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FUEL DESIGN FOR THE AI LMFBR DEMONSTRATION PLANT

by

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A. Goals to be Achieved in Demonstration Plant

The primary goals to be achieved in the area of fuel performance are related to establishing the economic desirability of LMFBR central station power plants. To achieve the economic potential of LMFBRs, these basic attributes of the fuel must be demonstrated: it must be capable of achieving high burnup (longevity) reliably and, it must be available at low cost.

1. Reliability

To date no single fuel design has been so exhaustively tested that it can be shown statistically to have attained the desired level of reliability. However, as a consequence of the broad range of designs that have been tested throughout the world, a large measure of confidence in the successful attainment of this goal can be drawn from the extremely low incidence of "infant mortality" failures and from the fact that, despite the wide range of parametric variations, fairly rudimentary models of mixed oxide fuel behavior permit successful design of fuel elements. A measure of the degree of this success may be assessed by recalling that, despite the large increase in the number of fuel rods subjected to test, the number of rods that have failed each year has steadily decreased.

Table I summarizes the world-wide experience in fast reactors. It shows that less than two percent of all fuel rods tested had failed, and if one eliminates the failures in the BR-5 irradiations (since these rods were equipped with extremely short fission gas plena), less than one-half of one percent have failed. And, if one recalls that overheating as a result of cover gas entrainment in DFR contributed heavily to those failures, the experience is even more favorable. Thus, one may conclude that the mixed oxide-stainless steel fuel system is extremely rugged.

TABLE I

OXIDE IRRADIATIONS IN FAST REACTORS

Country	Reactor	No. of Rods Irradiated	No. of Rods Failed
USSR	BR-5 and BOR-60	4600	120-150
UK	DFR	800	50
France	Rapsodie and DFR	8000	1
USA	EBR-II and SEFOR	1500	10
Other	Rapsodie and DFR	200	3

One may postulate several reasons for the "forgiving" nature of this fuel form. The fuel is inherently mobile; it is both "creepy" - soft and plastic (see Figure 1) - and volatile, permitting redistribution via vapor transport mechanisms from regions of high temperature to those at low temperature. Its low thermal conductivity is highly beneficial, establishing a steep temperature gradient which drives fission product gases from the fuel lattice minimizing its tendency to swell. Furthermore, it is characterized by great chemical stability, a high melting point and both high viscosity and surface tension in the molten state, permitting the consequences of transgressing into the molten state to be considered trivial.

Since absolute reliability is not practically attainable, it is prudent to incorporate features in the design of all plants to permit full power operation with a "few" failures. Release of radioactivity to the environment has been controlled and one can project that the LMFBR should prove superior to LWRs due to the intense chemical affinity of sodium for tritium and halogen fission products.

2. Longevity

World experience has demonstrated the attainability of near-term burnup goals, viz. those required for demonstration of desirable fuel cycle economics (see Figure 2). Again, widely different designs have attained burnup levels of economic significance. It may be anticipated that significantly higher burnups will be achieved. However, the demonstration of the ultimate capability of various designs must await the operation of prototypic power plants to provide appropriate test-bed environment. This view is confirmed by the universal decision (in all nations actively developing the LMFBR) to proceed expeditiously to the prototype reactor.

3. Low Cost

This attribute of the LMFBR is currently the weakest link, due to the low volume of mixed oxide fuels required at this time. Automated production facilities are not at hand from which to make firm projections. Additionally, current fuel costs are high due to the requirements of current experimental applications. That is, it has not been demonstrated to what degree specifications and tolerances may be relaxed to reduce cost without increasing the risk of fuel failure; to date, little effort has been focussed on such considerations. Thus, it can be projected that significant cost reductions will accrue from the elimination of over-specification.

B. Design Point Selections

At AI, the specific performance goals that have been formulated and from which plant system and component design criteria have been extracted are:

1. Reliability - There shall be a 0.999 probability that less than 0.1% of the fuel rods (in the core at any time) will be failed.

