of the cladding at the inside surfaces. The absence of such hydriding is an indication that there was no problem with contamination of the fuel with hydrogenous impurities. In other words, examination of fuel rods from the failed centermelt fuel assembly has revealed that the failures were not caused by impurities in the fuel, that clad temperatures were excessive and that there was an unusual accumulation of crud on the centermelt fuel rods and other reload fuel rods which also failed. We have concluded that these failures are not due to the high centerline fuel temperatures in the centermelt fuel assembly and we agree that the resultant higher than normal heat fluxes can cause significant increases in clad temperature unless the rate of crud accumulation is reduced. The licensee has stated (4e) that the new centermelt fuel assemblies will not be inserted into the Big Rock Point reactor until there is reasonable assurance that crud deposition on fuel rod surfaces has been significantly reduced to prevent local clad heating. Based on the evidence presented, we agree that this is prudent. The licensee plans to insert the five centermelt assemblies remaining from the original centermelt irradiation program some time in the future after 1) chemical cleaning of the fuel rods to remove the crud accumulated during three months of in-core irradiation and 2) substitution of low power rods for the high power density rods in the outside rows of fuel rods. The net effect of item 2 will be to reduce the number of high power rods from 188 in the six original assemblies to 170 in the 7 assemblies to be retained in the centermelt irradiation program. We have concluded that this reduction in the number of high power rods and compliance with the previously approved restriction that centermelt fuel assemblies be no closer than 16.5 inches center-to-center reduces the accident consequences below those that were reviewed and accepted for the original six centermelt assemblies. The licensee also has reported that the reactivity value for the new assemblies is lower (4f) than the core average thereby reducing fuel rod reactivity worths and increasing shutdown margins. Based on line 9 of the table, we concur that there is a significant reduction in U235 and therefore a corresponding reduction in reactivity. Similarly, the reactivity coefficients for the new assemblies are slightly more negative than the original centermelt fuel assemblies (4f) and therefore acceptable since the severity of accidents will not be increased beyond the values calculated for the original six centermelt fuel assemblies. We concur that 1) the hot cell examinations of irradiated centermelt fuel have been completed and reported (3)(6) in accordance with the requirements of Amendment No. 1(1), 2) the accumulation of crud on fuel rods should decrease with time, 3) the rate of crud accumulation on the centermelt fuel rods should be measured (at each refueling outage), 4) the instrumented Reload-F assembly rod may give insight into the crud deposition problem, and 5) the operational experience with centermelt fuel so far warrants a continuation of the centermelt fuel irradiation program.

We have noted the following inconsistencies in the application. The MCHFRs at the 122% overpower condition are increased although water enthalpy must have increased because the rods adjacent to the high power rods generate significant power in contrast to the depleted fuel rods in the original centermelt assemblies. The Advanced Performance high power rods may not achieve the objective of molten fuel at the center because, based on a reported heat flux of 535,000 Btu/hr. ft^2 at 122% power (4g), the rated heat flux is expected to be 440,000 Btu/hr.$ft.^2$, too low to cause melting at the center of the fuel rod (4h) at the start of life when such heat fluxes are attainable(4m). We also note that clad failure has been attributed to a very localized clad overtemperature condition resulting in accelerated corrosion of the cladding (4k) of centermelt and reload fuel rods, and that a contributory factor, crud accumulation, has been identified but the precise cause of local failures has not been determined. We are satisfied, however, that the failures were not caused by molten fuel conditions.

Additional information has been requested from the licensee to obtain greater accuracy in the comparative evaluation of the original and new centermelt performance characteristics but this information is not required to complete our safety evaluation. The general impression of some backing down from the original objective of definite center melting is evident. We have concluded that the hazards of operation with the two new centermelt assemblies and five of the original, chemically cleaned, and reconstituted assemblies are no greater than those considered in our previous evaluation of centermelt fuel assemblies for the Big Rock Point Nuclear reactor (1) and that the Technical Specifications may be changed to permit reactor operation with the two new centermelt fuel assemblies and five of the original centermelt fuel assemblies in the manner proposed by the licensee.

CONCLUSION

The two new centermelt fuel assemblies and five cleaned and reconstituted centermelt fuel assemblies together will include 172 fuel rods that will operate with centermelting or near centermelting temperatures, 16 less than were contained in the original six centermelt fuel assemblies. The total energy in the high performance fuel rods as a result of this change is lower than the value considered in our original evaluation. The mechanical design and fuel distribution of the new elements have been improved. We have therefore concluded that operation of the Big Rock Point Nuclear Reactor in the manner proposed by Consumers Power Company will not increase the probability of or change the consequences of the design basis accident nor does it involve significant hazards considerations not described or implicit in the Safety Analysis Report for Amendment No. 1 to the operating license or impair the effectiveness of engineered safety systems (Core Spray). There is reasonable assurance that the health and safety of the public will not be endangered by operation of the Big Rock Point Nuclear Reactor with two new and five previously irradiated centermelt fuel assemblies in the core and therefore, pursuant to Section 50.59 of 10 CFR Part 50, the Technical Specifications of Facility License No. DPR-6 should be changed as proposed.

