Nuclear Fuel Performance

Department of Nuclear Regulation
Atomic Energy Council, R.O.C

AEC/NRC Bilateral Technical Meeting
May 31 to June 2, 2005

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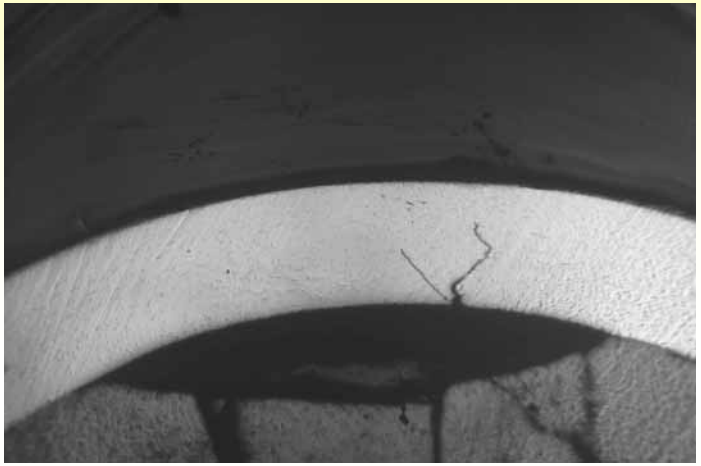
Background

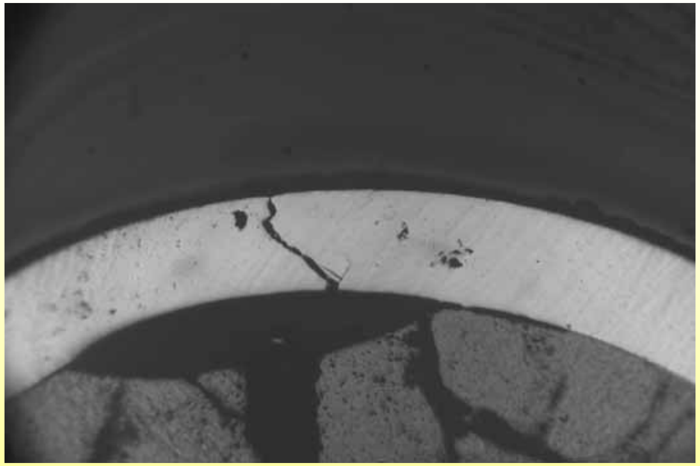
- To improve fuel cycle economics and operation flexibility, utilities implement more demanding operating conditions with less margins:
  - Longer fuel cycle
  - Fewer reload assemblies with higher enrichment
  - Higher peaking factors
  - Higher fuel burnup
- In 2003 and 2004, Kuosheng Unit 2 has experienced fuel failure and subsequent severe post-failure degradation which resulted in two mid-cycle outages.

Past Experience

- Kuosheng Unit 2 fuel failure investigation:
  - In 2000, two failed fuel rods in one assembly was found in Cycle 14. (KAD122, ATRIUM-9B, two-cycle fuel, burnup: 25.4 GWD/MTU, failed fuel rods A6 & E1)
  - The failure cause was initially determined to be fuel shuffling criteria violation induced PCI by FANP.
  - Failed fuel rods were transported to INER's hot lab for Post-Irradiation Examination (PIE).
  - The PIE results indicated that pellet missing cylindrical surface enhanced PCI failure for A6, and hydrogen contamination induced hydriding cracking for E1.

PIE results for the cross sections of failed fuel rod A6





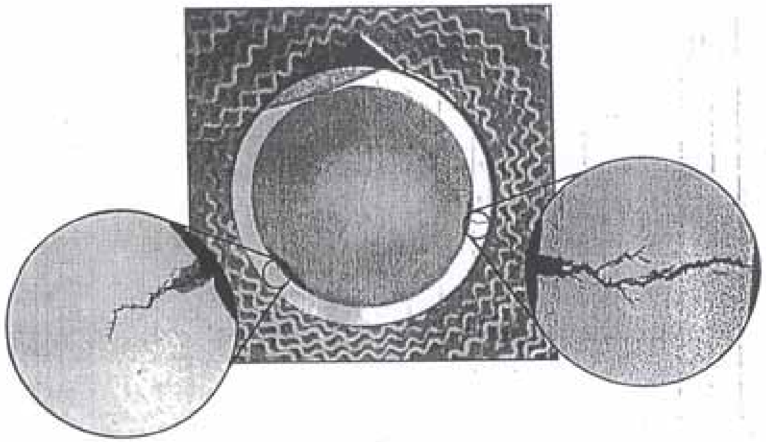


Figure 2. Rod D1 at EC Flaw Location Showing Cracks in Cladding Area Subtended by Missing Fuel Surface

Kuosheng Nuclear Power Plant

- GE BWR-6, Mark-III containment, 2984 MWt, 985 MWe.
- Commercial: Unit 1 Dec.28, 1981
  Unit 2 March 15, 1983
- Fuel vendor: Framatome-ANP

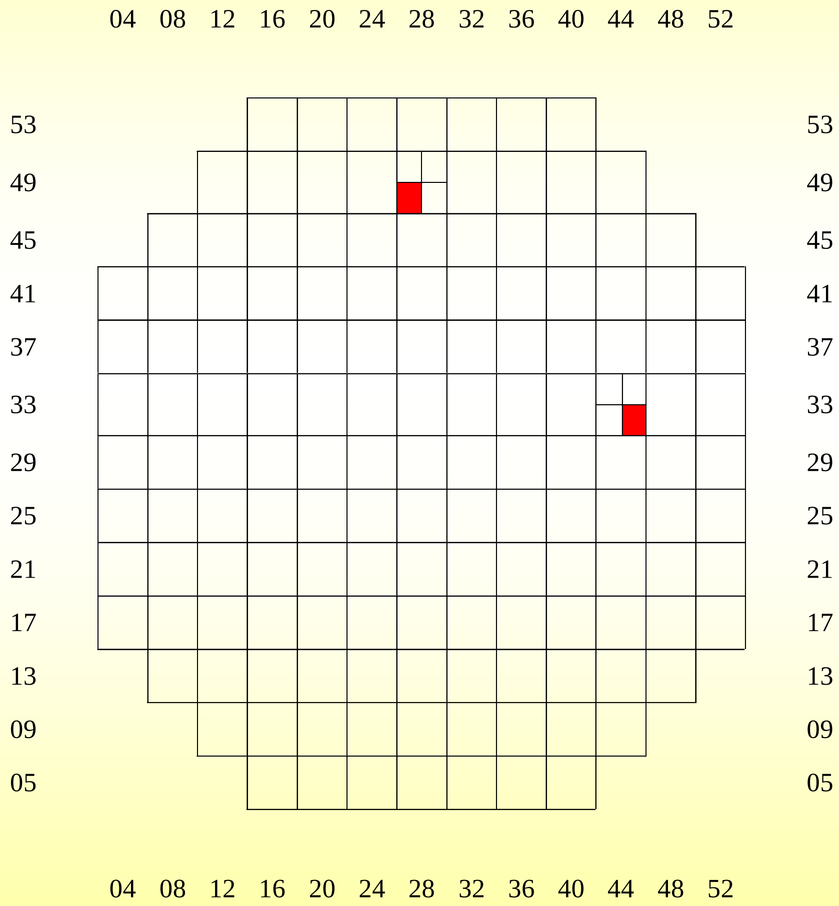
	Current Cycle	ATRIUM-9B	ATRIUM-10
Unit 1	18	112	512
Unit 2	17	276	348