2. **Longevity** - Fuel batches shall have an average burnup of 75 MWD/kgH; the corresponding maximum burnup is 110 MWD/kgH.

3. **Low Cost** - The fuel cycle cost is estimated at ~1.5 mills/kwh (near term(and < 1.0 mill/kwh for the mature plant. Since more than half of the fuel cycle cost arises from reprocessing, inventory, and shipping charges, etc., only the remainder is available for improvement via fuel element design alternative selections, primarily via core design decisions (breeding gain) and fabrication simplifications.

The key features of the AI fuel rod design are summarized in Table II together with a brief indication of the basis for the selection.

TABLE II

FEATURES OF AI FUEL ROD DESIGN AND BASIS OF SELECTION

Feature	Basis
Solid Pellet Fuel (Mixed Oxide)	Ease of fabrication-simple processing and simplified inspection
80% (T. D.) Smeared Density	Trade-off between operating interval and control absorber volume in core
	Adequate internal porosity (volume) to accommodate fuel swelling (and melting, if encountered)
0.006" (nominal) Diametral Cold Gap	Minimum gap for ease of pellet loading ≈ 0.003"
	Minimum gap to prevent plastic strain of tubing ≥ 0.002"
	Inconsequential thermal performance penalty over gap range of 0.003" to 0.009"

TABLE II
(continued)

Feature	Basis
~85% (T. D.) Fabricated Fuel Density (Fine Grain Size, ≤10μ)	Pellet shrinkage during sintering is minimized, so can use unground pellets (minimum cost) High porosity and small grain size in as-fabricated fuel provides for high fuel creep rate and low fuel swelling
Mechanically-Mixed Powders	Low density fuel form process readily accommodates powders from diverse sources Ease of scrap recycle and of compounding adjustments
Low O/M Ratio (< 1.96)	Minimizes fuel/fission product chemical attack on cladding Negligible swelling of fuel upon ingress of sodium Thermal/physical property variations with O/M are minor
Fuel Rod Dimensions	
1) 0.270-inch diameter (0.016-inch wall thickness)	Trade-off between Pu value and fabrication cost with a secondary effect of the capital cost of core volume Insensitivity of performance to rod diameter
2) 44-inch Fueled Height	Trade-off between capital and operating costs; economic core configurations have L/D > 0.5 Positive void coefficient effects are relatively insensitive to core height for unspoiled geometries Height typical of target LMFBRs
3) Axial Blanket Height: 12-inch Upper 18-inch Lower	Upper blanket is economic optimum Lower blanket combines operating economy and capital cost reduction via improved shielding downward

Table II
(continued)

Feature	Basis
4) Combined Blanket/Fuel Encapsulation	Economic optimum of fabrication and pumping (ΔP) costs
5) Unvented Fuel Rod: Gas Plenum Height and Cladding Wall Thickness	Trade-off between fuel rod reliability (plant unavailability) and operating cost (breeding gain and pumping power)
Cladding Material (CW 316 SS)	Low steel swelling rates
	Good compatibility with coolant and fuel
	Best characterized of available alloys
Helical Wire Spacer	Superior thermal/hydraulic performance
	Mechanical flexibility to accommodate differential swelling rates between fuel rods and duct
	Inherent mechanical stability with low bearing loads
	Economically attractive; fabrication simplicity
Fuel Column Restraint: Annular Felt Metal Plug	Simplicity of fabrication
	Room temperature retentivity, elevated temperature looseness guaranteed

C. Target Plant Requirements

If LMFBRs are to achieve the economic potential projected for them both domestically and abroad, they must be designed to provide flexibility within each plant to capitalize on the optimum combination of economic factors. Examples related to fuel rod design include:

1. Flexibility of Core Design - to permit optimization of fuel assembly geometric parameters to capitalize on future developments and to achieve the proper balance between fabrication costs, inventory costs and breeding benefits. Thus, with low cost plutonium, it is desirable to employ larger diameter fuel rods.

