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ASSESSMENT OF UNCERTAINTY IN VOLUME OF PRIOR MOLTEN ZONE BASED UPON BOREHOLE VIDEO DATA: TMI-2 REACTOR CORE

Richard P. Smith

EG&G Idaho

Work performed under DOE Contract No. DE-AC07-76ID01570

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INTRODUCTION

Examinations of video tapes generated by a remote camera inserted into each of the 10 boreholes through the previously melted zone of the TMI-2 reactor core have contributed greatly to our present knowledge of the end state configuration of damaged material in the core (Tolman, et. al., 1987). In order to use the volumes of the damaged zones for fission product mass balance calculations, the uncertainty associated with calculations of those volumes must be known. This report documents the method used for evaluating the uncertainty.

SOURCE OF UNCERTAINTY

Based upon previous visual, video, and sonar examinations, physical probe data and video examinations of the ten boreholes, the geometry of the post-accident core is reasonably well known (Tolman, et. al., 1987). The upper third of the core contains a large void generated by fragmentation and collapse of fuel rods during the accident. The middle third is composed of a loose debris bed of fuel, fuel rods, and cladding fragments. The bottom third is composed of a ceramic-agglomerate mass solidified from molten fuel, fuel rods, and cladding material resting upon intact fuel rod stubs.

The top surface of the prior molten zone is tightly constrained by the position of the hardstop determined by the probe operation. This is because 63 probe data points are evenly distributed across the core cross section. Errors in the position of the hard stop surface are likely to be insignificant, ±2.5 cm (1 inch). Very little uncertainty is associated with the void volume because it is determined by sonic means and the loose debris bed volume and is bounded by the floor of the void and the hardstop surface. The major uncertainty is in the volume of the prior molten zone. This is because of uncertainties associated with establishing the position of the interface between prior molten material and fuel rod stubs from the borehole video data. Three sources of error occur in determining the interface position.

(1) Minor [±2.5-cm (1-inch) or less] errors are associated with determining the position of nearly horizontal interfaces in the boreholes. Since these interfaces are near visible spacer grids in some holes (D-4, G-8, D-8, N-5), their positions are known fairly accurately.

(2) Large [up to ±23-cm (9-inch)] errors are associated with steeply sloping interfaces which occur much higher on one side of the borehole than on the other. This problem is especially evident in drill holes K-6, K-9, G-12, and N-12. The elevations (axial positions) of the high and low points are reasonably well known because they sometimes occur near spacer grids and/or they were measured on the camera cable by the filming crew. The big uncertainty associated with these holes is the radial orientation (look direction) of the camera is unknown. Had the camera positioning rods been used during the filming, the look directions could have been recorded, and the errors could have been reduced considerably. Instead, the camera was allowed to swing freely on the cable in the drill holes. This makes it necessary to accept the distance from the high point of the interface to its low point in each drill hole as the uncertainty range (see Figure 1). This range amounts to as much as 17 inches in drill hole K-6.

(3) A special situation is evident in drill hole K-9, where a molten mass extends to the base of the fuel (lower end fitting spacer grid) and can be seen between fuel rods beyond the drill hole wall. The direction of that molten channel from drill hole K-9

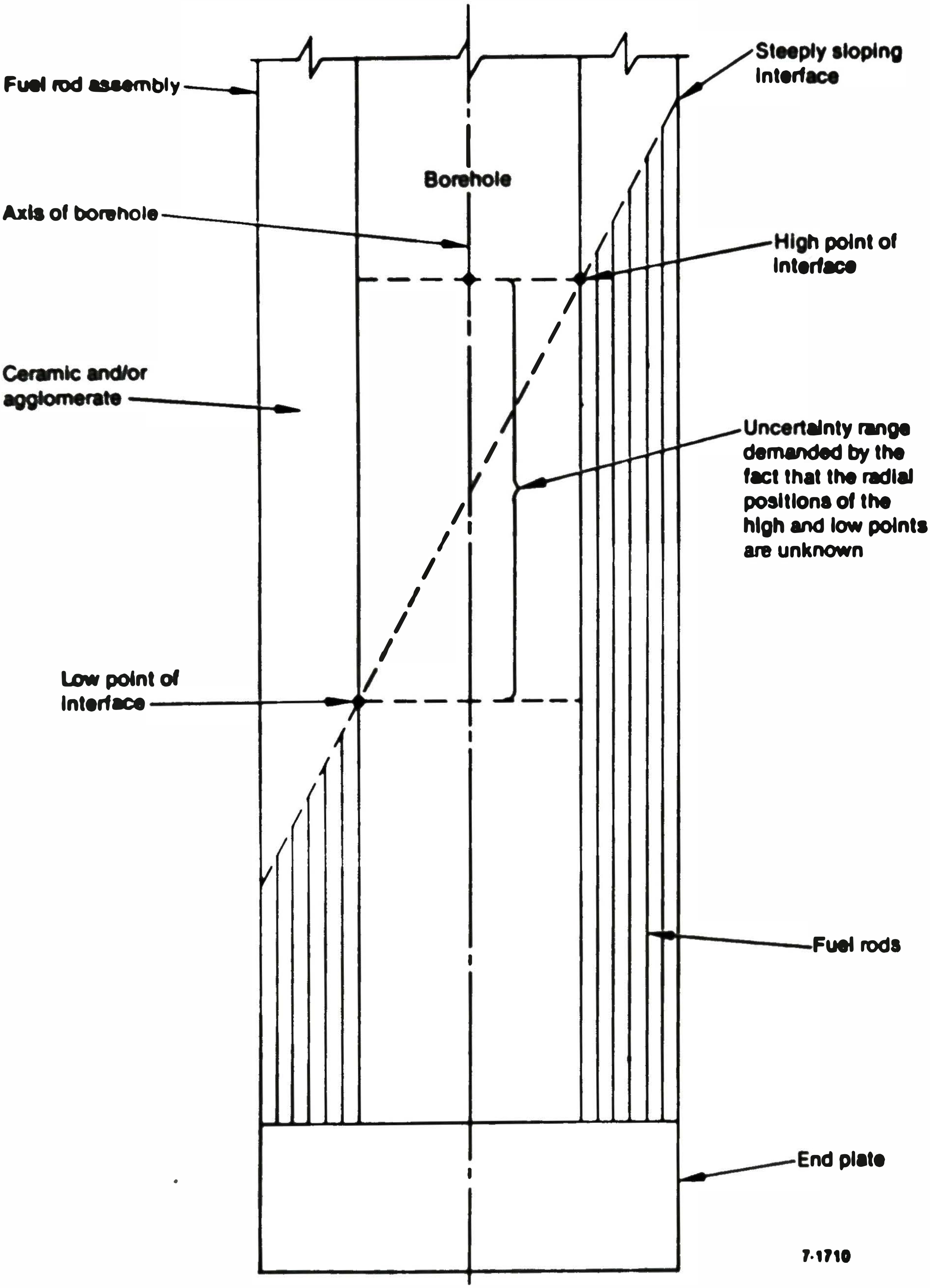


Figure 1. Geometry of borehole in fuel assembly with steeply sloping interface between rod stubs and molten material.

is unknown, but a reasonable configuration of contours on the interface (Figure 2) suggests it is to the south of K-9 and is smaller than the width of a fuel assembly.

METHODOLOGY AND RESULTS

Recognizing the uncertainties in location of the interface, a minimum and a maximum height above the base of fuel for the interface is listed for each drill hole (Table 1). Also indicated is the range of uncertainty and the additional range probable near drill hole K-9. Using the numbers listed in this table, two contour maps were generated for the interface; one (Figure 2) shows the lowest possible position (corresponding to the maximum amount of core melting) and the other (Figure 3) shows the highest possible position of the interface (corresponding to the minimum amount of core melting). From these contour maps, cross sections of the core through the lettered rows of fuel rod assemblies (B through P) were constructed (Figures 4 through 16) in the manner described in more detail in Tolman, et. al., 1987. These core cross-sections show the highest and lowest possible positions of the interface and allow computation of the volume of prior molten material and fuel rods for each case. The area of the prior molten zone and intact fuel rods is measured for each core cross-section and multiplied by the width of the fuel rod assemblies, 0.218 m (0.7156 ft) to obtain the associated volumes. The volume of the prior molten zone and intact rods are listed in Tables 2 and 3 for each fuel assembly row and for the total end state reactor core. The ranges of uncertainty both in volumetric units and in percent of the estimated volumes are also given for the total end state reactor core.