- Five failed fuel assemblies from 2003 to 2004.

Fuel Performance of Kuosheng NPP

- In 2003, two failed fuel rods in two fuel assemblies were found at Unit 2 Cycle 16.
- ATRIUM-9B, non-barrier two-cycle fuel, burnup: 28.9 & 28.6 GWD/MTU.
- KAG115, core location: 28-49, failed fuel rod F2.
- KBH069, core location: 44-33, failed fuel rod F2.
- The root cause is still under investigation.

Failure fuel assembly & failure fuel rod locations



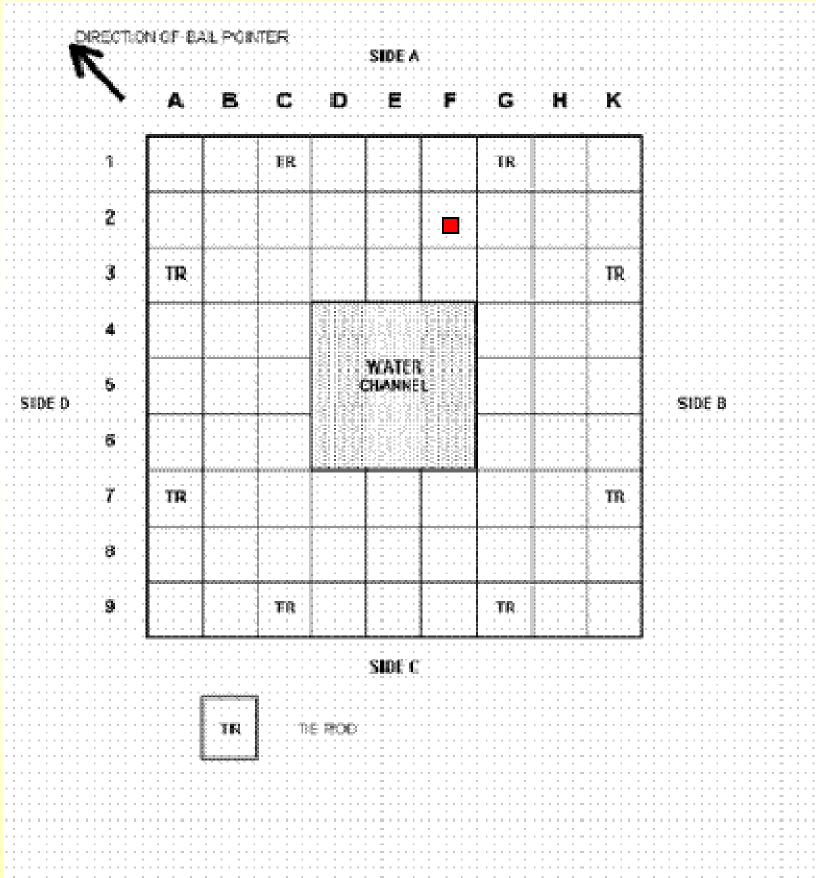
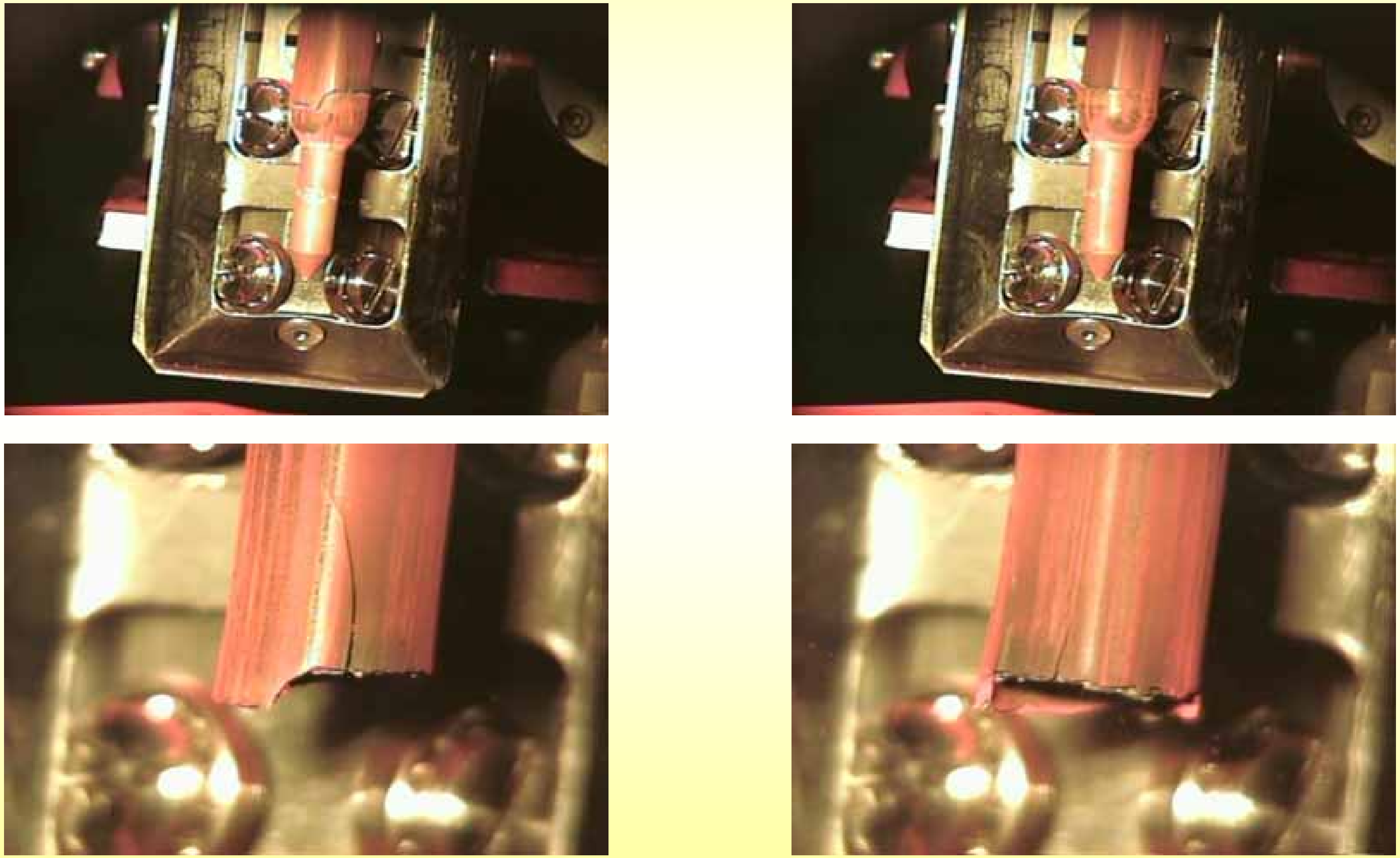
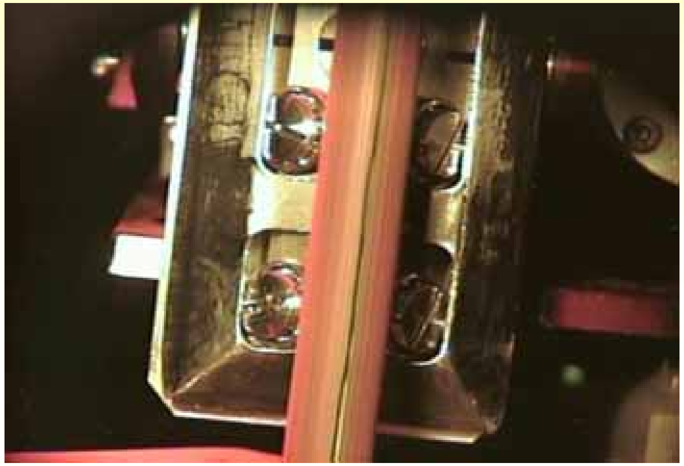