2. Flexibility of Fuel Assembly Design - to permit optimization of thermal/hydraulic vs. mechanical design to reap the benefits of improved (higher strength, higher ductility and lower swelling) alloys, to permit adjustment of bundle looseness and edge channel dimensions, to permit the use of vented fuel with its attendant improvement in breeding (reduced steel and sodium volume), etc.

3. Improved Fuel Cycle Economics - via reduced Q/A cost in cladding procurement (acceptability of relaxed specifications); via relaxed tolerances on fuel pellet parameters (density, shape, Pu content); via simplification of fabrication processes (unsintered pellets); and, via simplification of accountability requirements and operations.

At AI, all three of the above areas are kept firmly in mind to assure that the LMFBR Demonstration Plant will prove to be not only an initial success, but that it will also remain an economic power producer throughout its lifetime. With a successful demonstration of the LMFBR concept, its components and its economics, the scale-up to the Target (1000 Mwe and perhaps larger) Commercial Plant should prove a comparatively simple step.

Figure 3 illustrates the fuel assembly for the Fast Breeder Reactor.

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IN-PILE CREEP OF MIXED (U-Pu) OXIDE FUEL

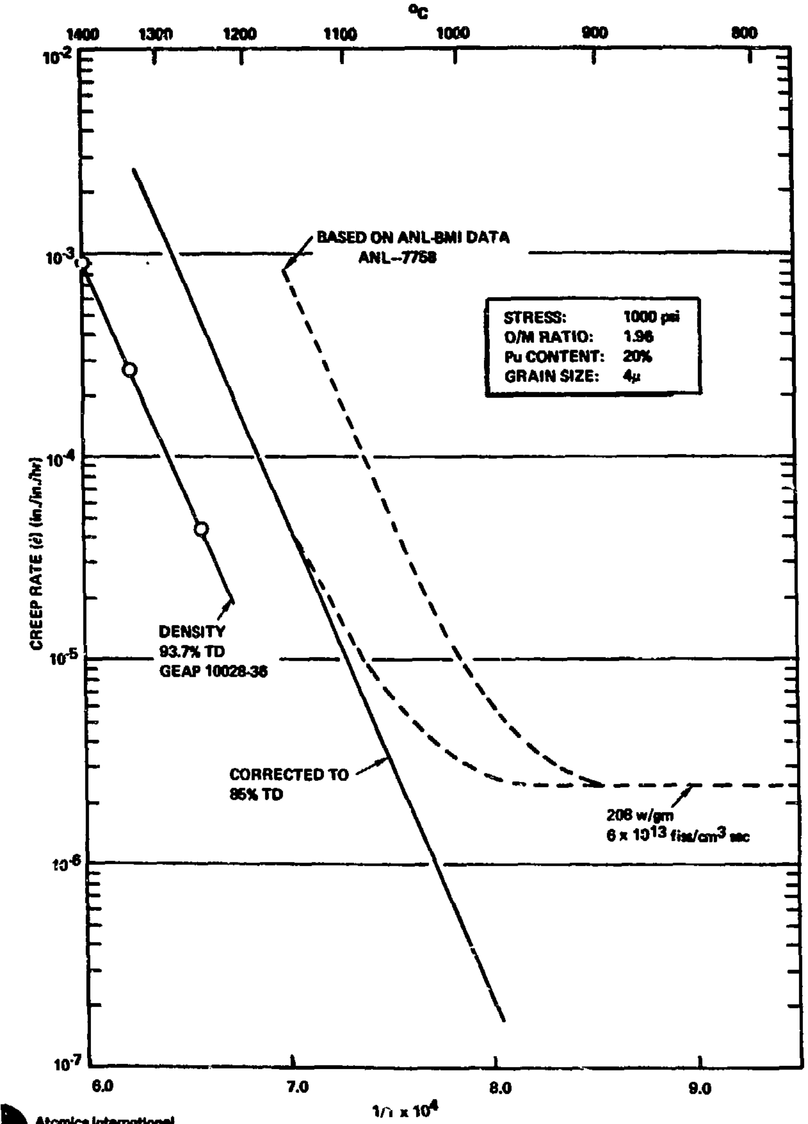

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Figure 1

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CUMULATIVE NUMBER OF PuO_2 AND MIXED OXIDE RODS

