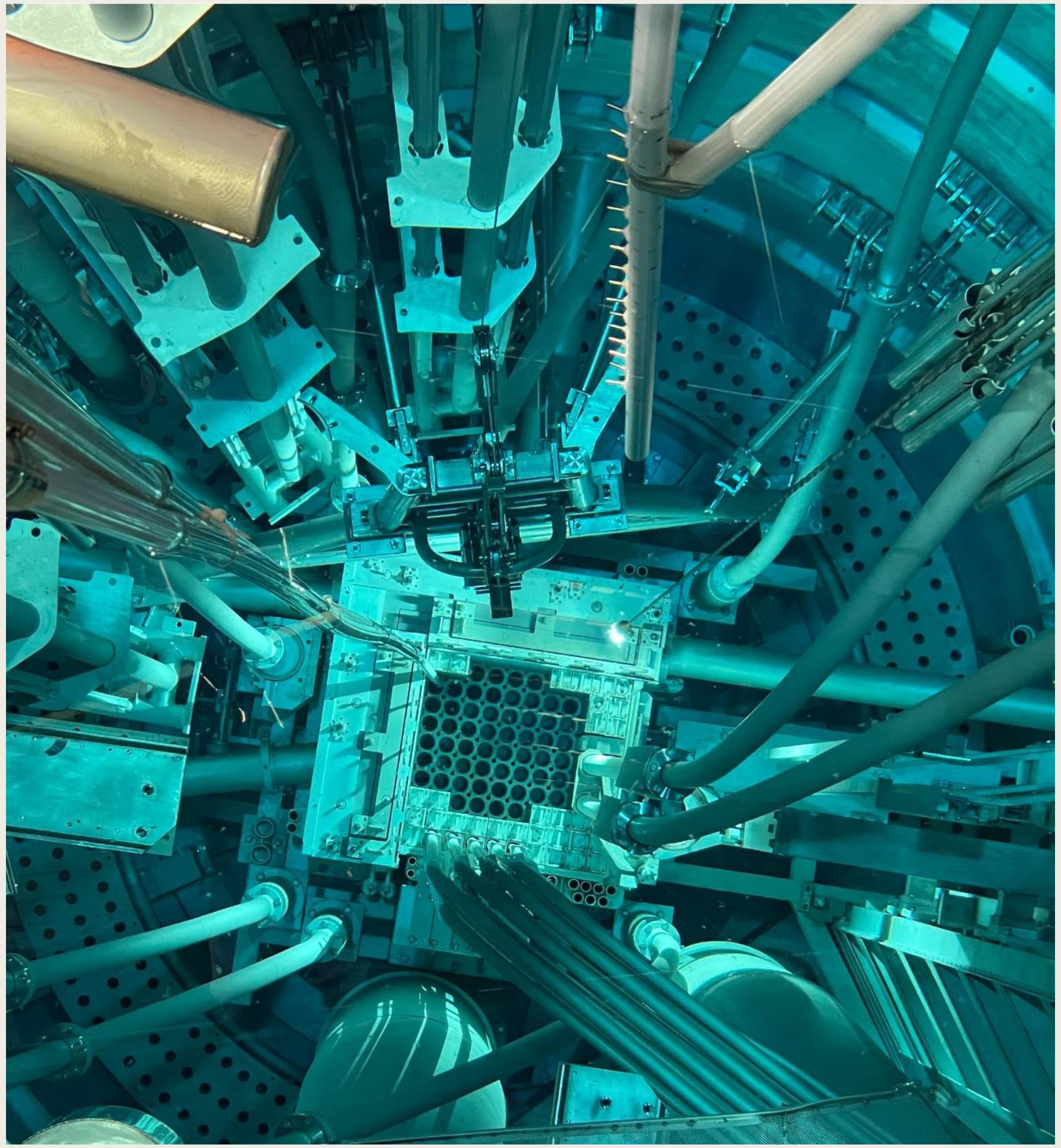
The Role of an Innovative Equilibrium Core for Simpler In-Core Fuel Management of the Indonesian RSG GAS Reactor

The RSG GAS reactor in Indonesia successfully transitioned from oxide to equilibrium silicide core. This innovation simplified in-core fuel management and enhanced operational safety while maintaining stable neutronic parameters.