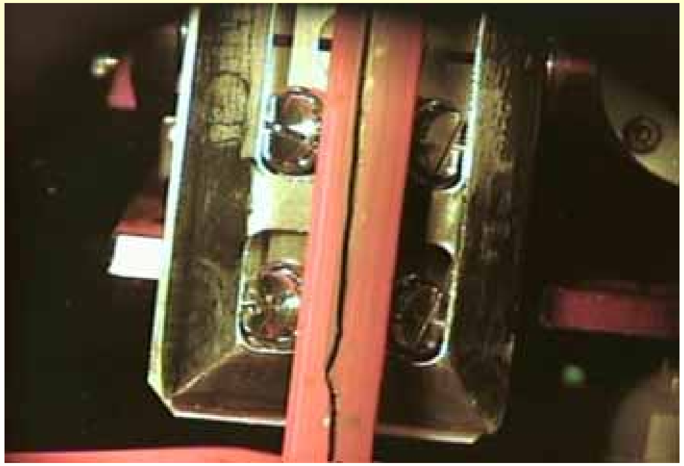
Figure 1 ATRIUM-9B Fuel Design - Rod Location Convention

KAG115 failed fuel rod F2: Circumferential crack just above weld area of lower end cap



KAG115 failed fuel rod F2: 35 to 40 cm axial split on span 5





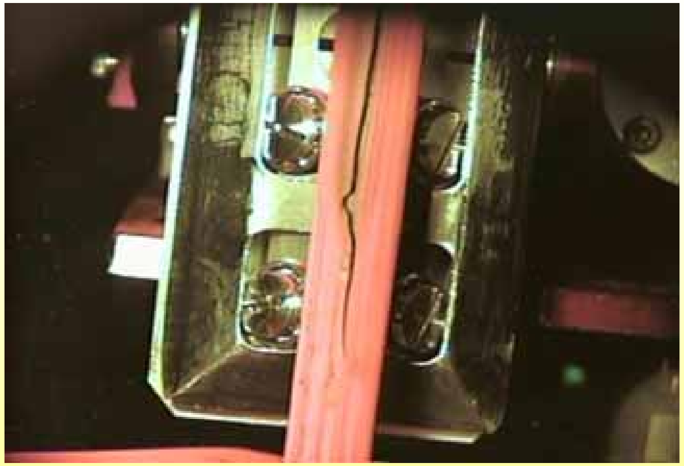
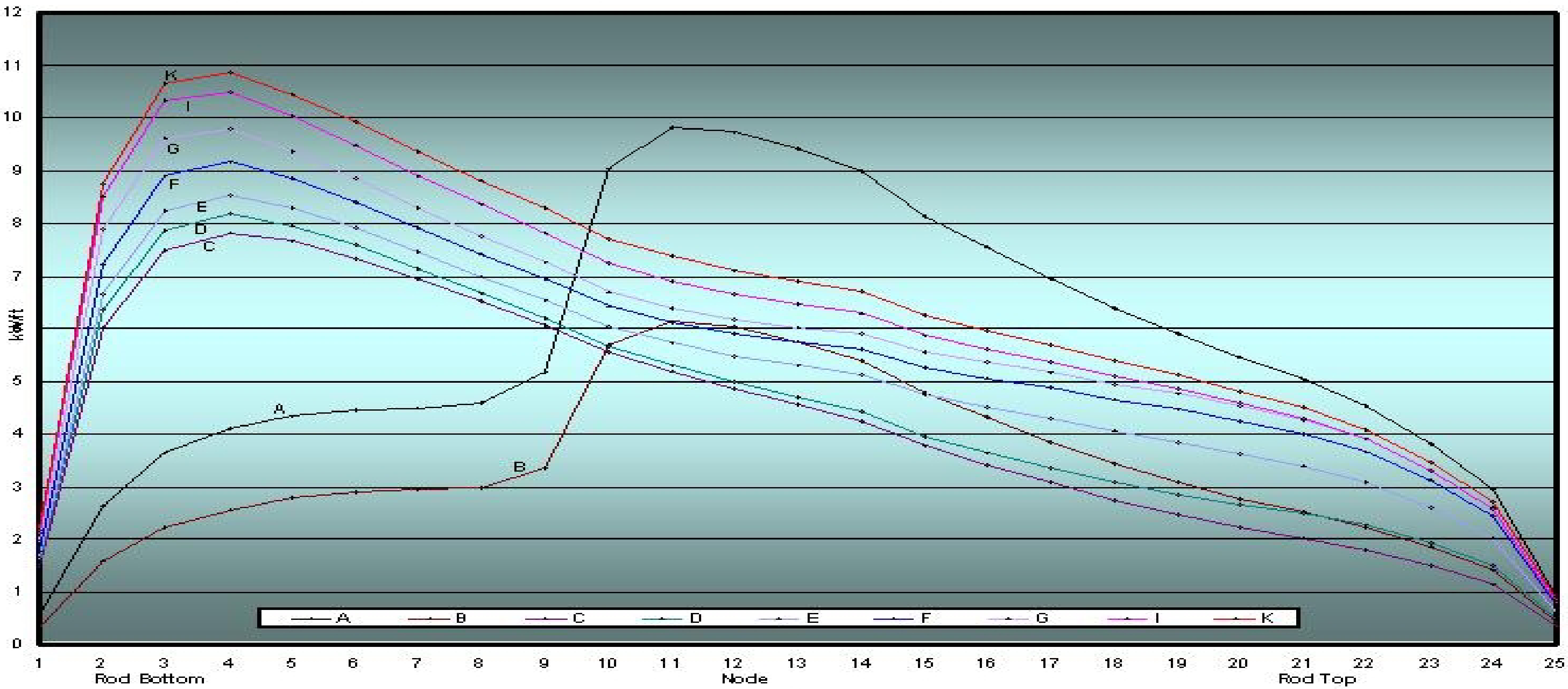


Fig 1. Kuosheng Unit 2 Cycle 16 LHGR (kW/ft) of KAG115 Rod F-02 During the April 13, 2003 Control Rod Sequence Exchange



A - 99.9%CTP Prior to the sequence exchange. Adjacent control rod was at 30.	F - 84.9%CTP Power ascension to rated. Adjacent control rod was fully withdrawn.
B - 59.9%CTP Prior to fully withdrawn the adjacent control rod.	G - 90.6%CTP Power ascension to rated. Adjacent control rod was fully withdrawn.