DISCUSSION

The original estimate of the volume of the prior molten zone, 3.5 m^3 (122 ft^3) (Tolman, et. al., 1987) is very near the average value, 3.7 m^3 (129 ft^3), obtained from averaging the maximum and minimum volumes estimated in this report. The estimated uncertainty in the molten core zone (corresponding to the volume encompassed by the two surfaces representing the maximum and minimum depth of melting) is approximately

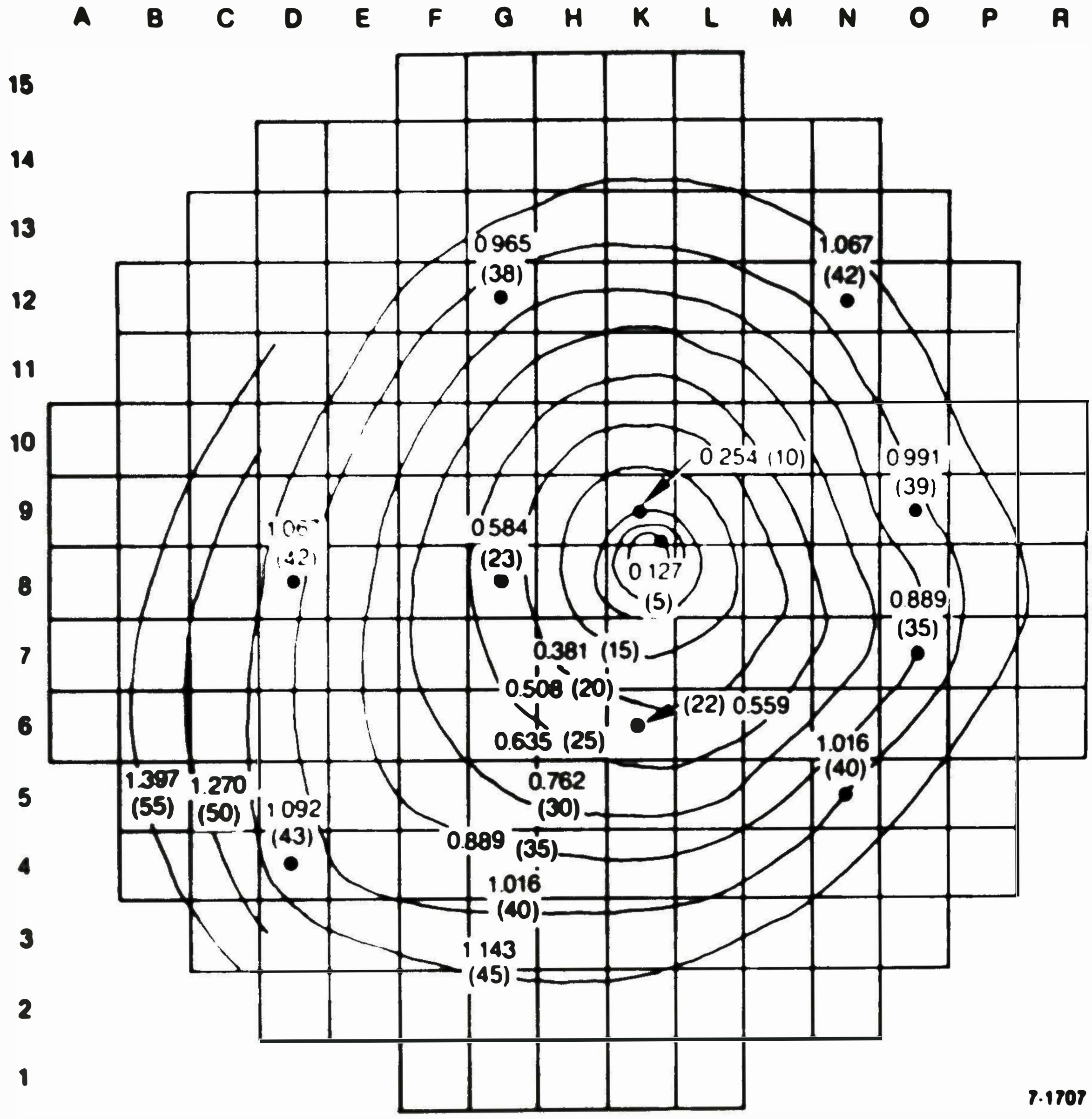


Figure 2. Contour map showing lowest possible position of interface (corresponding to maximum amount of core melting). Data are in meters (inches).

TABLE 1. LIST OF MAXIMUM AND MINIMUM HEIGHTS OF INTERFACE[a] ABOVE BASE OF FUEL

Drill Hole	Observed Minimum Height of Rods (m/in.)	Observed Maximum Height of Rods (m/in.)	Uncertainty Range	Probable Additional Range
N-5	1.02 (40)	1.12 (44)	0.10 (4)	
N-12	1.07 (42)	1.25 (49)	0.18 (7)	
G-8	0.56 (22)	0.61 (24)	0.05 (2)	
G-12	0.97 (38)	1.09 (43)	0.13 (5)	
K-9	0.25 (10)	0.51 (20)	0.25 (10)	One channel extends to bottom of fuel (first spacer grid)
D-8	1.07 (42)	1.12 (44)	0.05 (2)	
K-6	0.56 (22)	0.99 (39)	0.43 (17)	
D-4	1.09 (43)	1.17 (46)	0.10 (4)	
O-7	0.89 (35)	1.02 (40)	0.13 (5)	
O-9	0.99 (39)	1.04 (41)	0.05 (2)	

a. Interface between ceramic/agglomerate mass and intact fuel rod stubs.

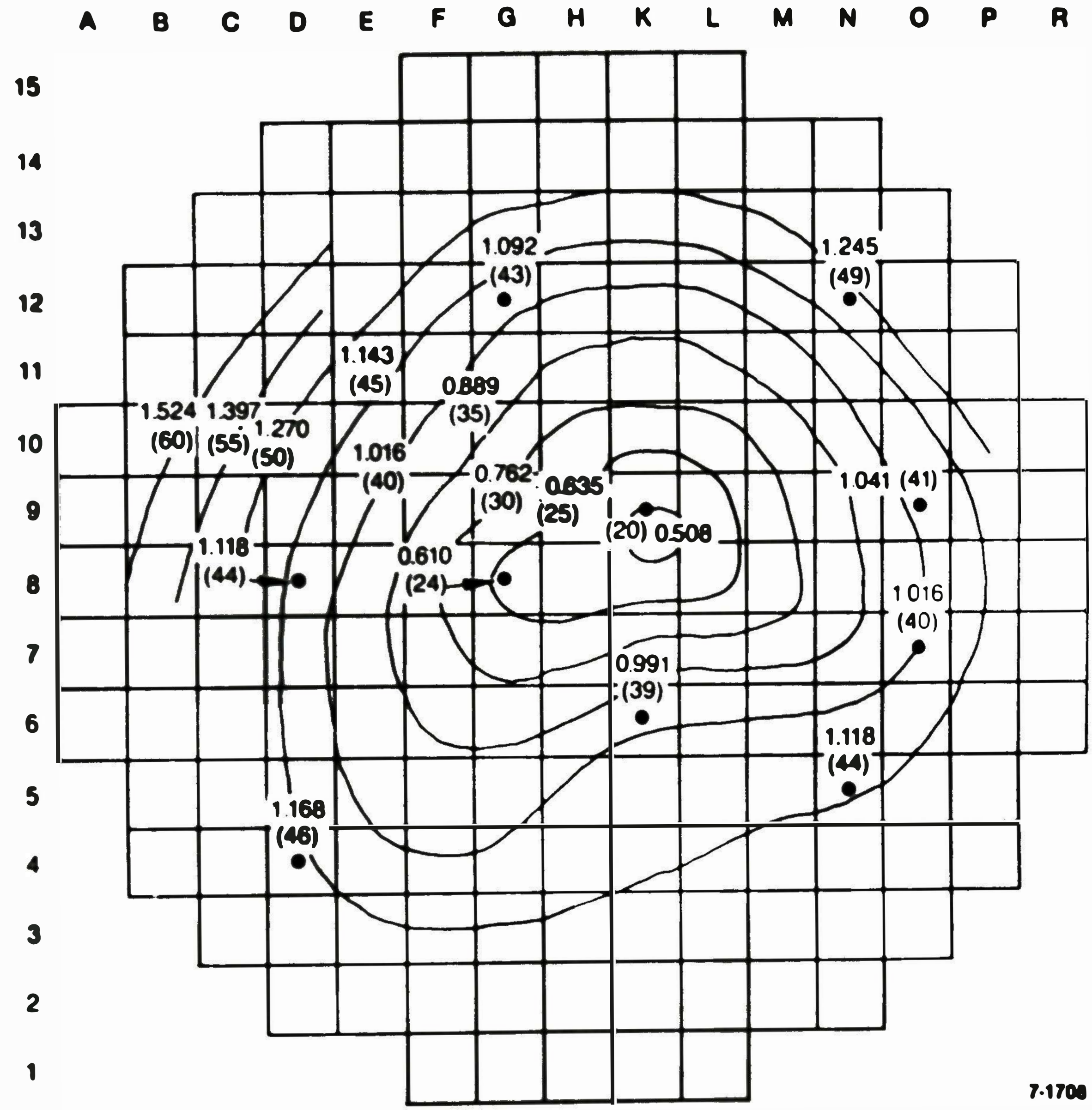


Figure 3. Contour map showing highest possible position of interface (corresponding to minimum amount of core melting). Data are in meters (inches).

