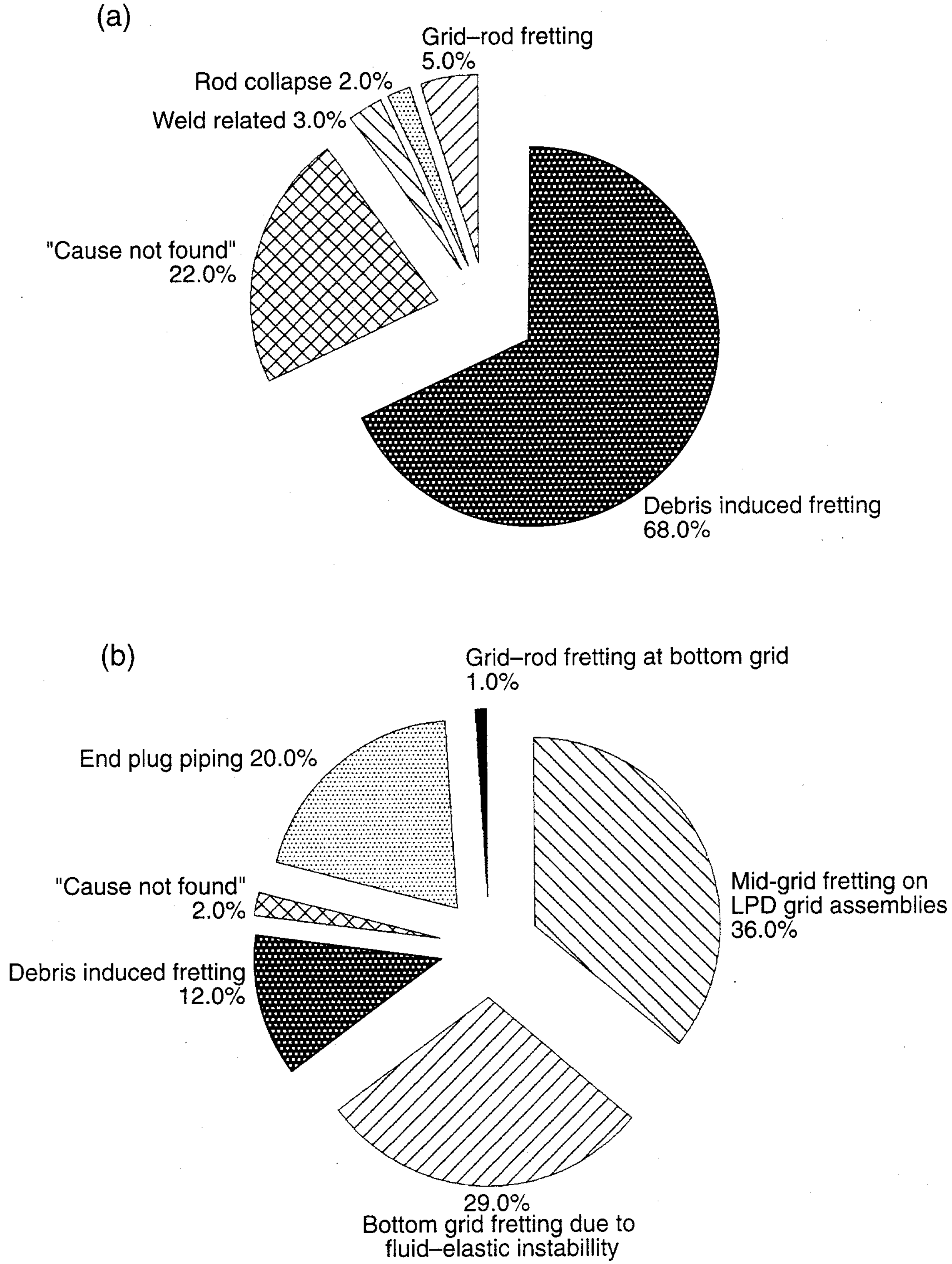


FIG. 3.8. Leakage mechanisms identified for Westinghouse fuel [3.2, 3.19]. (a) Fuel fabricated after 1983; (b) fuel fabricated after 1987.