C - 60.4%CTP After the adjacent control rod was fully withdrawn (from 30 to 48).	I - 94.9%CTP Power ascension to rated. Adjacent control rod was fully withdrawn.
D - 65.2%CTP Power ascension to rated. Adjacent control rod was fully withdrawn.	K - 99.7%CTP Rated power reached. Adjacent control rod was fully withdrawn.
E - 75.3%CTP Power ascension to rated. Adjacent control rod was fully withdrawn.	

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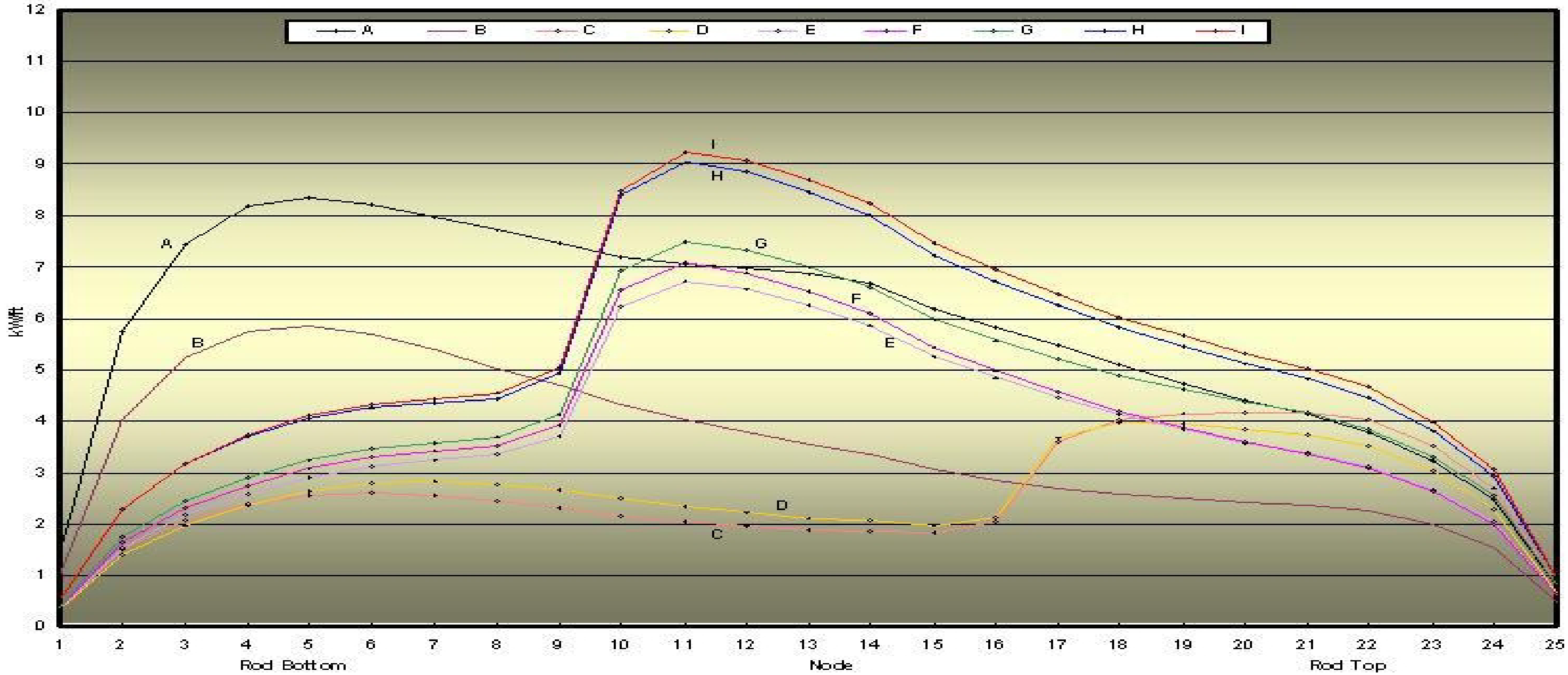
Fig 2. Kuosheng Unit 2 Cycle 16 LHGR (kW/ft) of KAG115 Rod F-02 During the September 7, 2003 Control Rod Sequence Exchange



A - 99.8% CTP Prior to the sequence exchange. Adjacent control rod was fully withdrawn.