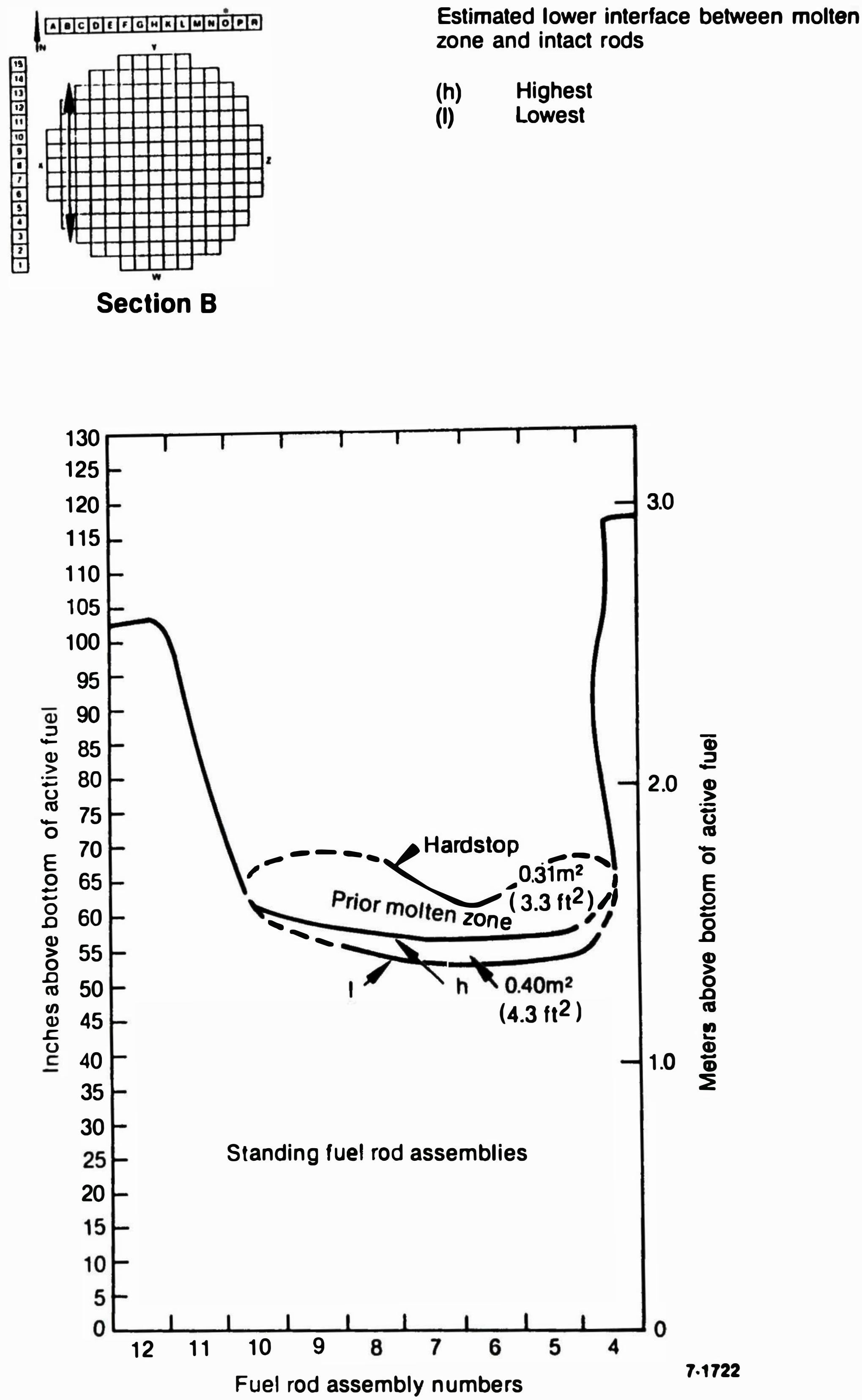


Figure 4. Cross section through B row of fuel assemblies showing hardstop and highest and lowest possible positions of molten/intact rod interface.

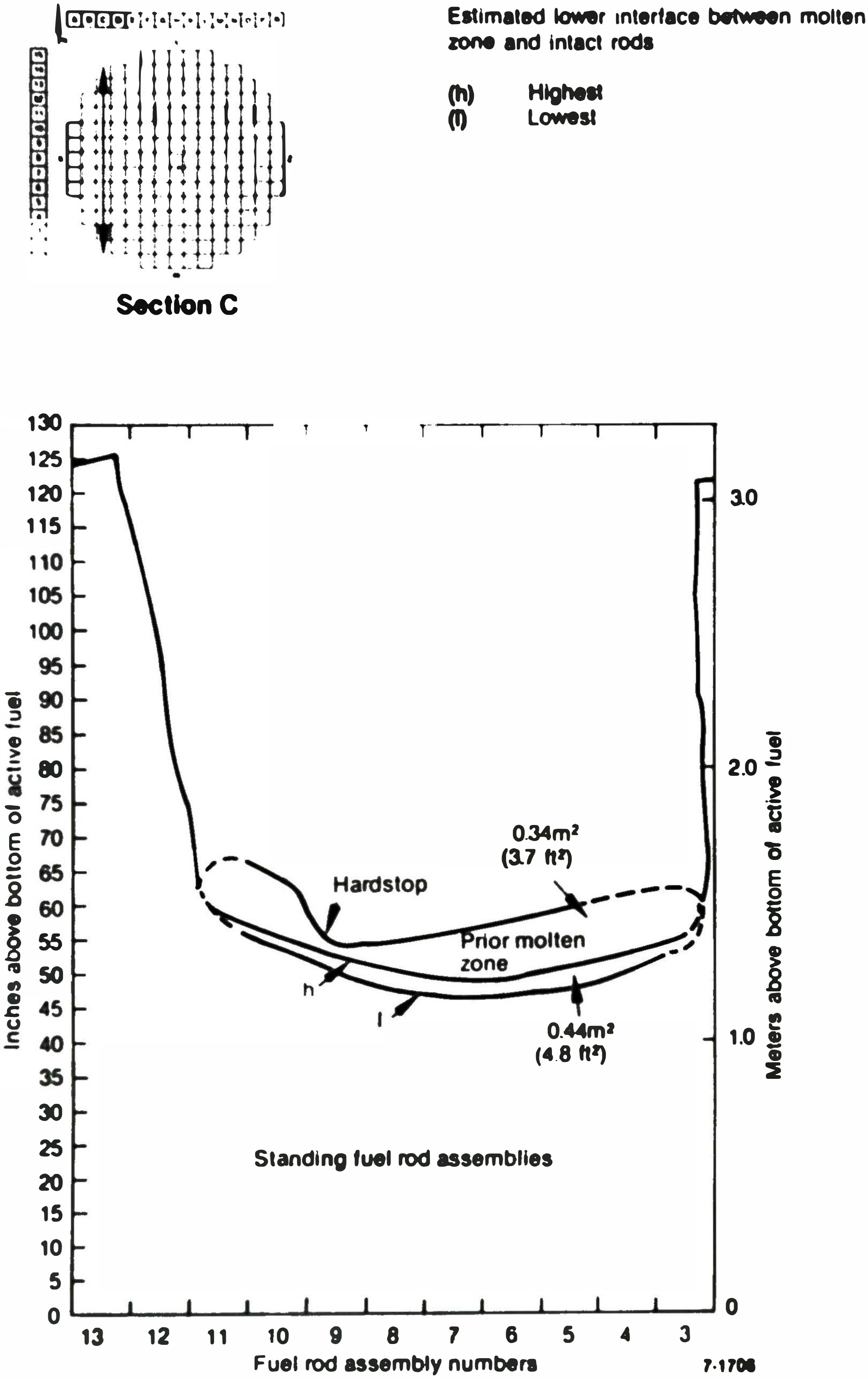
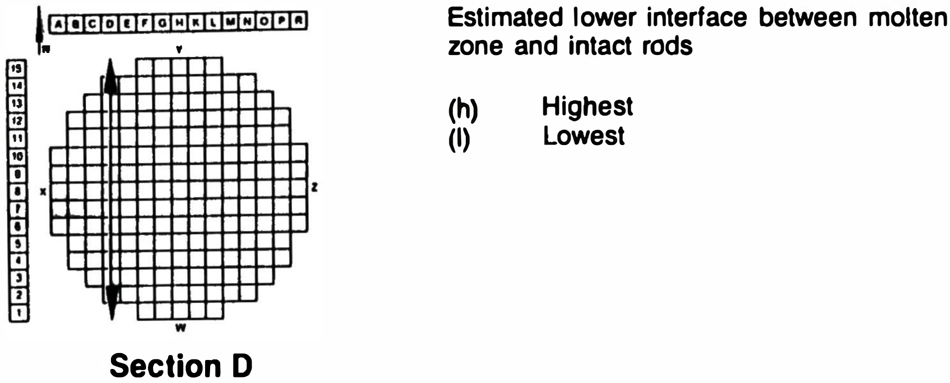


Figure 5. Cross section through C row of fuel assemblies showing hardstop and highest and lowest possible positions of molten/intact rod interface.