REMOVED FROM FAST REACTORS - DECEMBER 31 EACH YEAR

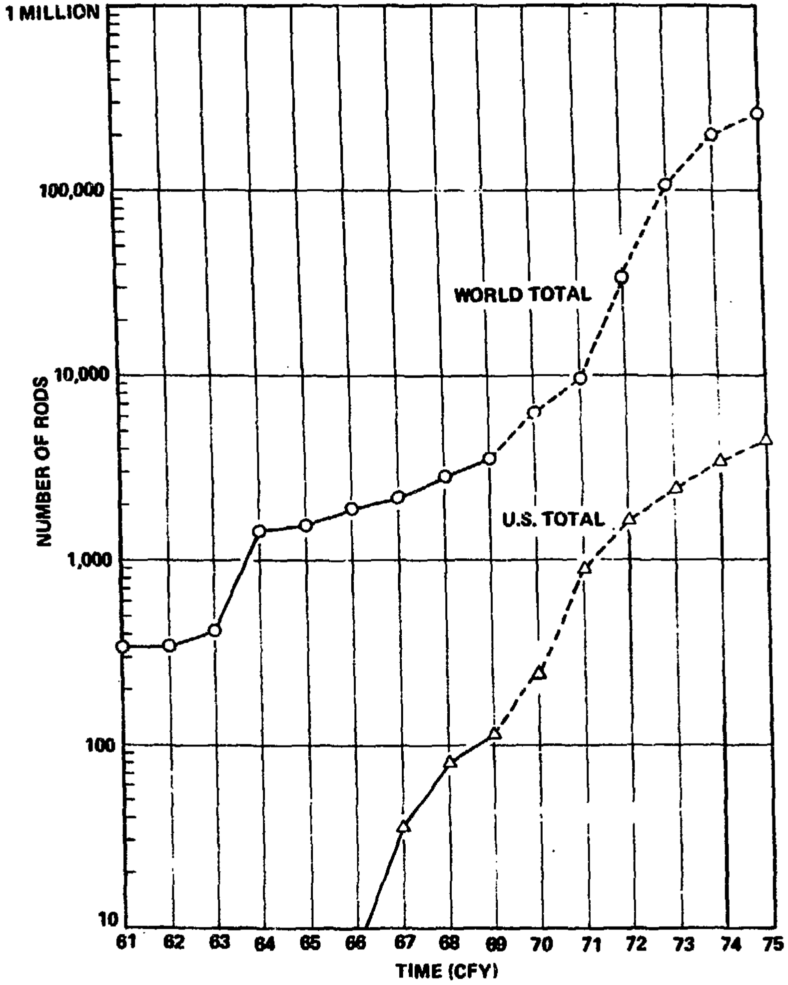

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Figure 2(a)