B - 58.2% CTP Prior to inserting adjacent control rod.

C - 61.0% CTP After the adjacent control rod was inserted from 48 to 16.

D - 58.5% CTP Prior to adjusting the adjacent control rod.

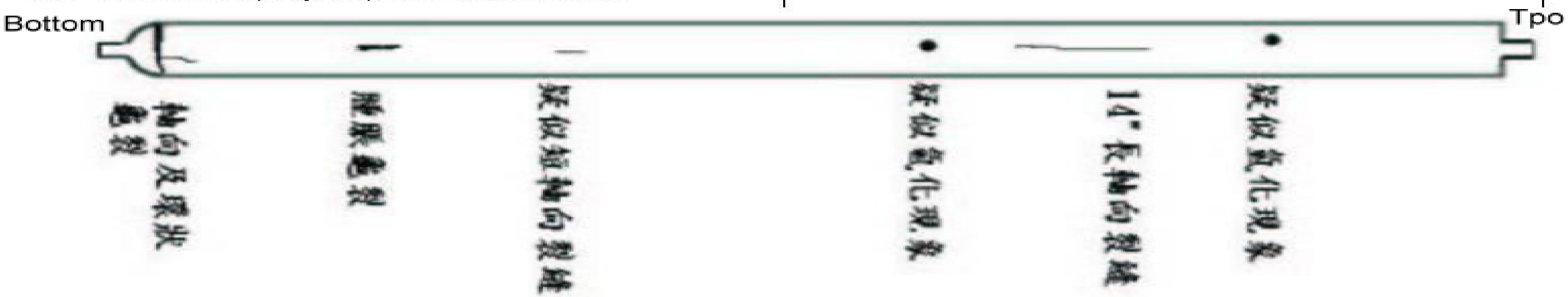
E - 66.4% CTP After adjusting the adjacent control rod from 16 to 30

F - 72.5 % CTP Power ascension to rated. Adjacent control rod was at 30.

G - 79.8% CTP Power ascension to rated. Adjacent control rod was at 30.

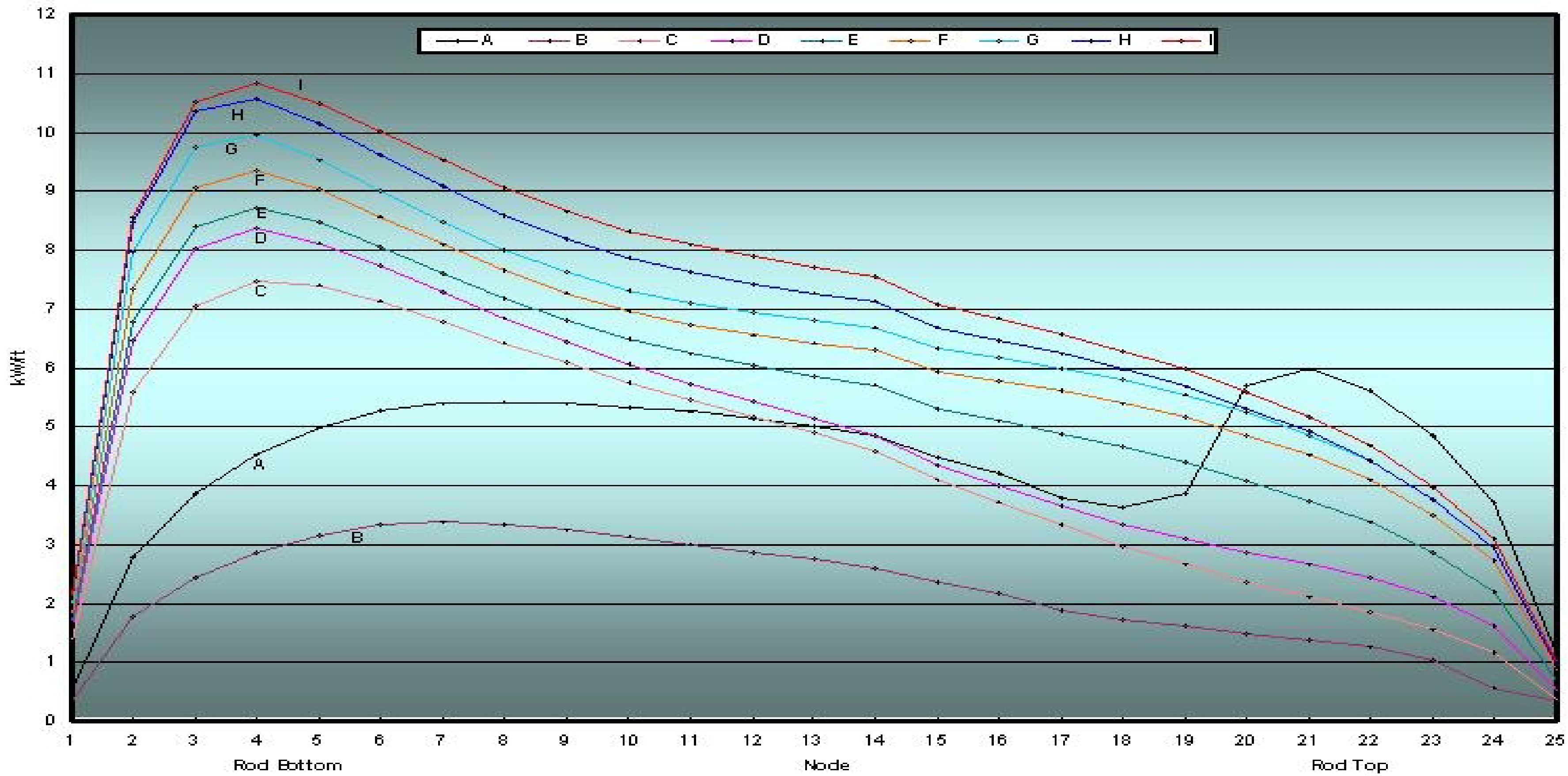
H - 97.6% CTP Power ascension to rated. Adjacent control rod was at 30.