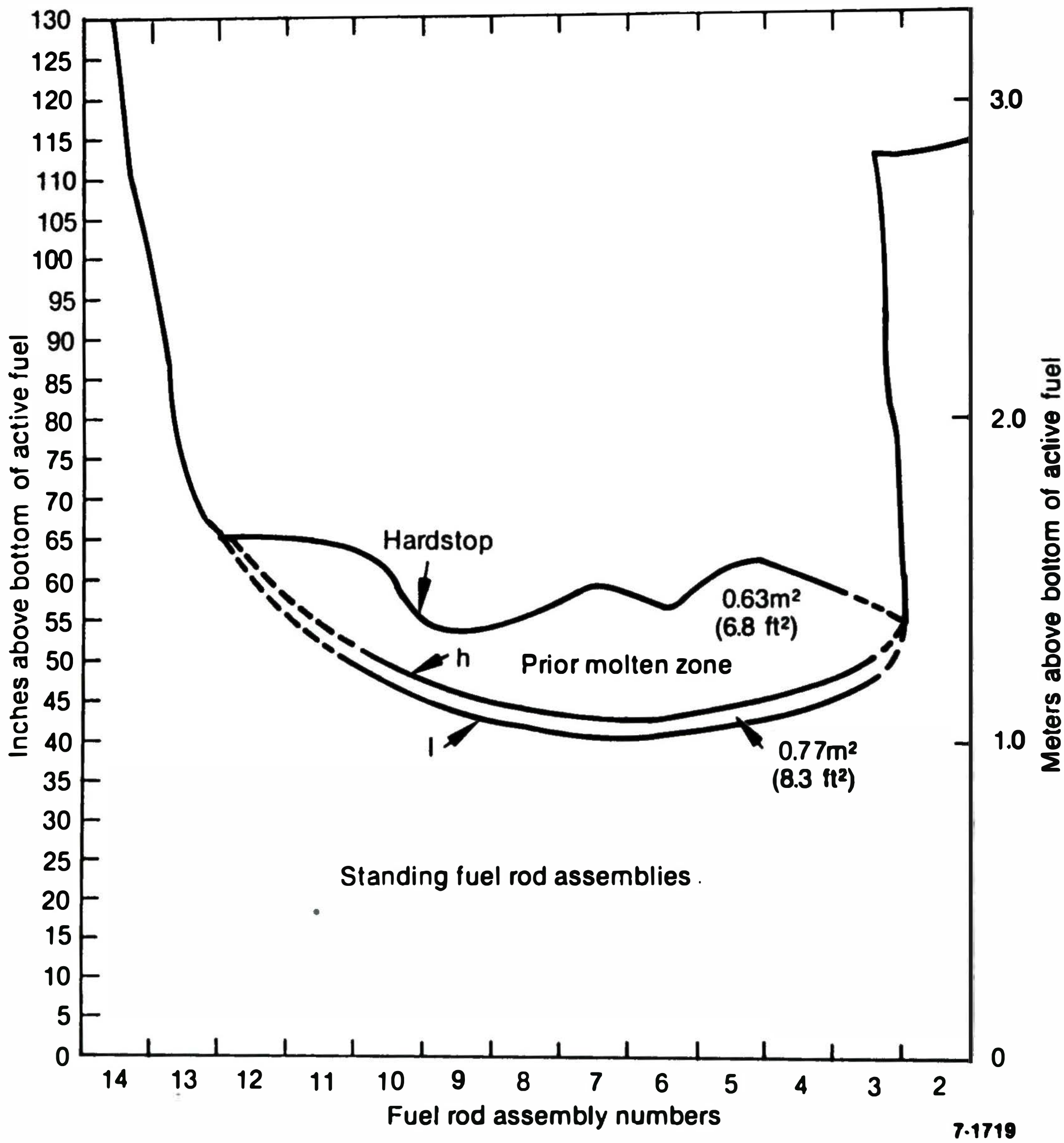


Figure 6. Cross section through D row of fuel assemblies showing hardstop and highest and lowest possible positions of molten/intact rod interface.

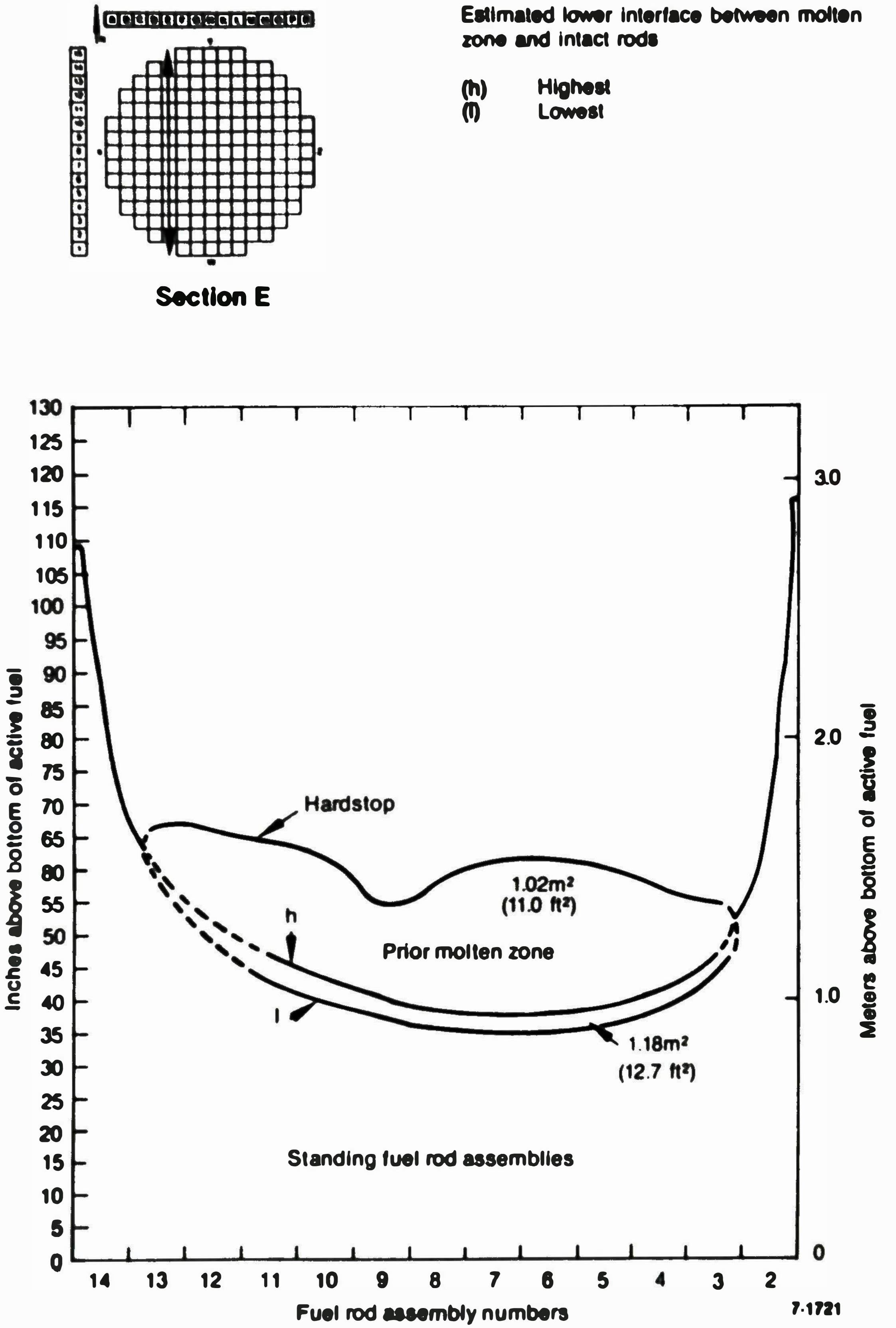
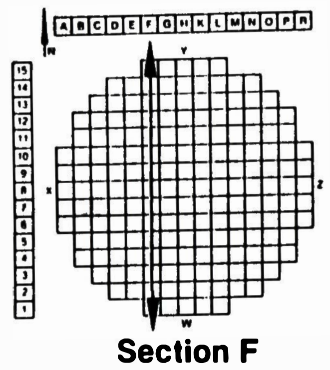


Figure 7. Cross section through E row of fuel assemblies showing hardstop and highest and lowest possible positions of molten/intact rod interface.