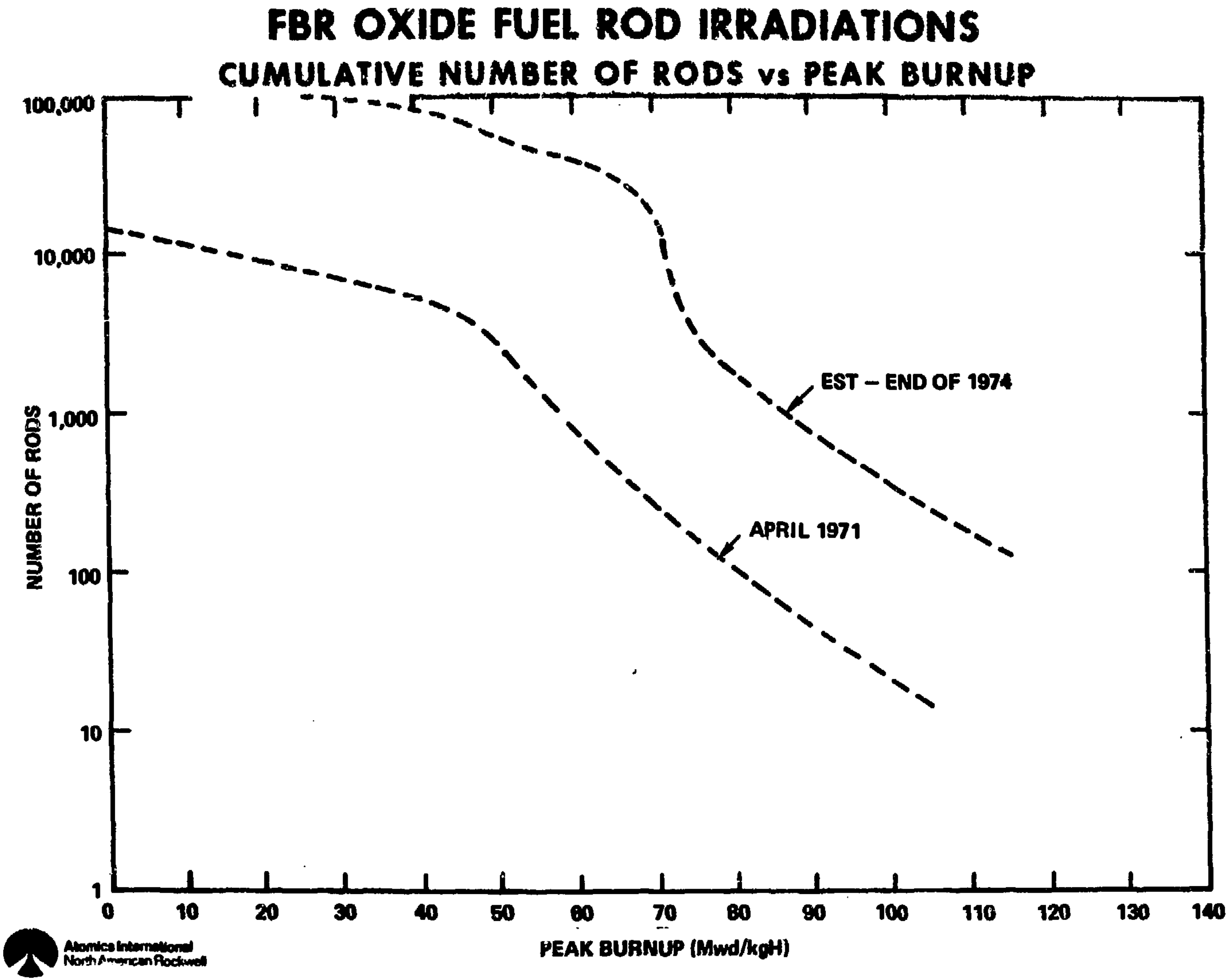

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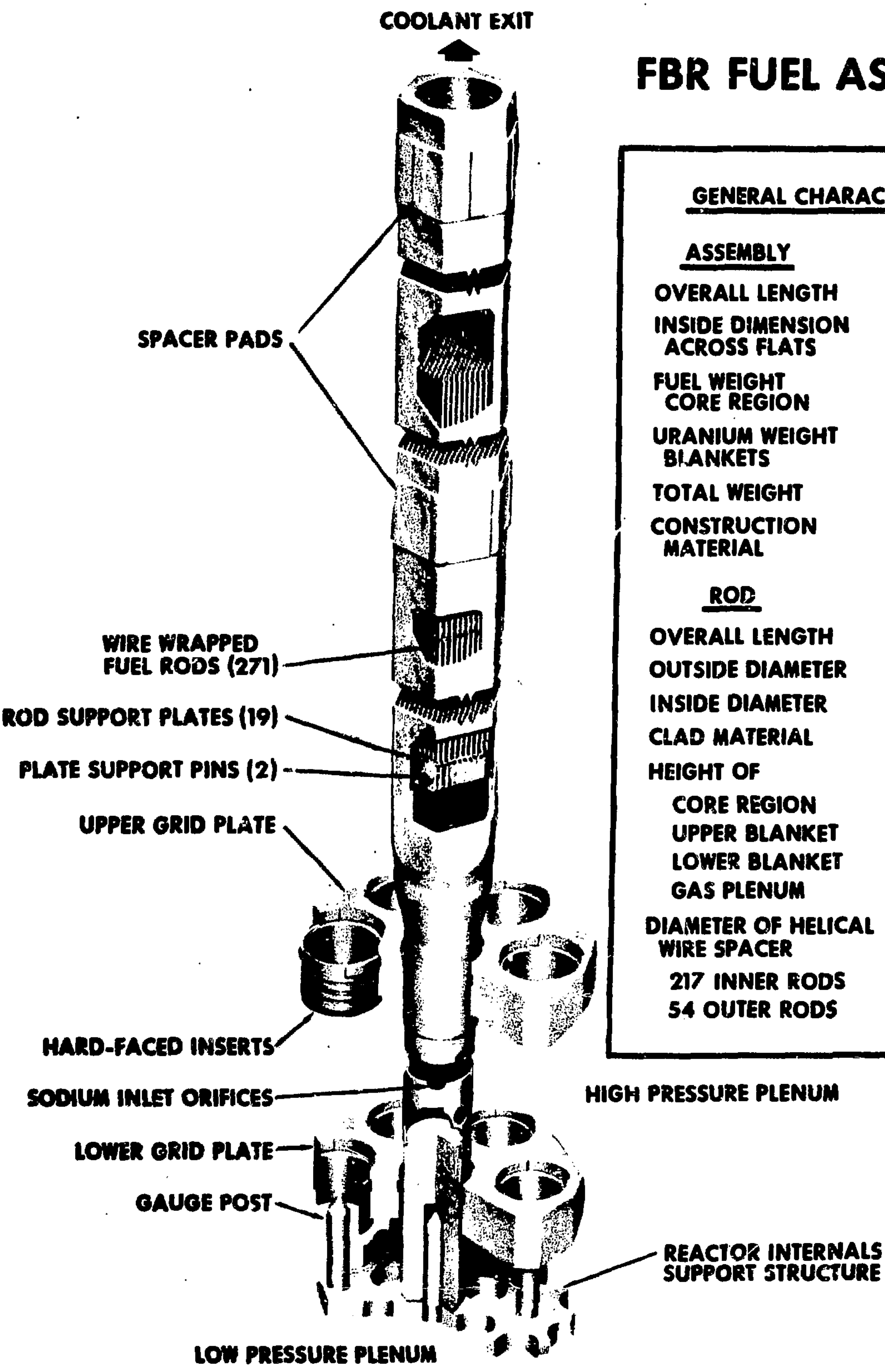
Figure 2(b)

FBR FUEL ASSEMBLY



GENERAL CHARACTERISTICS

ASSEMBLY	
OVERALL LENGTH	188 in.
INSIDE DIMENSION ACROSS FLATS	5.320 in.
FUEL WEIGHT CORE REGION	67.5 Kg
URANIUM WEIGHT BLANKETS	53.0 Kg
TOTAL WEIGHT	~600 lb
CONSTRUCTION MATERIAL	316 SS
ROD	
OVERALL LENGTH	102.8 in.
OUTSIDE DIAMETER	0.270 in.
INSIDE DIAMETER	0.238 in.
CLAD MATERIAL	316 SS
HEIGHT OF	
CORE REGION	44 in.
UPPER BLANKET	12 in.
LOWER BLANKET	18 in.
GAS PLENUM	26 in.
DIAMETER OF HELICAL WIRE SPACER	
217 INNER RODS	0.046 in.
54 OUTER RODS	0.023 in.

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Figure 3