I - 99.9% CTP Rated power. Adjacent control rod was at 30.



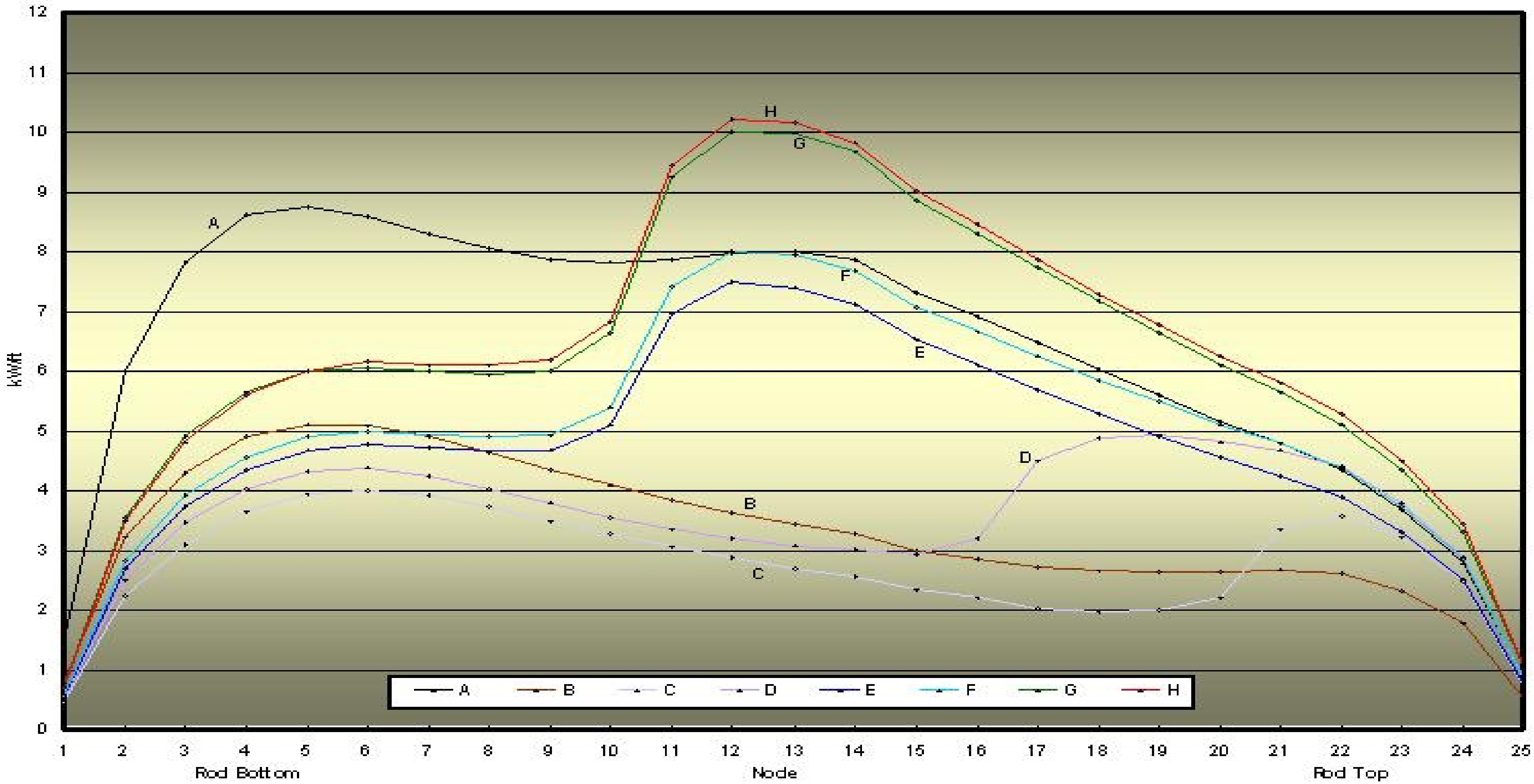
KBH069 failed fuel rod F2: Circumferential crack on span 2

Fig 3. Kuosheng Unit 2 Cycle 16 LHGR (kW/ft) of KBH069 Rod F-02 During the April 13, 2003 Control Rod Sequence Exchange



A - 99.9% CTP. Adjacent control rod was at 10. Rated power prior to sequence exchange.	F - 84.9% CTP. Adjacent control rod was at 48 (Fully withdrawn). Power Ascension.
B - 56.9% CTP. Adjacent control rod was at 00. Rod adjusted during sequence exchange.	G - 90.6% CTP. Adjacent control rod was at 48 (Fully withdrawn). Power Ascension.
C - 59.1% CTP. Adjacent control rod was at 48 (Fully withdrawn). Rod in new pattern.	H - 94.9% CTP. Adjacent control rod was at 48 (Fully withdrawn). Power Ascension.
D - 65.2% CTP. Adjacent control rod was at 48 (Fully withdrawn). Power Ascension.	I - 99.9% CTP. Adjacent control rod was at 48 (Fully withdrawn). Rated power reached.
E - 75.3% CTP. Adjacent control rod was at 48 (Fully withdrawn). Power Ascension.	