Estimated lower interface between molten zone and intact rods

(h) Highest
(l) Lowest

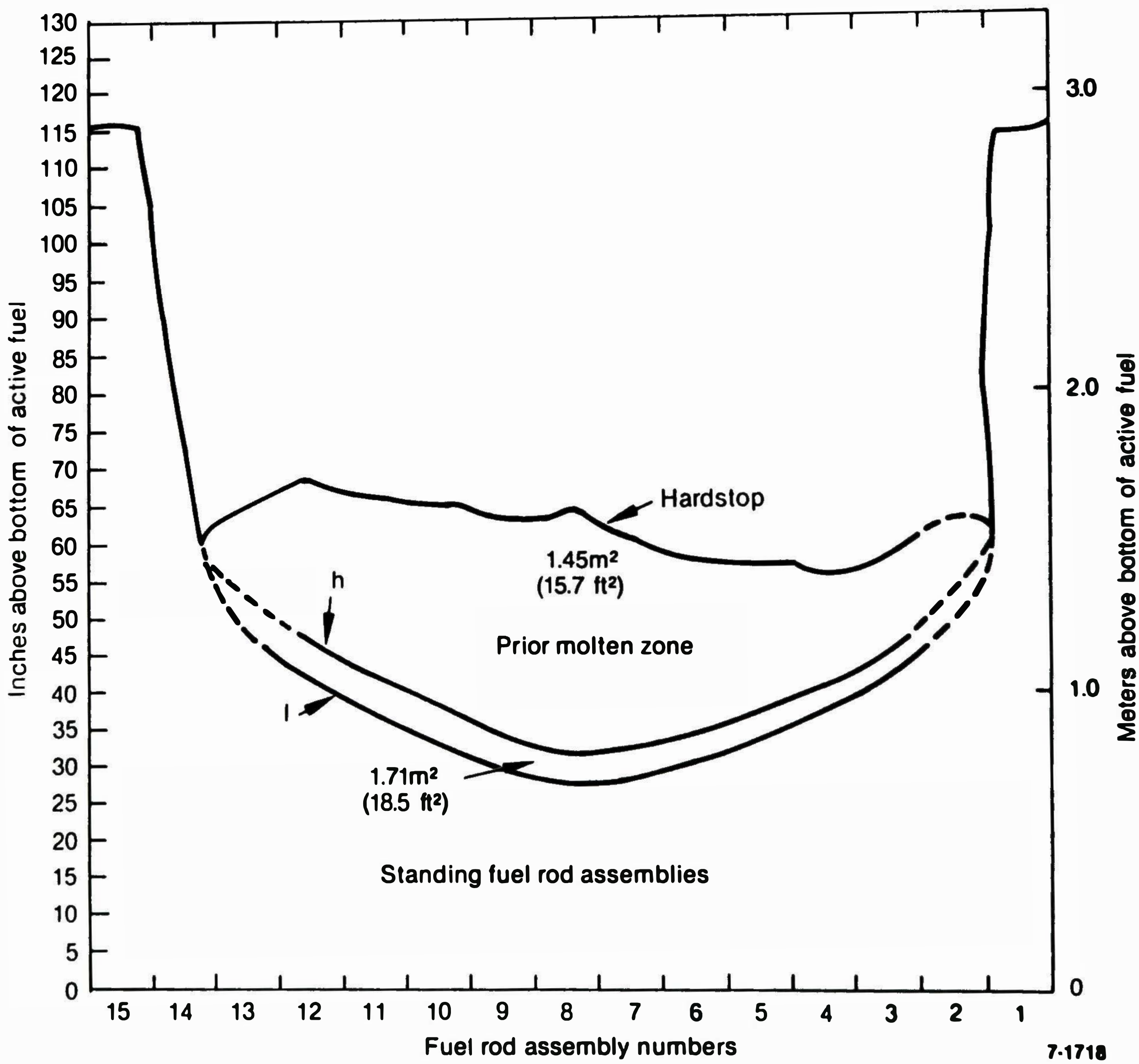


Figure 8. Cross section through F row of fuel assemblies showing hardstop and highest and lowest possible positions of molten/intact rod interface.

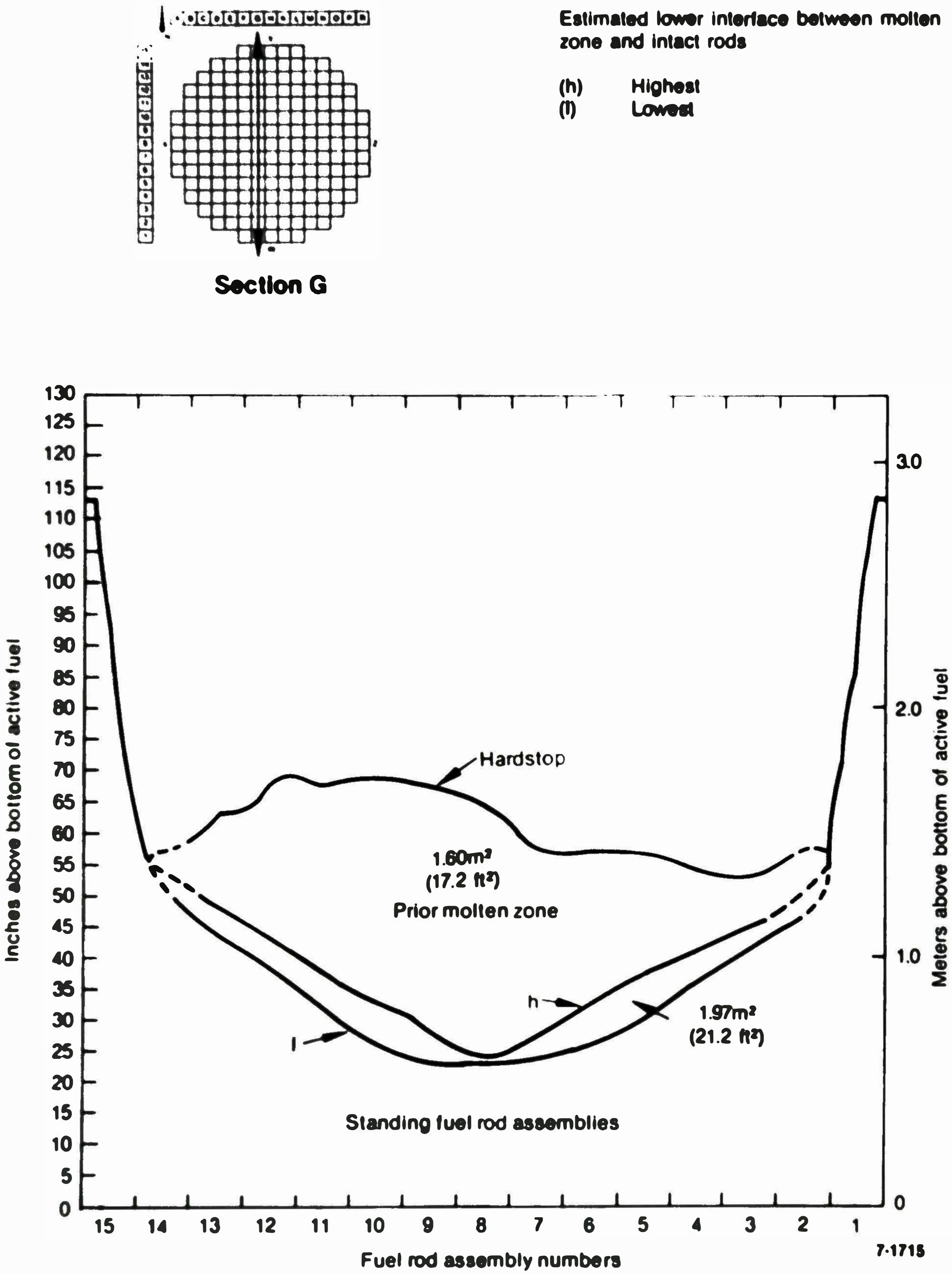


Figure 9. Cross section through G row of fuel assemblies showing hardstop and highest and lowest possible positions of molten/intact rod interface.

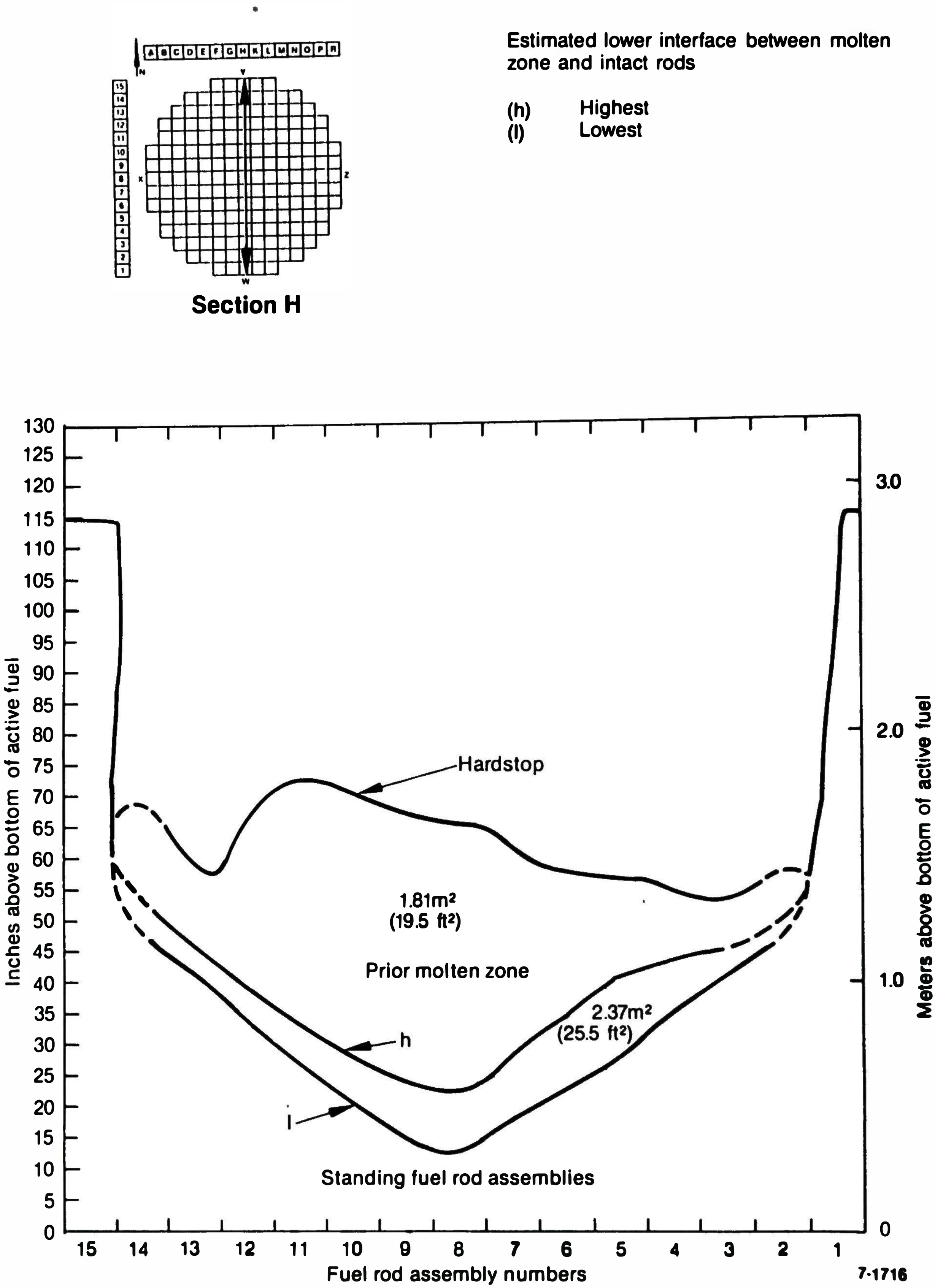


Figure 10. Cross section through H row of fuel assemblies showing hardstop and highest and lowest possible positions of molten/intact rod interface.