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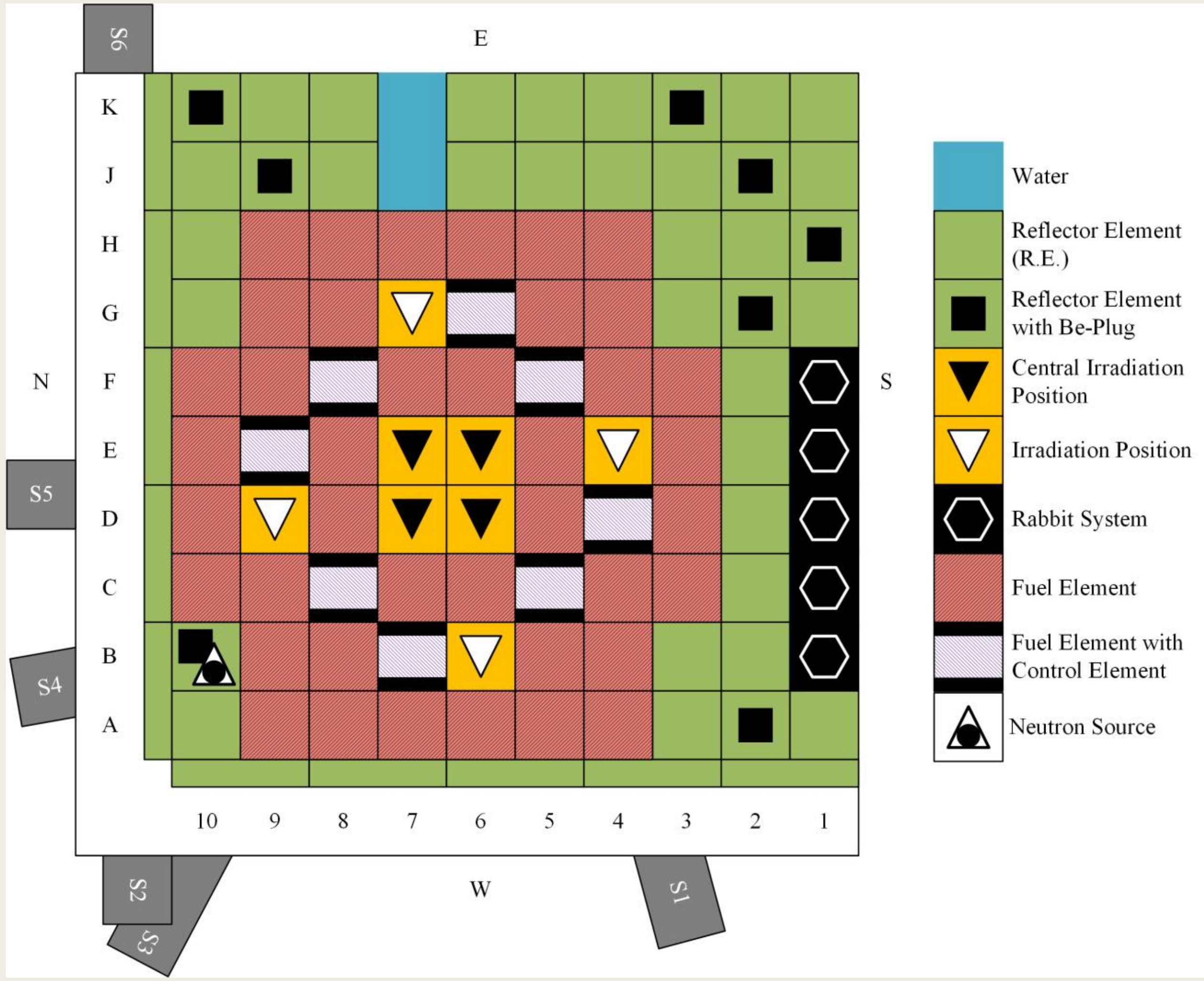


RSG GAS Reactor Overview

Multipurpose Research Reactor

Open pool reactor with light water coolant-moderator and beryllium reflector, operating at max. 30 MWth with MTR-type fuel.

Long-Running Facility

First reached criticality on July 29, 1987, serving Indonesia for over 38 years (4~6 cycles/year, 25 effective days/cycle).