TABLE 3.7. GE 8 × 8 FUEL FAILURE EXPERIENCE UP TO AUGUST 1993 (NUMBER OF FAILED ASSEMBLIES) [3.20]

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
PCI														
Non-barrier	8	4	4	12	9	4	16	7	13	1	2	0	0	2
Barrier	—	0	0	0	0	0	0	0	0	0	0	0	0	0
CILC														
Conventional	7	67	55	47	79	41	22	16	42	13	4	1	0	0
Corrosion Improved	—	—	—	—	0	0	0	0	0	45[a]	0	0	0	0
Debris fretting	2	1	2	2	2	0	1	0	3	0	2	13	4	2
Manufacturing defects	1	0	0	1	2	0	2	1	6	10	7	6	7	2
Unknown											1			6
Total	18	72	61	62	92	45	41	24	64	69	16	20	11	12

[a] Severe chemical intrusion event at one US reactor.

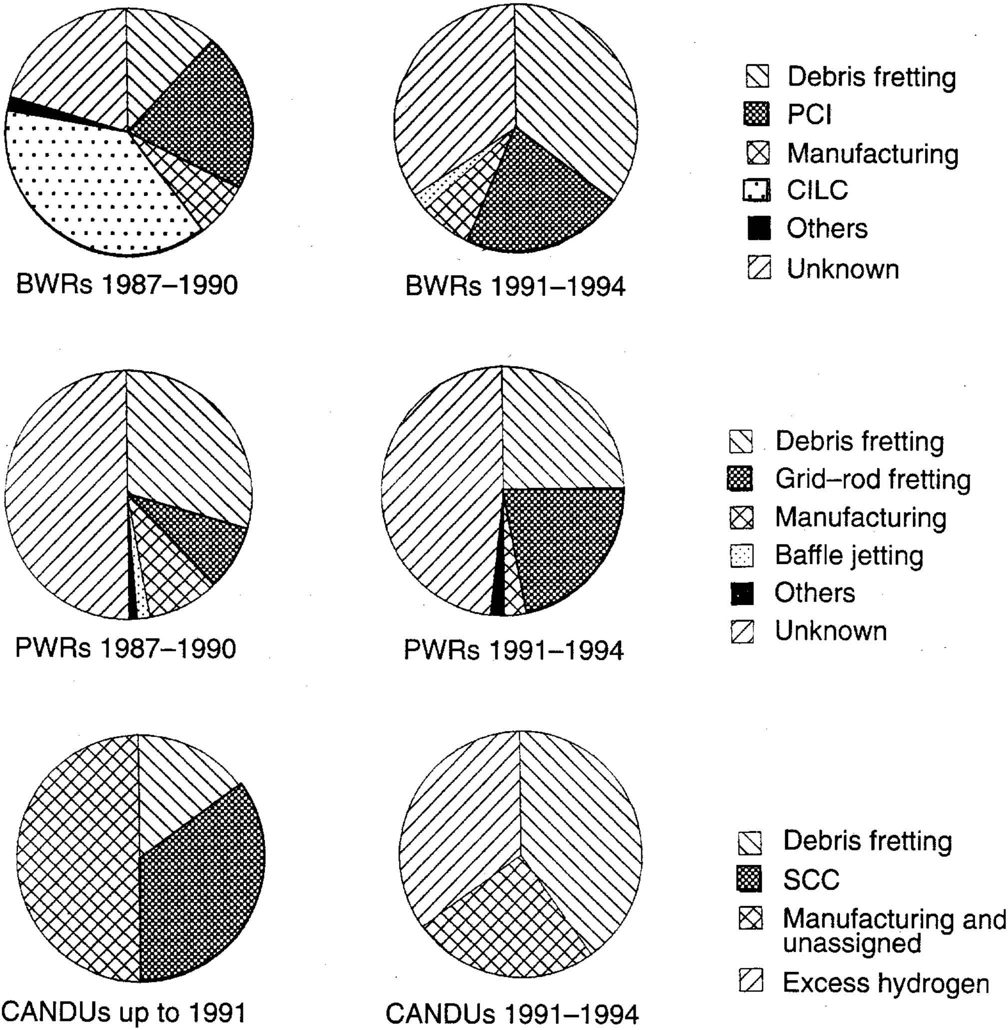


FIG. 3.10. Estimated world distribution of fuel failure causes.