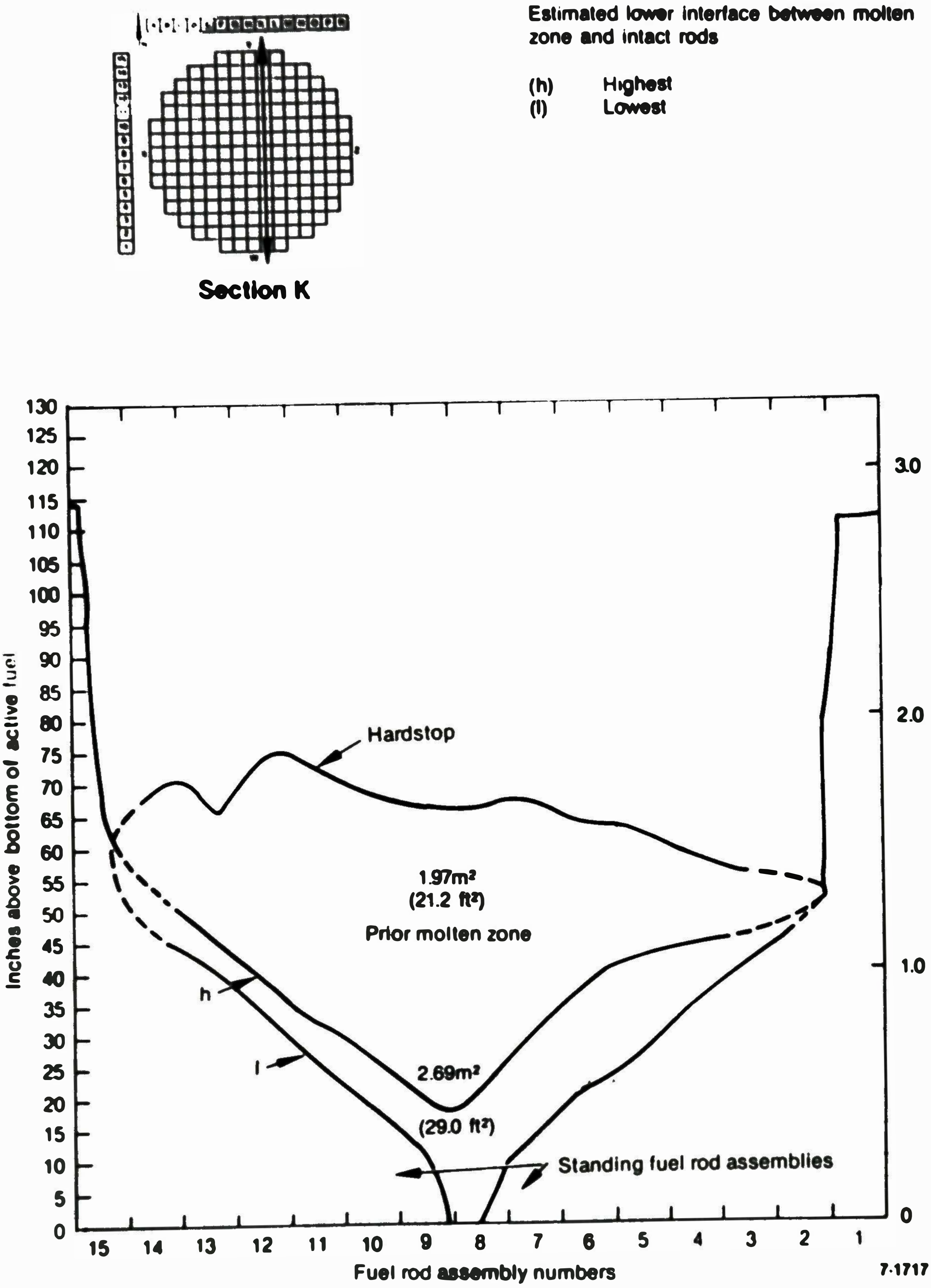


Figure 11. Cross section through K row of fuel assemblies showing hardstop and highest and lowest possible positions of molten/intact rod interface.

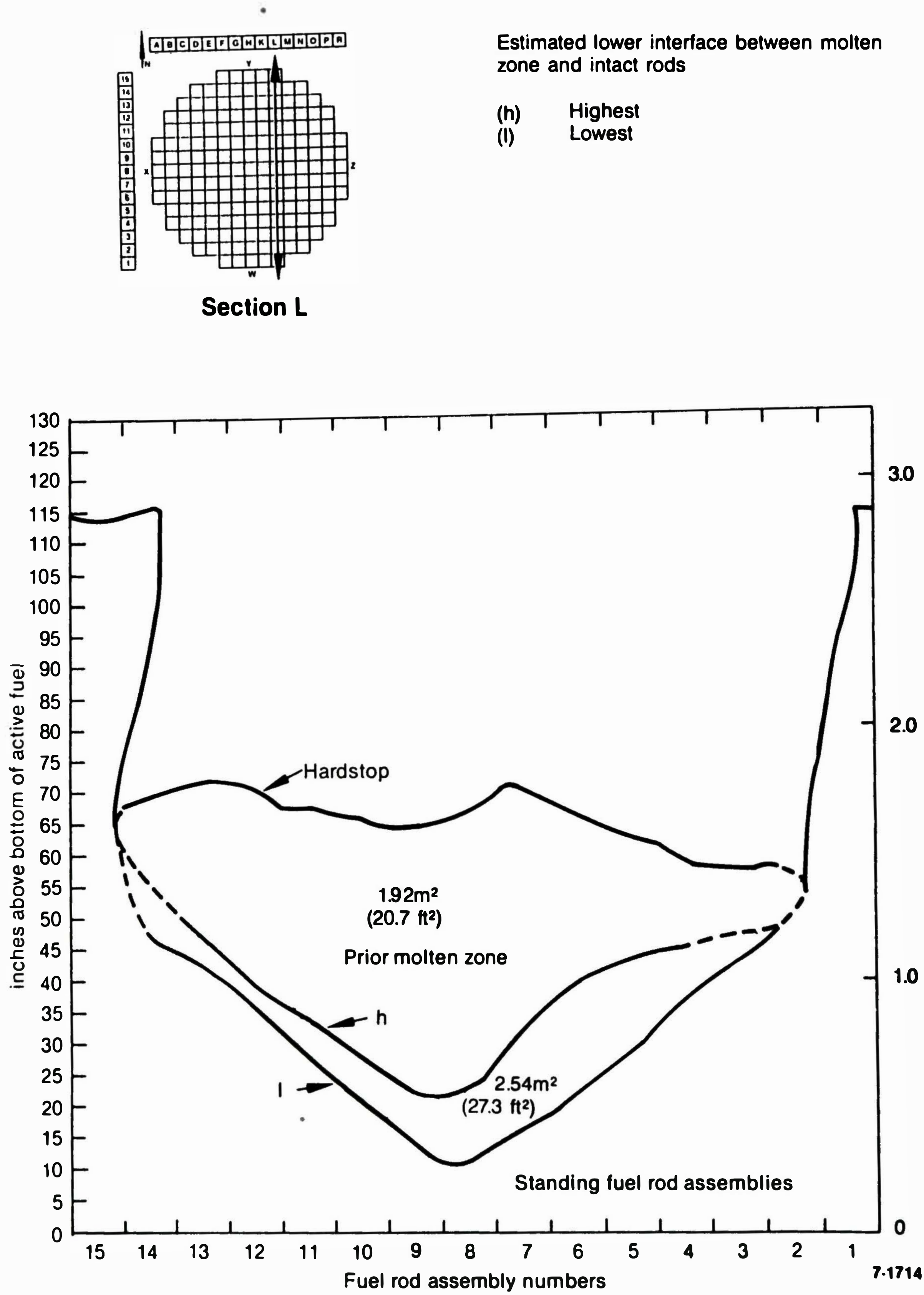


Figure 12. Cross section through L row of fuel assemblies showing hardstop and highest and lowest possible positions of molten/intact rod interface.