James J. Shea
Operating Reactors Branch #2
Division of Reactor Licensing

Enclosure:
References

cc: D. J. Skovholt, DRL
R. H. Vollmer, DRL
D. L. Ziemann, DRL
J. J. Shea, DRL
R. M. Diggs, DRL
Mary Jinks (2)

References

1. DRL approval to operate the Big Rock Point reactor with six centermelt fuel bundles in the core.

   Amendment No. 1 to Facility Operating License No. DPR-6 dated March 12, 1968.

   a. Page 3 - Comparison with "Type C" Fuel.

2. Consumers Power Company Proposed Change No. 13 dated May 26, 1967.

   a. Figure 14 }
   b. Figure 15 } Individual Fuel Rod Relative Power at Beginning of Life

   c. Page 8 - Centermelt fuel exposure.

3. Special Report No. 10 dated April 7, 1969 - "Performance Evaluation of Centermelt Fuel after the First Period of Irradiation in the Big Rock Point Reactor":

   a. Figure 2 - Page 16 - Rod Local Power Factors

4. Consumers Power Company Proposed Change No. 24 dated December 21, 1970 - "Information on New Centermelt Fuel Assemblies":

   a. Figure 1, Rod Power Factors.

   b. Table 1, Enrichment Distribution.

   c. Table 5, Thermal-Hydraulics at 122% Power Level.

   d. Bundle Average Exposure - reactivity and rod power, page 14.

   e. Reduction in crud deposition, page 4.

   f. Centermelt fuel assembly reactivity, page 14.

   g. MCHFR, page 21.

   h. Figure 4.

   k. Cause of clad failure, page 23.

:t bundle power, page 17.

5. :r Company - Answers to DRL questions - dated August 15, 1967.

MCHFRs, page 10.

6. S : - February 1971 - "Failure Analysis and Performance Eval-
u :ermediate Performance Centermelt Fuel after 10,000 MWd/T
E

a no hydriding of the cladding at the inside surfaces.

MAR 3 1971

Docket No. 50-155

Consumers Power Company
ATTN: Mr. Gerald J. Walke
Nuclear Fuel Management
Administrator
212 West Michigan Avenue
Jackson, Michigan 49201

Change No. 24
License No. DPR-6

Gentlemen:

We have reviewed your Proposed Change No. 24 dated December 21, 1970, to the Technical Specifications of Facility License No. DPR-6 for reactor operation with two new centermelt fuel bundles and five of the original six centermelt fuel bundles.

The new centermelt fuel bundles are different from the original centermelt assemblies in the following respects: 1) sheet metal corner angles have been eliminated, 2) removable cobalt targets have been placed in new stainless steel corner tubes, 3) there are fewer (16 compared with 29 and 36) high power fuel rods, and 4) rod-to-rod power gradients have been reduced. Before the five original centermelt fuel assemblies that were irradiated during April, May and June 1967 are returned to the Big Rock Point Nuclear Reactor, the crud accumulated during that irradiation period will be removed by chemical cleaning and eight of the high power rods in the outer rows will be replaced by low power rods. With two new centermelt fuel bundles in the core, there will be a total of 32 high power rods at or near centermelt conditions at rated power. When the five original centermelt fuel assemblies have been reconstituted and reinserted into the Big Rock Point core, the total number of high power rods will be 172 compared with 188 for the six centermelt fuel bundles as originally fabricated and irradiated in the Big Rock Point core in March 1967.

We have concluded that the proposed change does not present significant hazards considerations not described or implicit in Consumers' Safety Analysis Report and Proposed Change No. 13 dated May 26, 1967, and approved by DRL Amendment No. 1 to the Facility Operating License No. DPR-6 dated March 12, 1968. There is reasonable assurance that the health and safety of the public will not be endangered by operation of the Big Rock Point Nuclear Reactor in the manner described by Consumers

Dupe of
8110120126

Power Company with two new centermelt fuel bundles or with the two new centermelt fuel bundles and five of the original centermelt fuel bundles as proposed.