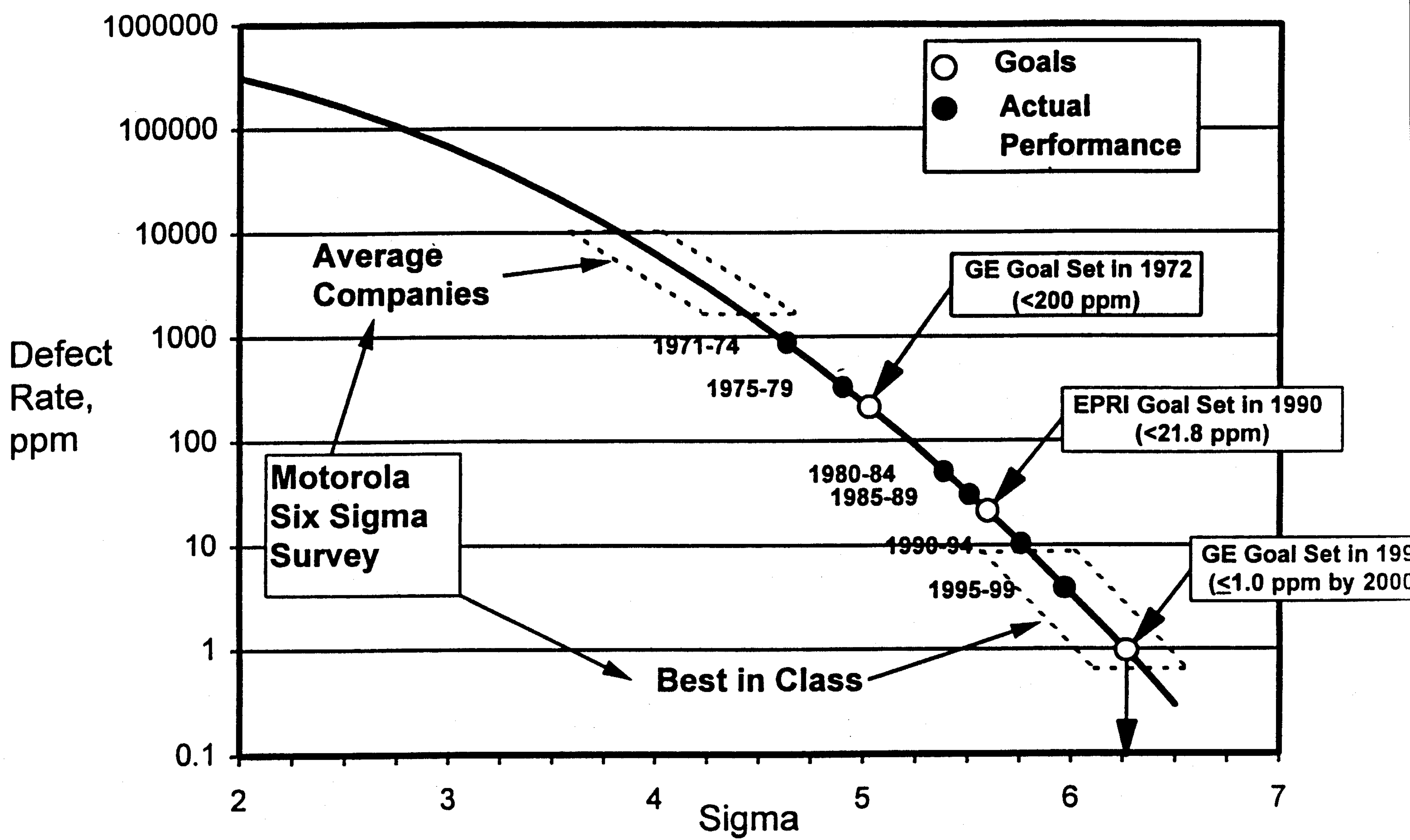
Table 1
GE Fuel Experience
May 1974 through October 1996