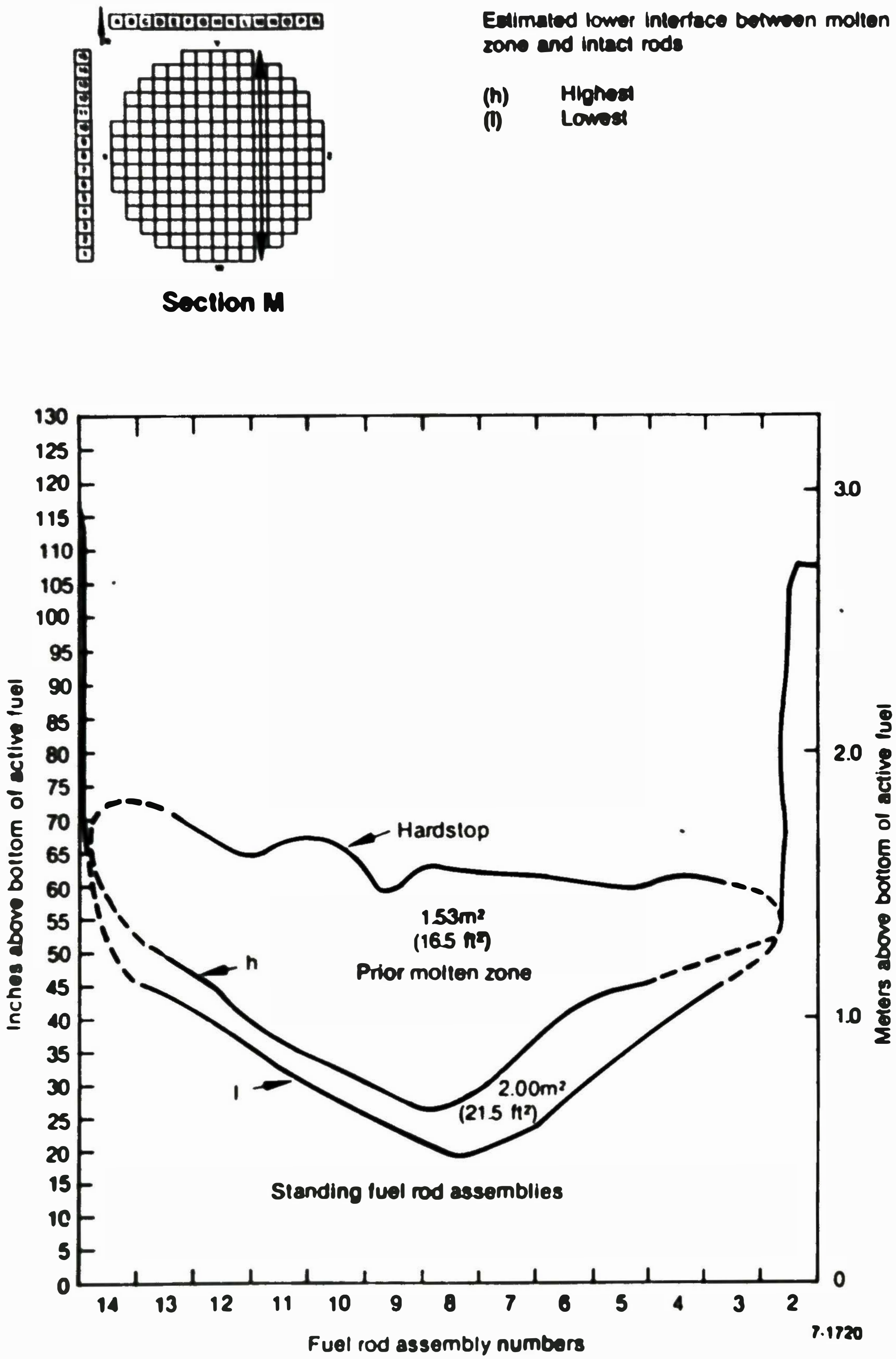


Figure 13. Cross section through M row of fuel assemblies showing hardstop and highest and lowest possible positions of molten/intact rod interface.

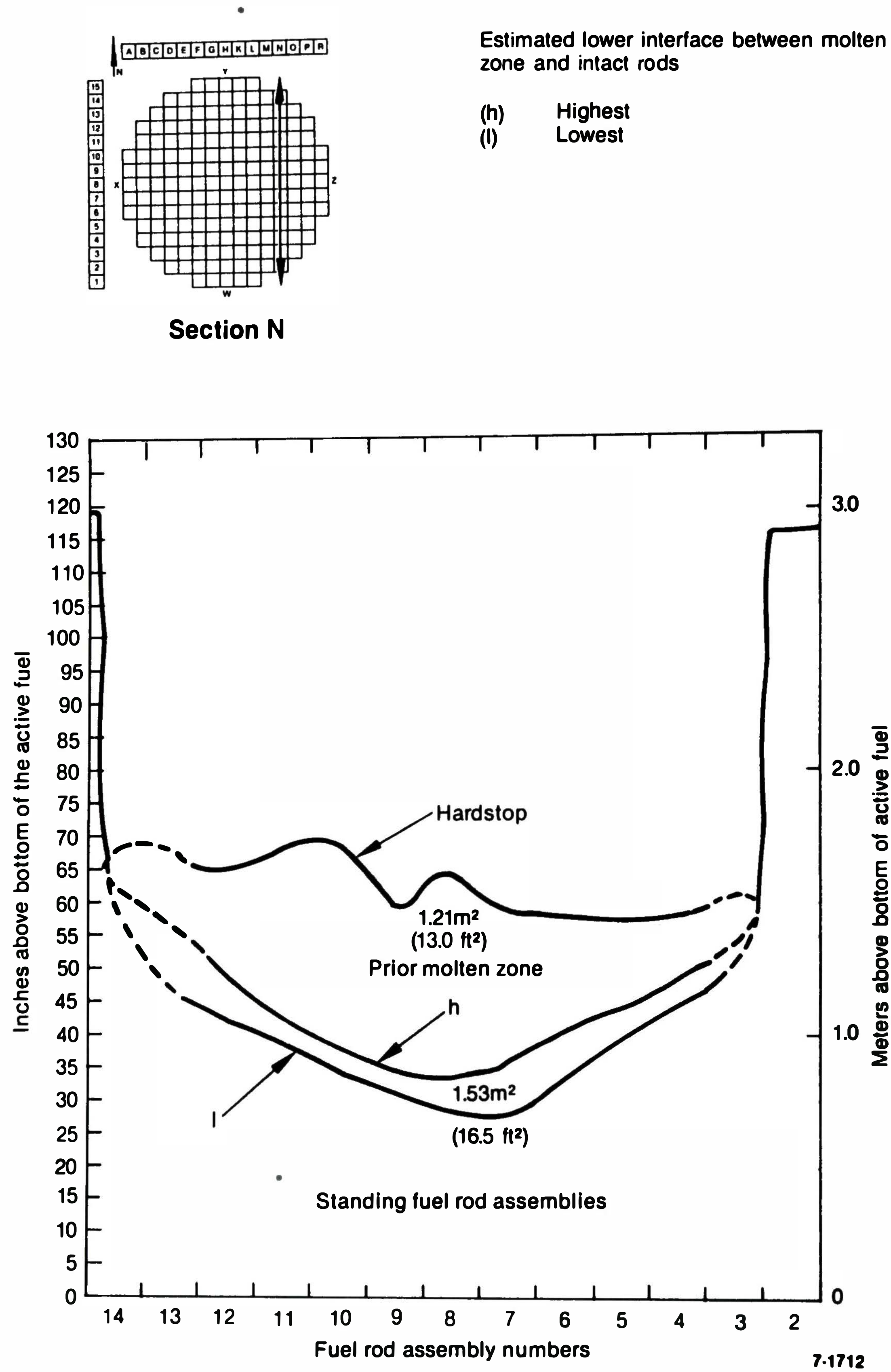


Figure 14. Cross section through N row of fuel assemblies showing hardstop and highest and lowest possible positions of molten/intact rod interface.