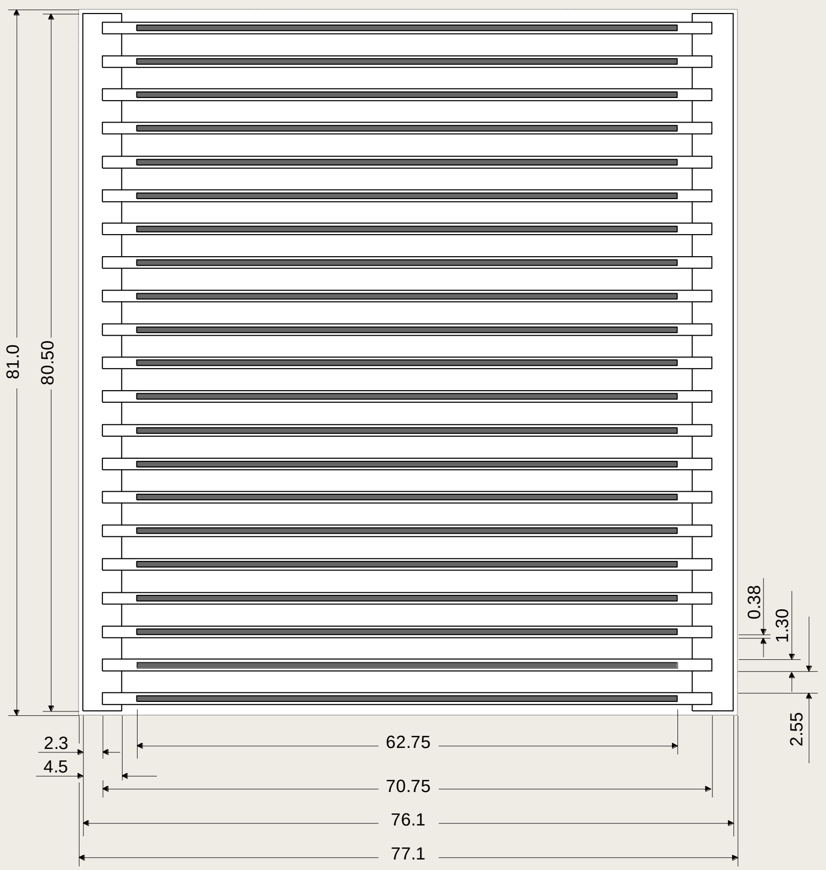
Research Applications

Supports material testing, radioisotope production, precious stone irradiation, neutron activation analysis, and reactor aging management & safety studies, etc.

Fuel Element Design

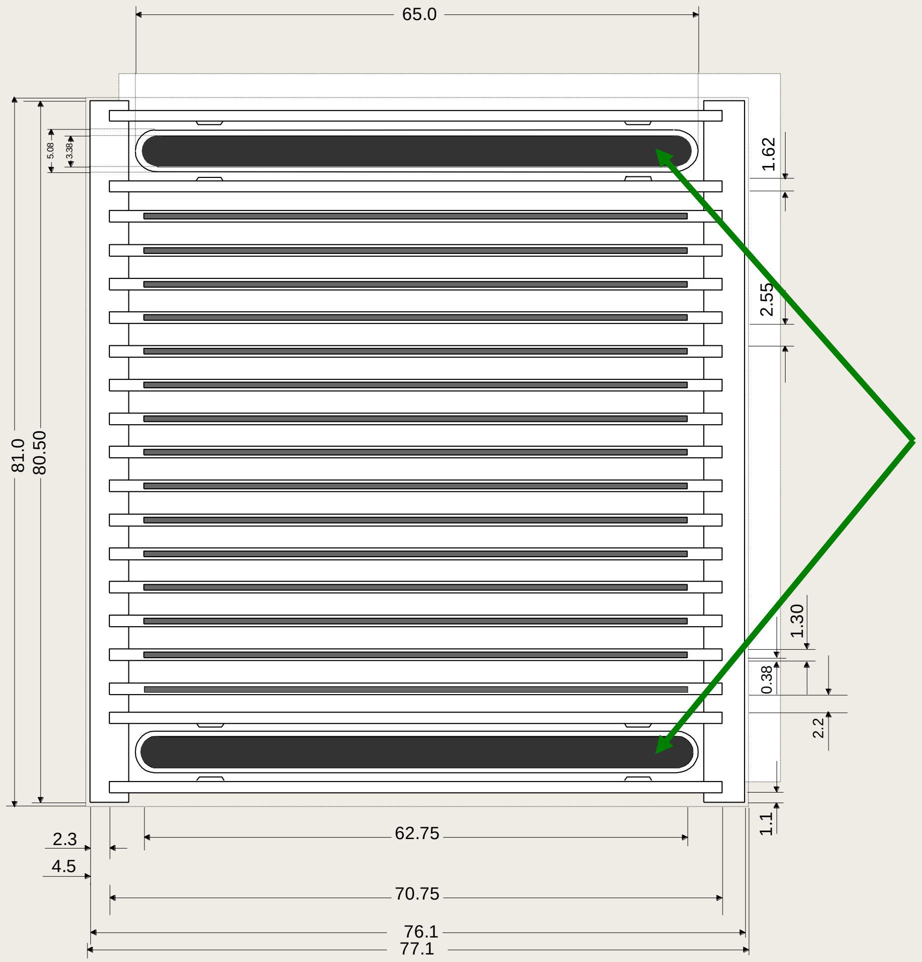
Standard Fuel Element (FE)