Accordingly, pursuant to Section 50.59 of 10 CFR Part 50, the Technical Specifications of Facility License No. DPR-6 are hereby changed as indicated in Attachment A to this letter.

Sincerely,

Peter A. Morris, Director
Division of Reactor Licensing

Enclosure:
Attachment A - Changes to
Technical Specifications

cc: George F. Trowbridge, Esquire

Distribution
W. Dooly, DR
R. Engelken, CO (2)
H. Shapar, OGC
N. Dube, DRL (5)
J. R. Buchanan, ORNL
T. W. Laughlin, DTIE
Document Room
Docket File
DR Reading
DRL Reading
Branch Reading
ACRS (3)
R. DeYoung, DRL
R. S. Boyd, DRL
D. J. Skovholt, DRL
R. H. Vollmer, DRL
D. L. Ziemann, DRL
J. J. Shea, DRL
R. M. Diggs, DRL

dispatched 3/5/71

OFFICE ▶	DRL	DRL	DRL	DRL	DRL	DRL
SURNAME ▶	JJShea:sjg	RMDiggs	DLZiemann	DJSkovholt	FSchroeder	PAMorris
DATE ▶	3/1 /71	2/24/71	3/1 /71	3/1 /71	2/ /71	2/ /71

ATTACHMENT A

CHANGE NO. 24 TO TECHNICAL SPECIFICATIONS

FACILITY LICENSE NO. DPR-6

CONSUMERS POWER COMPANY

DOCKET NO. 50-155

1. Change the first paragraph of Section 8.1 to read:

   "8.1 The general dimensions and configuration of the developmental fuel designs shall be as shown in Figures 8.1 through 8.7. Principal design features shall be essentially as shown in Table 8.1."

2. Section 8 - Figures:

   Add Figure 8.6 - New Intermediate Performance Fuel Centermelt Assembly (8 x 8 Array) and Figure 8.7 - New Advanced Performance Fuel Centermelt Assembly (7 x 7 Array).

3. Delete Table 8.1 and insert the revised Table 8.1.

4. Table 8.2 - Change the number of centermelt fuel bundles to read:

"Number of Bundles	Centermelt	
	Intermediate	Advanced
Pellet UO_2	1	3
Powder UO_2	1	2 "

5. Change Section 8.2.1(c) to read:

   "(c) Fuel Examinations

   Nondestructive examinations of selected fuel rods in the centermelt fuel bundles shall be performed during each core refueling period. Any rods displaying unexpected increases in diameter shall not be returned to the core.

   Selected fuel rods shall be removed during each refueling period for destructive examinations. The bundles shall be reconstituted with replacement fuel rods and may be returned to the core for continued irradiation."

Table 8.1

General	RESEARCH AND DEVELOPMENT FUEL TYPES					
	Centermelt Intermediate	Centermelt Advanced	"Modified E-G"	EEI UO_2-PuO_2	New Centermelt Intermediate	New Centermelt Advanced
Geometry, Fuel Rod Array	8 x 8	7 x 7	9 x 9	9 x 9	8 x 8	7 x 7
Rod Pitch, Inch	0.807	0.921	0.707	0.707	0.807	0.921
Standard Fuel Rods per Bundle	36 (3)	29 (3)	52 (1, 2, 4)	0 (6, 7)	60 (1)	45 (1)
Special Fuel Rods per Bundle	28	20	29	81	4	4
Spacers per Bundle	5	5	3	3	5	5
Fuel Rod Cladding						
Material	Zr-2	Zr-2	Zr-2 With Various Initial Mechanical Properties Zr-3Nb-1Sn	Zr-2	Zr-2	Zr-2
Standard Rod Tube Wall, Inch	0.035	0.040	0.040	-	0.035	0.040
Special Rod Tube Wall, Inch	0.035	0.040	0.040	0.040	0.031	0.031
Fuel Rods						
Standard Rod Diameter, Inch	0.570	0.700	0.5625	-	0.570 (8)	0.700 (8)
Special Rod Diameter, Inch	0.570	0.700	0.5625	0.5625	0.347	0.347
Fuel Stacked Density, Percent Theoretical	94 Pellet 85 Powder	94 Pellet 85 Powder	94 Pellet (5)	82 Powder	92-93 Pellet	92-93 Pel
Active Fuel Length, Inches						
Standard Rod	66-67.3	65-66.3	70	70	67.3	66.3
Special Rod	-	-	64.9 Central, 68.6 Removable	-	-	-
Fill Gas	Helium	Helium	Helium	Helium	Helium	Helium

See attached page for footnotes.

(Revised with Change No. 24 issued 3/3/71.)