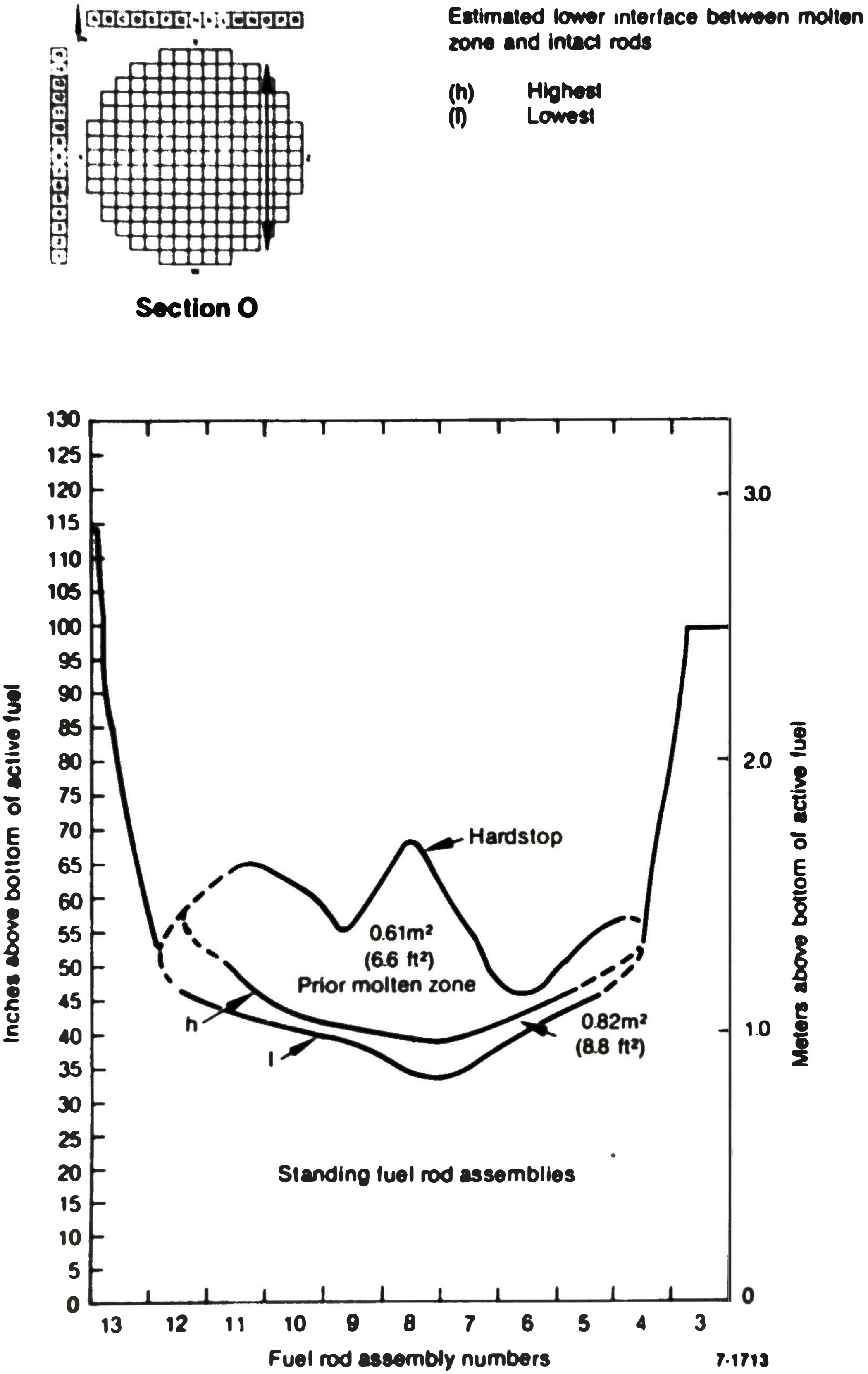
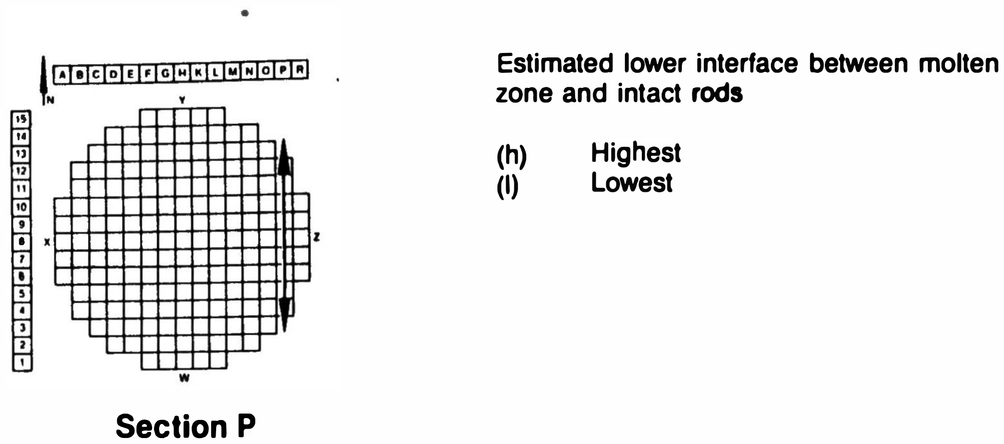


Figure 15. Cross section through O row of fuel assemblies showing hardstop and highest and lowest possible positions of molten/intact rod interface.



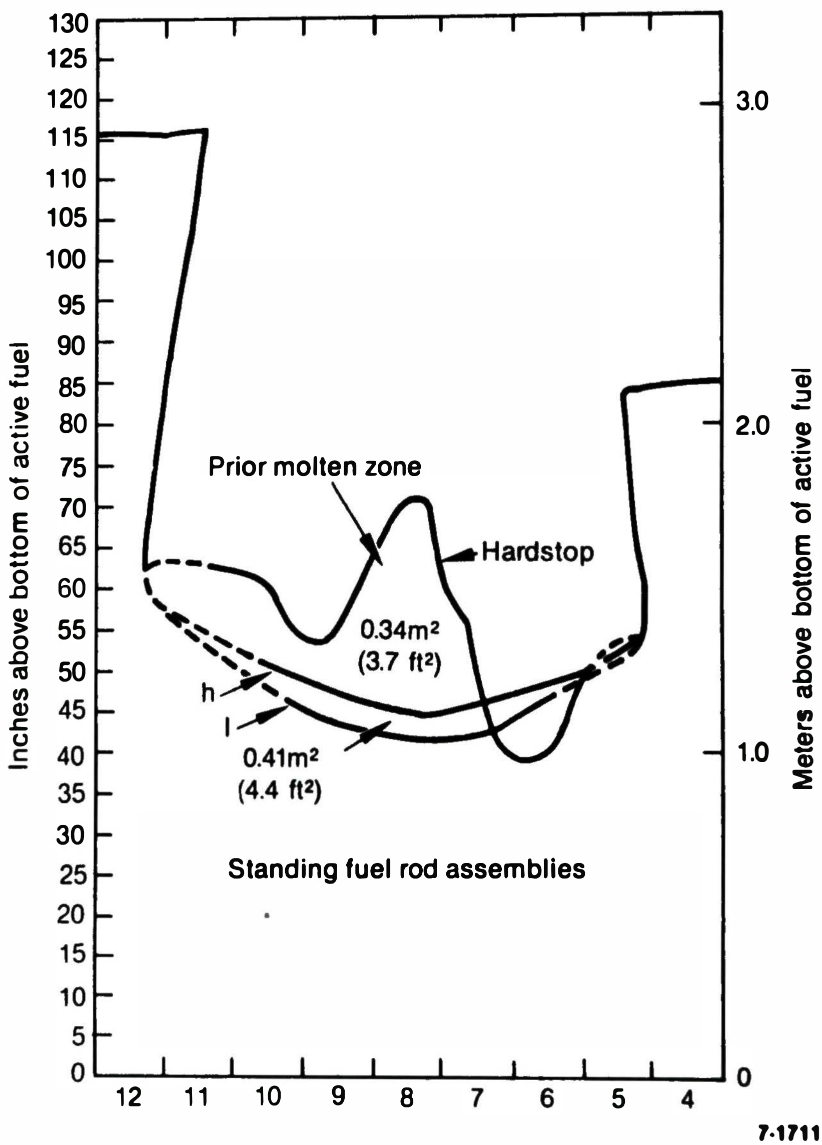


Figure 16. Cross section through P row of fuel assemblies showing hardstop and highest and lowest possible positions of molten/intact rod interface.

TABLE 2. UNCERTAINTY IN VOLUME OF PRIOR MOLTEN MATERIAL[a]

Fuel Assembly Row	Minimum Volume m^3 (ft^3)	Maximum Volume m^3 (ft^3)
A	--	--
B	0.068 (2.4)	0.088 (3.1)
C	0.074 (2.6)	0.096 (3.4)
D	0.139 (4.9)	0.167 (5.9)
E	0.224 (7.9)	0.258 (9.1)
F	0.317 (11.2)	0.374 (13.2)
G	0.348 (12.3)	0.428 (15.1)
H	0.396 (14.0)	0.518 (18.3)
K	0.430 (15.2)	0.589 (20.8)
L	0.419 (14.8)	0.552 (19.5)
M	0.334 (11.8)	0.436 (15.4)
N	0.263 (9.3)	0.334 (11.8)
O	0.139 (4.7)	0.178 (6.3)
P	0.074 (2.6)	0.091 (3.2)
R	--	--
Total	3.220 (113.7)	4.109 (145.1)

a. Average volume with uncertainty range
= 3.665 ± 0.445 m^3 (129.4 ± 15.7 ft^3)
= 3.665 ± 0.445 m^3 (129.4 ft^3 ± 12%).

TABLE 3. UNCERTAINTY IN VOLUME OF FUEL RODS[a]

Fuel Assembly Row	Minimum Volume[b] m^3 (ft^3)	Maximum Volume[b] m^3 (ft^3)
A	0.935 (33.0)	0.935 (33.0)
B	0.898 (31.7)	0.918 (32.4)
C	0.918 (32.4)	0.940 (33.2)
D	1.048 (37.0)	1.076 (38.0)
E	0.786 (27.6)	0.838 (29.6)
F	0.971 (34.3)	1.028 (36.3)
G	0.813 (28.7)	0.892 (31.5)
H	0.807 (28.5)	0.929 (32.8)
K	0.736 (26.0)	0.892 (31.5)
L	0.886 (31.3)	1.020 (36.0)
M	0.657 (23.2)	0.756 (26.7)
N	0.827 (29.2)	0.895 (31.6)
O	0.756 (26.7)	0.799 (28.2)
P	0.861 (30.4)	0.878 (31.0)
R	0.371 (13.1)	0.371 (13.1)
Total	12.265 (433.1)	13.166 (464.9)

a. Volume of fuel rods equals volume of rods and fuel plus the open volume between rods.

b. Average volume with uncertainty range

$= 12.716 \pm 0.445\ m^3\ (449 \pm 15.7\ ft^3)$

$= 12.716 \pm 0.445\ m^3\ (449\ ft^3 \pm 3.5\%)$.

0.91 m^3 (±32 ft^3). This uncertainty in the molten core volume also represents the uncertainty in the intact rod region.

REFERENCE

Tolman, E. L.; Smith, R. P.; Martin, M. R.; McCardell, R. K.; and Broughton, J. M.; (1987) TMI-2 Core Bore Acquisition Summary Report, EGG-TMI-7385, Rev. 1, February 1987.