	Non-Barrier	Barrier
Fuel Operated		
Initial Cores	28	7
Reloads	226	232
Bundles	45,361	43,881
Fuel Rods	2,804,833	2,752,942
Lead Exposure, GWd/MTU		
Batch Average	36.0	43.5
Bundle Average	45.6	45.5
Rod Average	50.2	65.0
Fuel Rods Completed ≥ 1 Cycle	2,785,281	2,358,786

Table 2
GE BWR Fuel Experience
Manufactured After January 1, 1989 (through October 1996)

Fuel Operated	
Initial Cores	3
Reloads	155
Bundles	26,835
Fuel Rods	1,708,518
Lead Exposure, GWd/MTU	
Batch Average	42.2
Bundle Average	43.6
Rod Average	48.0
Fuel Rods Completed ≥ 1 Cycle	1,333,250
Fuel Rod Failures	
Debris Fretting	8
Undetected Fabrication Defects	8
Uninspected	6

Figure 1
GE Fuel Performance Experience



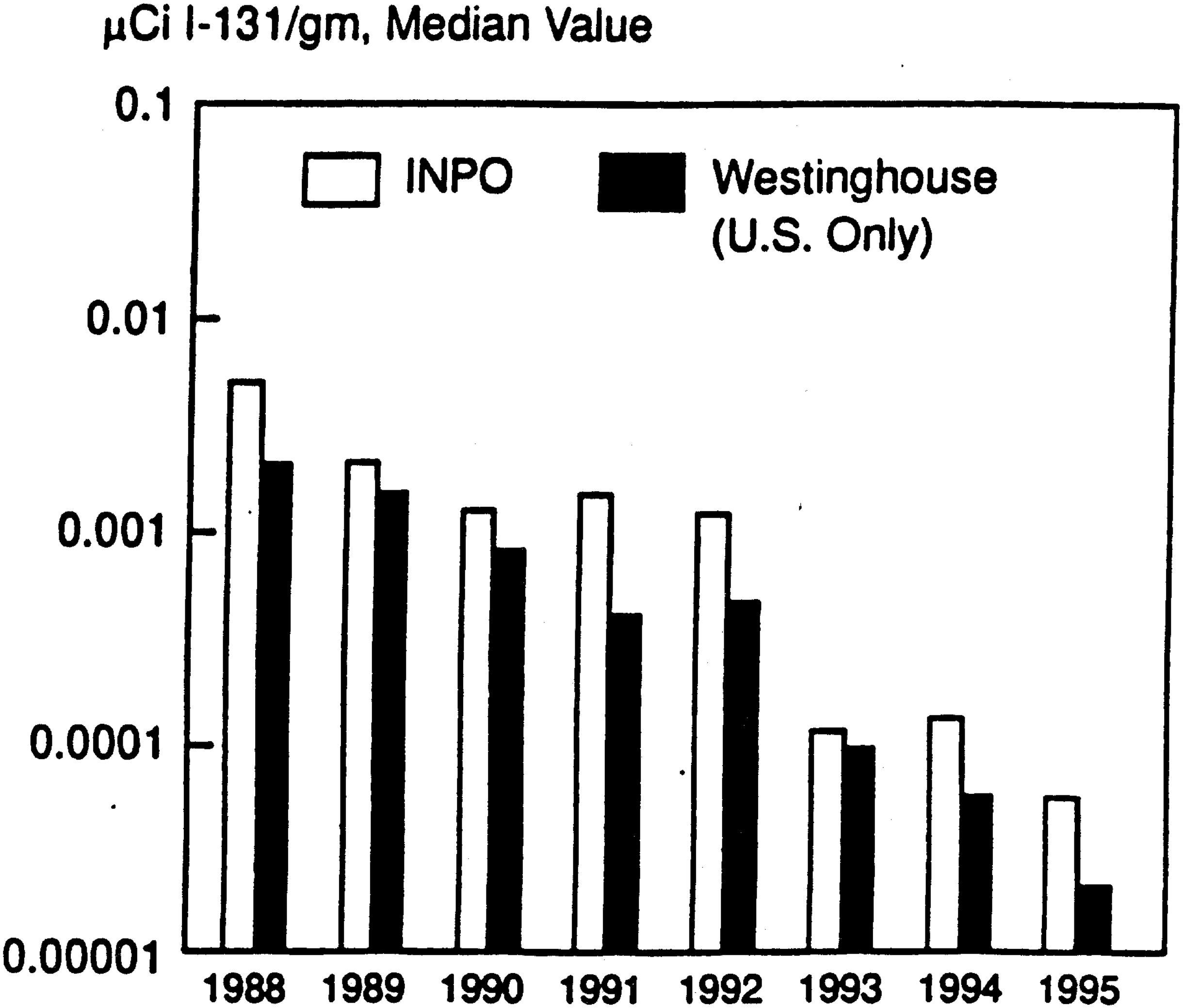


Figure 2: Westinghouse fuel reliability compared to industry averages.