Footnotes to Table 8.1

(1) Modified E-G and EEI UO_2-PuO_2 and new centermelt fuel bundles may contain (in the corner regions of the bundle) four Zr-2 tubes having encapsulated cobalt targets sealed within.

(2) Modified E-G and EEI UO_2-PuO_2 fuel bundles have a special central fuel rod to which the bundle spacers are fixed. In addition, two of the interior bundle fuel rods are removable and may contain UO_2-PuO_2 fuel.

(3) Special rods have depleted uranium.

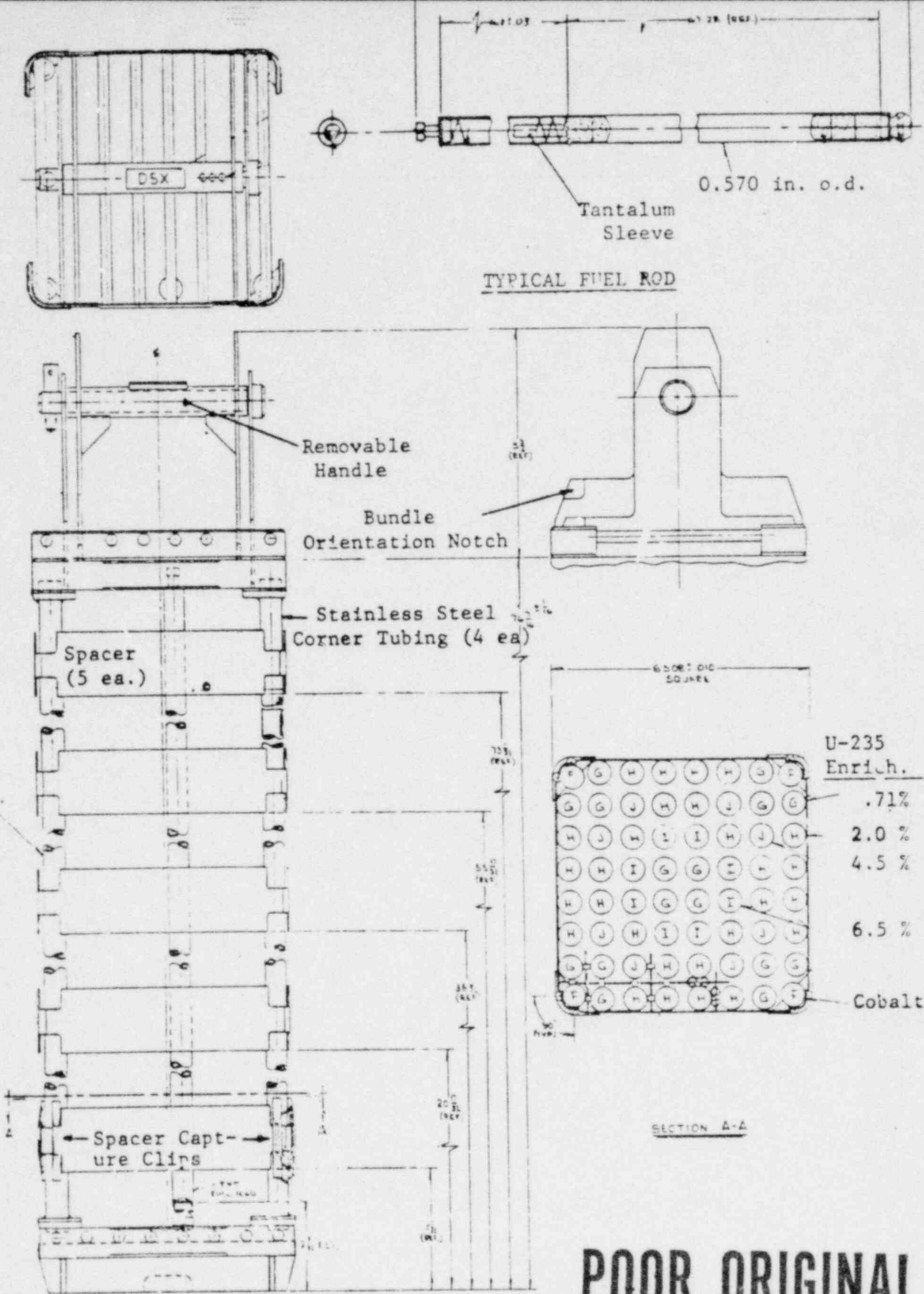
(4) Also has four gadolinia-containing rods.

(5) With 3% dishing on selected rods.

(6) UO_2-PuO_2 fuel rod stack density will vary from 74 to 92% theoretical by using annular, dished, or nondished pellets in selected rods.