Fig 4. Kuosheng Unit 2 Cycle 16 LHGR (kW/ft) of KBH069 Rod F-02 During the September 7, 2003 Control Rod Sequence Exchange

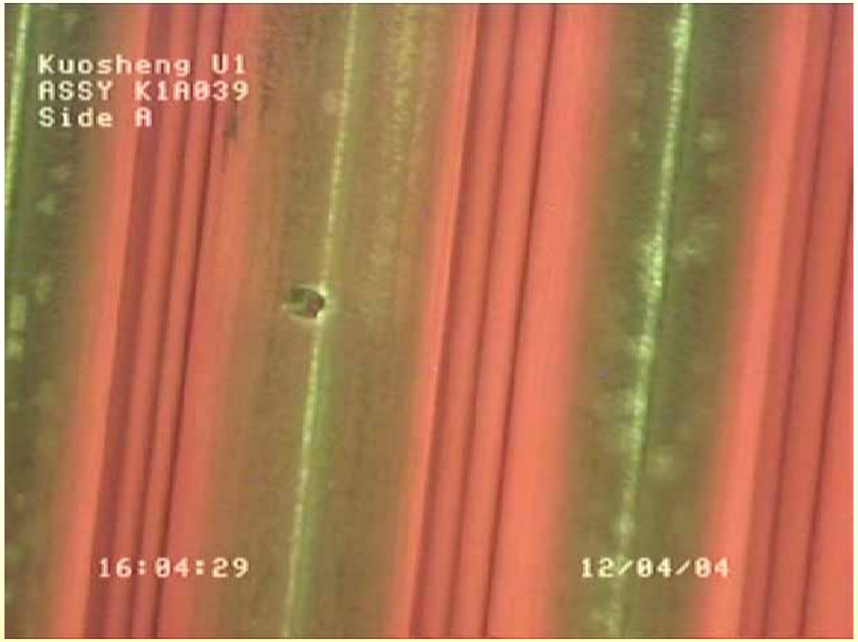


A - 99.8% CTP. Adjacent control rod was at 48 (Fully withdrawn) prior to sequence exchange.	E - 72.5% CTP. Adjacent control rod was at 28. Rod adjusted & Power Ascension.
B - 50.9% CTP. Adjacent control rod was at 48 (Fully withdrawn) prior to sequence exchange.	F - 79.8% CTP. Adjacent control rod was at 28. Power Ascension.
C - 57.5% CTP. Adjacent control rod was at 8. Rod in new pattern.	G - 97.6% CTP. Adjacent control rod was at 28. Power Ascension.
D - 66.4% CTP. Adjacent control rod was at 16. Rod adjusted & Power Ascension.	H - 99.8% CTP. Adjacent control rod was at 28. Rated power reached.

Fuel Performance of Kuosheng NPP (cont'd)

- In 2004, one failed fuel rod was found at Unit 1 Cycle 17.
- ATRIUM-10, non-barrier with small hole lower tie plate two-cycle fuel, burnup: 31.2 GWD/MTU.
- K1A039, core location: 25-22, failed fuel rod H1.
- The root cause is debris-induced fretting.

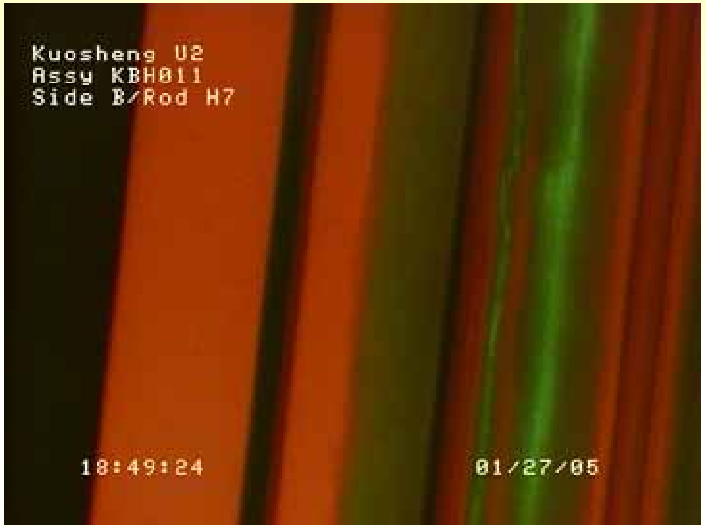
K1A039 failed fuel rod H1:Debris fret hole on span 3



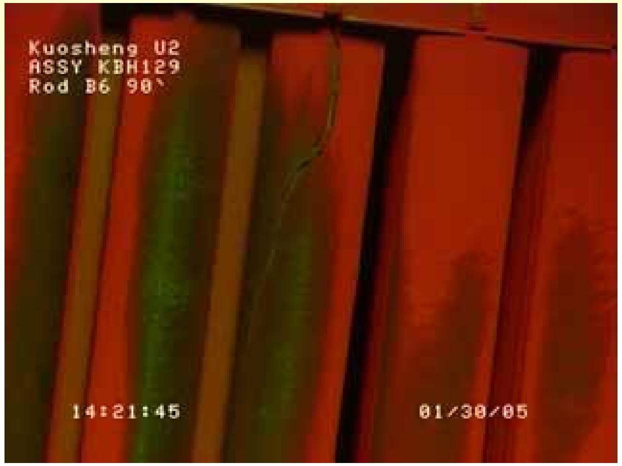
Fuel Performance of Kuosheng NPP (cont'd)

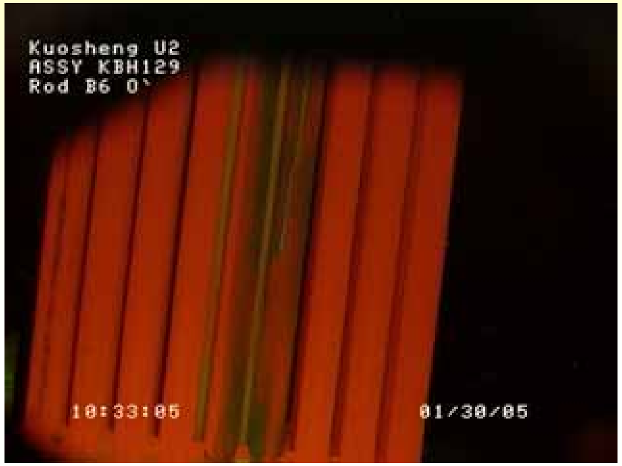
- In 2004, two failed fuel rods in two fuel assemblies were found at Unit 2 Cycle 17.
- ATRIUM-9B, non-barrier two-cycle fuel, burnup: 33.7 & 35.2 GWD/MTU.
- KBH011, core location: 21-32, failed fuel rod H7.
- KBH129, core location: 44-33, failed fuel rod B6.
- The root cause is still under investigation.