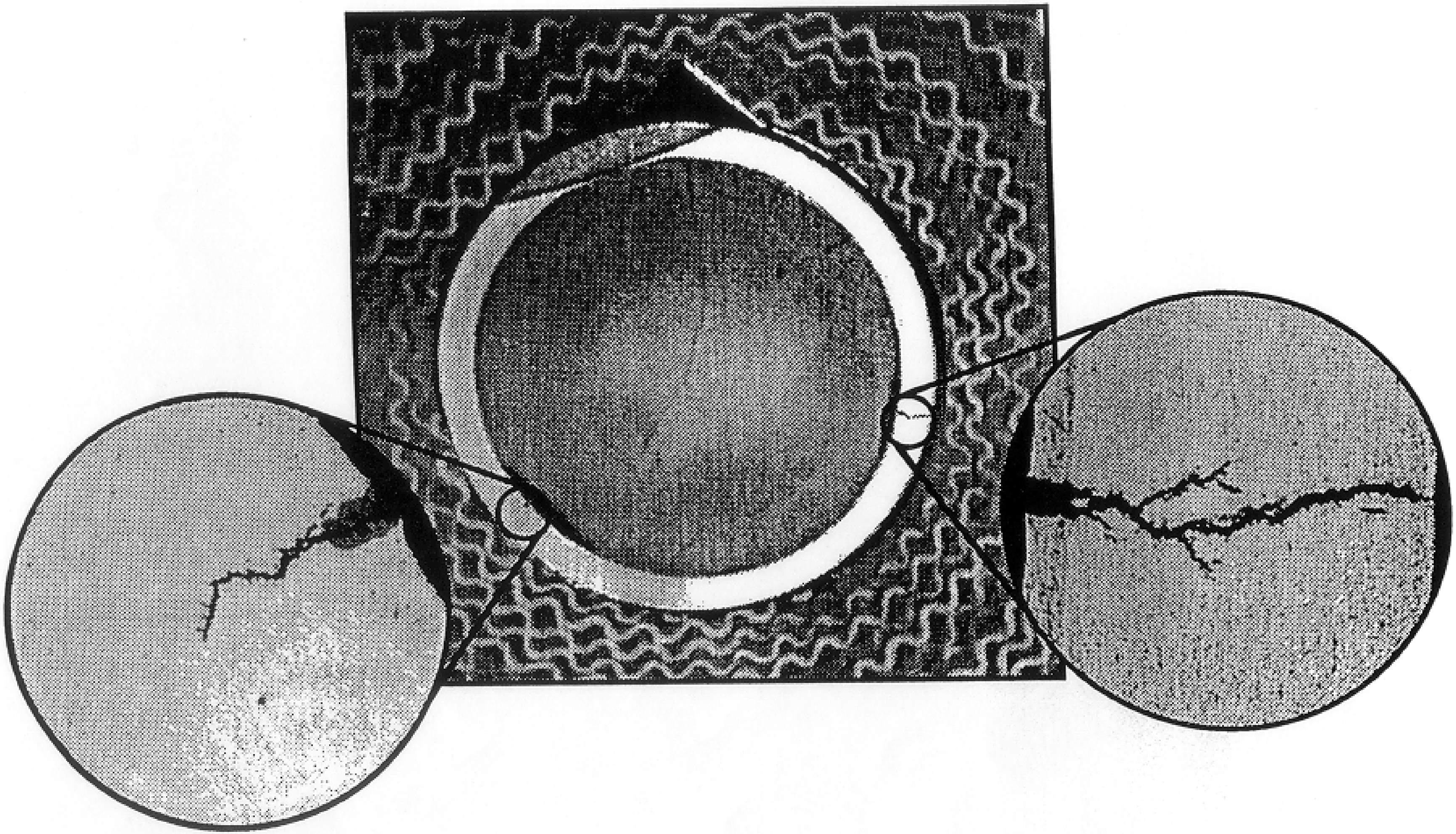


Figure 2. Rod D1 at EC Flaw Location Showing Cracks in Cladding Arcs Subtended by Missing Fuel Surface

Detection of Fuel Failures

Generally, the detection of 3 families of radioisotopes tells a lot about the nature of the failure.

Family	Radioisotopes	Insight
Noble Gases	^{133}Xe, ^{133m}Xe, ^{135}Xe, ^{138}Xe, ^{85m}Kr, ^{88}Kr	Helps identify leak character or size
Iodine	^{131}I, ^{132}I, ^{133}I, ^{134}I, ^{135}I	I is trapped between fuel and cladding-only released if water enters gap
Cesium	^{134}Cs, ^{137}Cs	Indicates fuel dissolution and BU level in leaking fuel. $^{134}Cs \alpha$ BU, $^{137}Cs \alpha (BU)^2$