(7) Sixty-four UO_2-PuO_2 rods similar to standard UO_2 rods, four removable PuO_2 rods, eight gadolinia-containing rods, four cobalt corner rods and one empty (water-[illegible] during operation) spacer rod.

(8) Diameter of cobalt targets inside SS corner tubes.



POOR ORIGINAL

FIGURE 8.6 NEW INTERMEDIATE PERFORMANCE FUEL CENTERMELT ASSEMBLY
(8x8 ARRAY)

(Issued with Change No. 24 dated 3/3/71.)

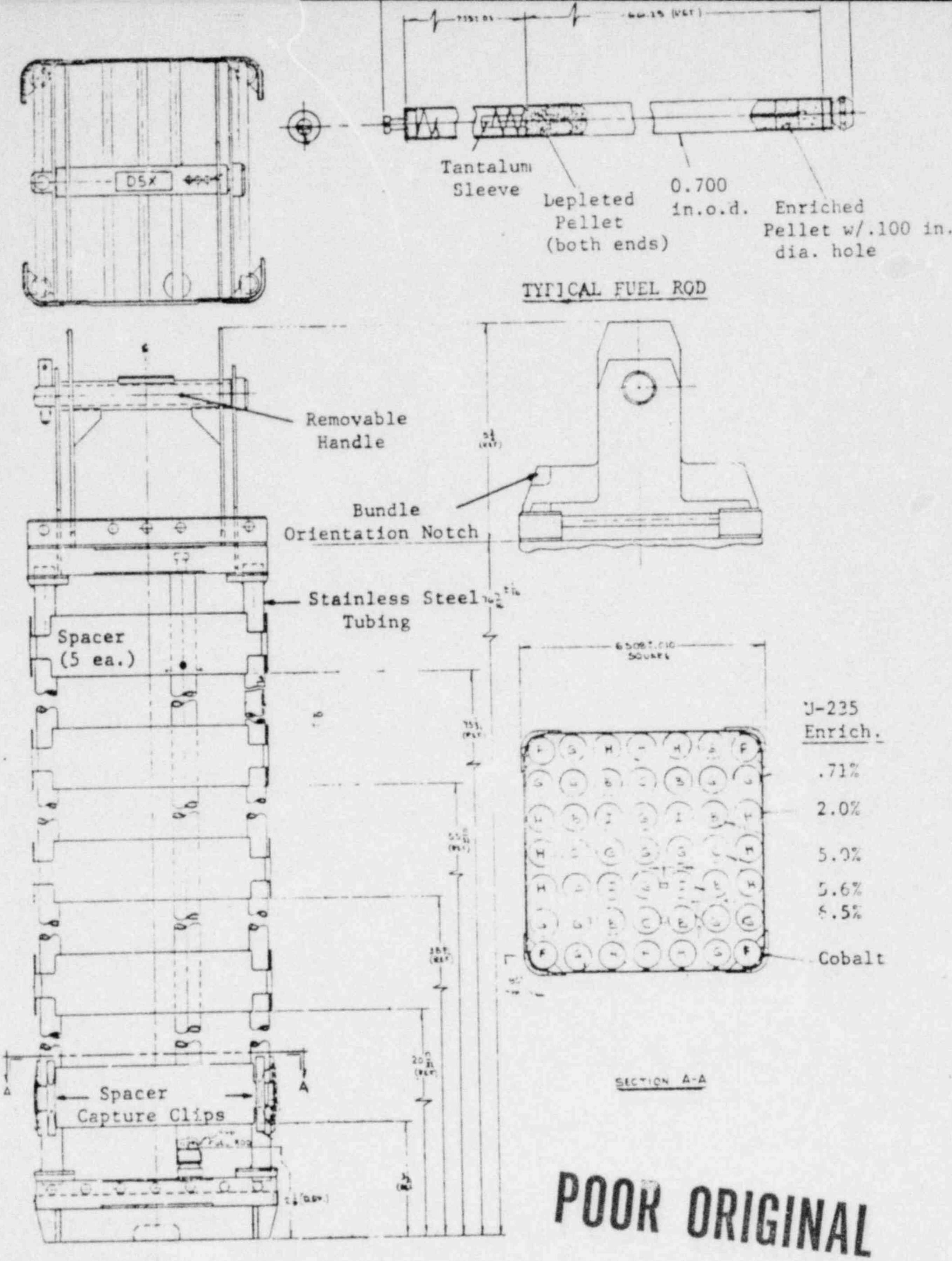


FIGURE 6.7 NEW ADVANCED PERFORMANCE FUEL CENTERMELT ASSEMBLY (7x7 ARRAY)