KBH011 failed fuel rod H7:Axial split on span 1,axial crack on span 3 &7



KBH129 failed fuel rod B6: Axial split on span 1 & 2, axial crack on span 4, circumferential crack below weld area of upper end cap





Maanshan Nuclear Power Plant

- Westinghouse 3-loop PWR, Dry containment, 2785 MWt, 951 MWe.
- Commercial: Unit 1 July 27, 1984
  Unit 2 May 18, 1985
- Fuel vendor: Westinghouse

Current Cycle		VANTAGE+	OFA
Unit 1	16	157	0
Unit 2	16	157	0

- Two failed fuel assemblies in 2003.

Fuel Performance of Maanshan NPP

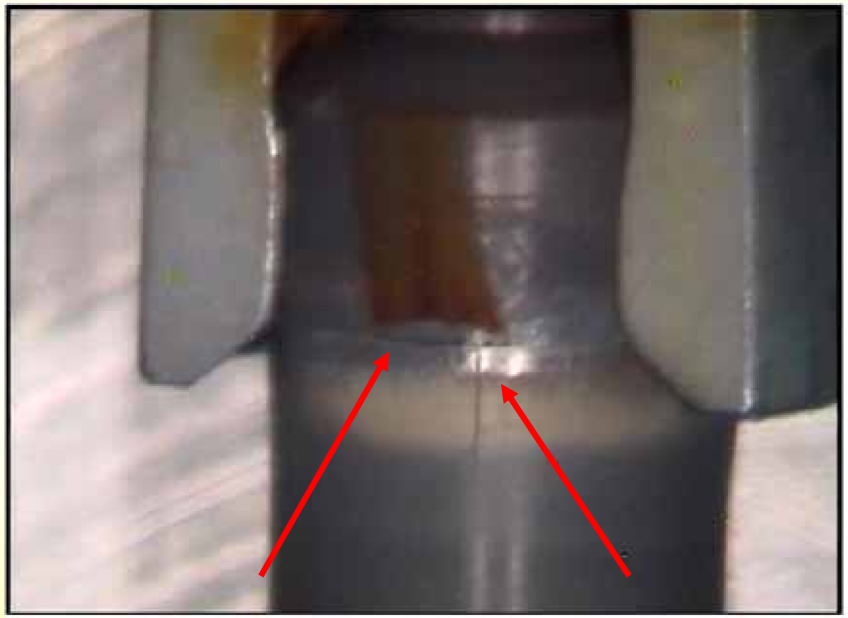
- In 2003, one failed fuel rod was found at Unit 2 Cycle 14.
- OFA, third-cycle fuel, burnup: 46.2 GWD/MTU.
- D166, core location: A-9, failed fuel rod L1.
- The root cause is debris-induced fretting.

D166 failed fuel rod L1: Wear scar below bottom grid, horizontal & vertical crack on top end plug

Fuel Performance of Maanshan NPP (cont'd)

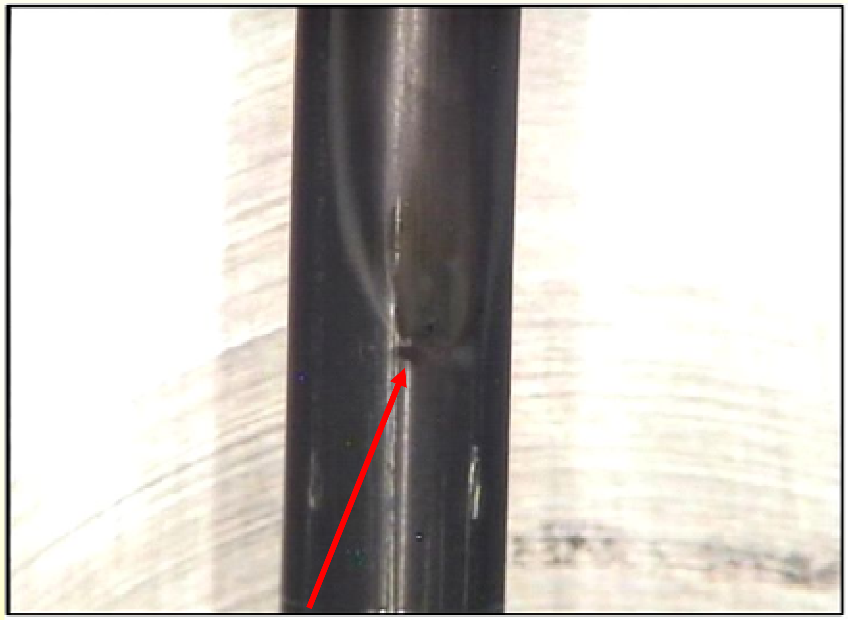
- In 2003, one failed fuel rod was found at Unit 1 Cycle 15.
- VANTAGE+, first-cycle fuel, burnup: 22.5 GWD/MTU.
- G121, core location: N-5, failed fuel rod O7.
- The root cause is debris-induced fretting, but needs further verification.

G121 failed fuel rod O7: Crack between clad & top end plug, small vertical crack on clad, small hole above bottom grid



Crack between clad & top end plug

small vertical crack on clad



Small Hole (0.008” dia)

Regulatory Actions

- Raise plant action level
  - Increase frequency of coolant activity analysis. （BWR only）
  - Perform flux tilt to locate the failed assembly. （BWR only）
  - Insert control rod to suppress power and hence reduce further degradation.
- Root cause analysis
  - Mandatory pool-side inspection.
  - Hot cell examination if needed.
  - Power history calculation with emphasis on change in rod pattern.
  - Revisit the fuel manufacturing record.
- Revise the fuel loading report

Framatome ANP Actions

- Improvement in manufacturing process
  - Tightened inspection criteria of pellet chips.
  - 100% visual inspection of pellets.
  - Vibratory loading of pellets.
  - Robust welding process for end caps.
- Reduce fuel initial power and power ascension rate

Final Remarks

- The remaining ~ 100 ATRIUM 9B assemblies located in the central core region of Kuosheng Unit 2 will follow more stringent operating limits recommended by FANP.
- Hot cell examination will be performed for all non-debris failed rods.
- To achieve zero-defect goal,Taipower needs to reconsider operating strategy in addition to minimizing manufacturing problems.
- In view of severe fuel degradation which causes large system contamination and potential personnel dose, regulatory actions to tighten operating limits may be necessary.