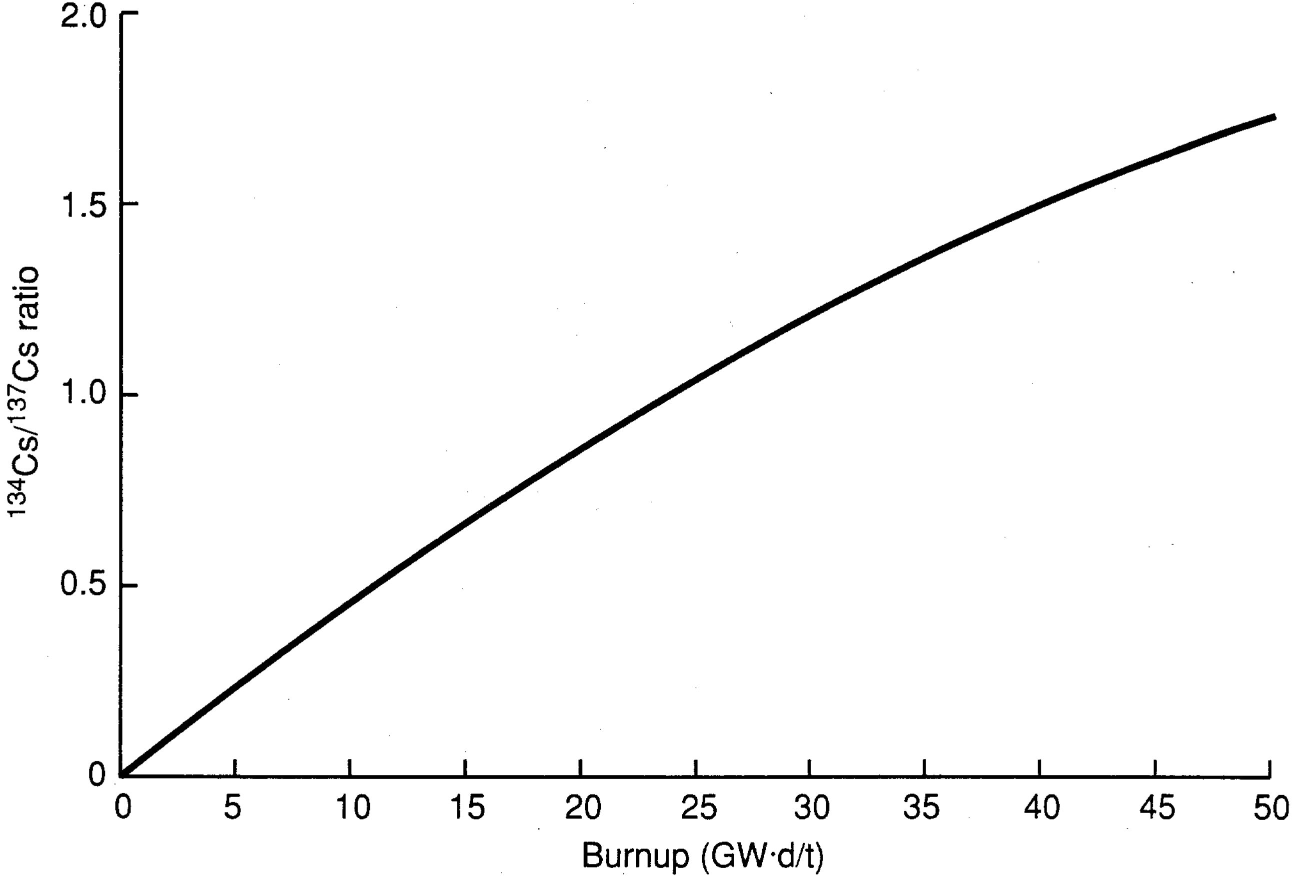


FIG. 4.3. $^{134}Cs/^{137}Cs$ activity ratio versus burnup.

Current Areas of R & D Focus

General

1.) **Fuel and Cladding Material Properties at High Burnup**

(Concern here is for transient conditions)

- **Thermal diffusivity is different (lab vs in-reactor)**
- **Cladding ductility shows wide scatter due to H_2 concentration, sample preparation, and measurement techniques**
- **Must understand in-reactor behavior**

2.) Failure Root cause Investigation

(To achieve zero defects, must understand causes)

- **Poolside inspections valuable for identification**
- **Expensive hotcell studies done only if poolside investigation does not work**

3.) Updated Codes and Analytical Tools

(Especially important for high BU in PWR's)

- **Gadolinia absorbers, local boiling, effect of boiling on flow properties**
- **Integrated nuclear and thermal hydraulic codes**

Current Areas of R & D Focus (cont.)

4.) Transient Fuel Behavior

(Controversy over reactor-initiated accidents [RIA])

- **All parties (regulators, utilities, and vendors) agree that simulated conditions are much more severe than reality**
- **Particularly interested in post-LOCA and post-DNB conditions**
- **Difficult to conduct meaningful experiments**

5.) Next Generation Fuel

(Concern here is to increase reliability and operational flexibility)

- **New fuel designs and materials**
- **>60 GWd/T burnup, load following, extended cycle time**
- **Water chemistry changes**

Current Areas of R & D Focus (cont.)

PWR Specific

1.) Cladding Corrosion

(Plant surveillance shows that cladding corrosion is limiting further BU extension)

2.) Water Chemistry Control

- **Codes are now availible to predict corrosion rate as a function of:**

  heat flux
  coolant temperature
  neutron fluence
  cladding hydrogen content
  cladding intermetallic particles
  heat treatment
  coolant Li concentration

- **Reccomendation is to raise pH and reduce source of crud**

  (requires 30% enriched ^{10}B to keep Li concentration<3 ppm)

Current Areas of R & D Focus (cont.)

BWR Specific

1.) **Finding cladding barrier that is resistent to PCI failures**

2.) **Reduce "fuel washout" from failed fuel**