Contains 21 fuel plates with low-enriched uranium (LEU, 19.75 %). The core uses 40 standard elements.



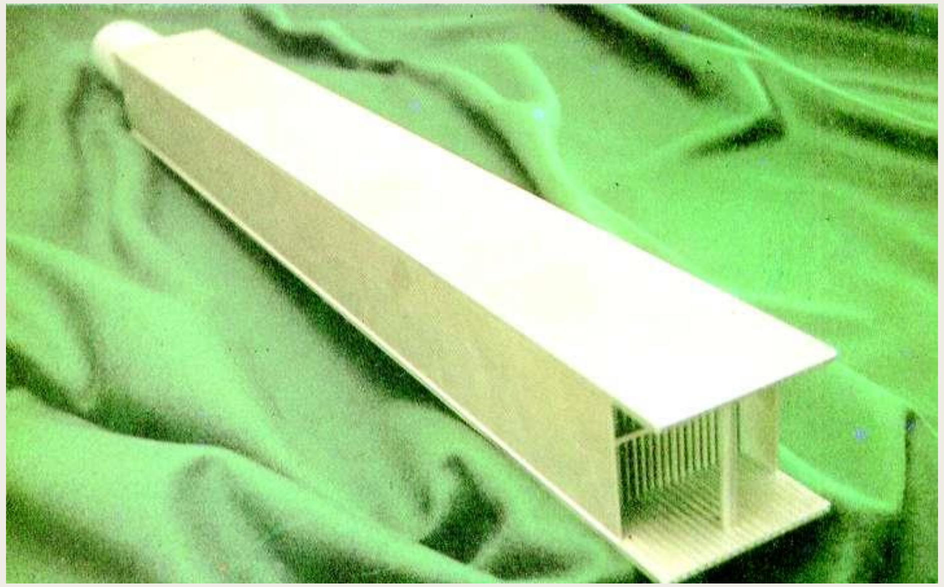
Control Fuel Element (CE)

Contains 15 fuel plates with space for control blade movement. The core uses 8 control elements.



Effective height (fuel meat) of FE and CE is 60 cm.

Domestically Manufactured FE & CE



Absorber Material

Control blades use Ag-In-Cd (18% Ag, 15% In, 5% Cd) as neutron absorber material.

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Initial Fuel Management Challenges (1990s)

Inconsistent Loading Patterns

Early cores used 6 FEs/1 CE or 6 FEs/2 CEs loading patterns with unpredictable configurations.

Reactivity Variations

Fluctuations in core excess reactivity, control rod worth, shutdown margin, and neutron flux levels in irradiation positions created operational challenges.

Inefficient Fuel Utilization

Some fuel was discharged before reaching the optimal 56% burnup level.

Transition to Equil. Silicide Core

Enhancing Reactor Utilization

- Use higher uranium density (silicide fuel) for longer core life and less frequent refueling.
- Oxide to silicide core conversion program:
  - New equilibrium silicide core design.
  - Strategy for transition cores.
  - Irradiation of miniplate silicide fuels with higher uranium density (~ 4.8 g/cm^3).
  - Licensing procedures.

Options & Considerations

- Transition to higher uranium density silicide fuel:
  - Direct (2.96 → 4.8 g/cm^3).
  - Staged (2.96 → 3.55 → 4.8 g/cm^3).
- Transition from oxide to silicide fuel:
  - Small to nominal core (all silicide).
  - Mixed (oxide-silicide) cores.

1 **Oxide Fuel Era (~1999)**

Initial operation with U_3O_8-Al oxide fuel at 2.96 g U/cc density.

2 **Mixed (Oxide-Silicide) Core Phase (1999~2003)**

Gradual introduction of silicide fuel through 10 transition cores (TMIX-1 to TMIX-10).

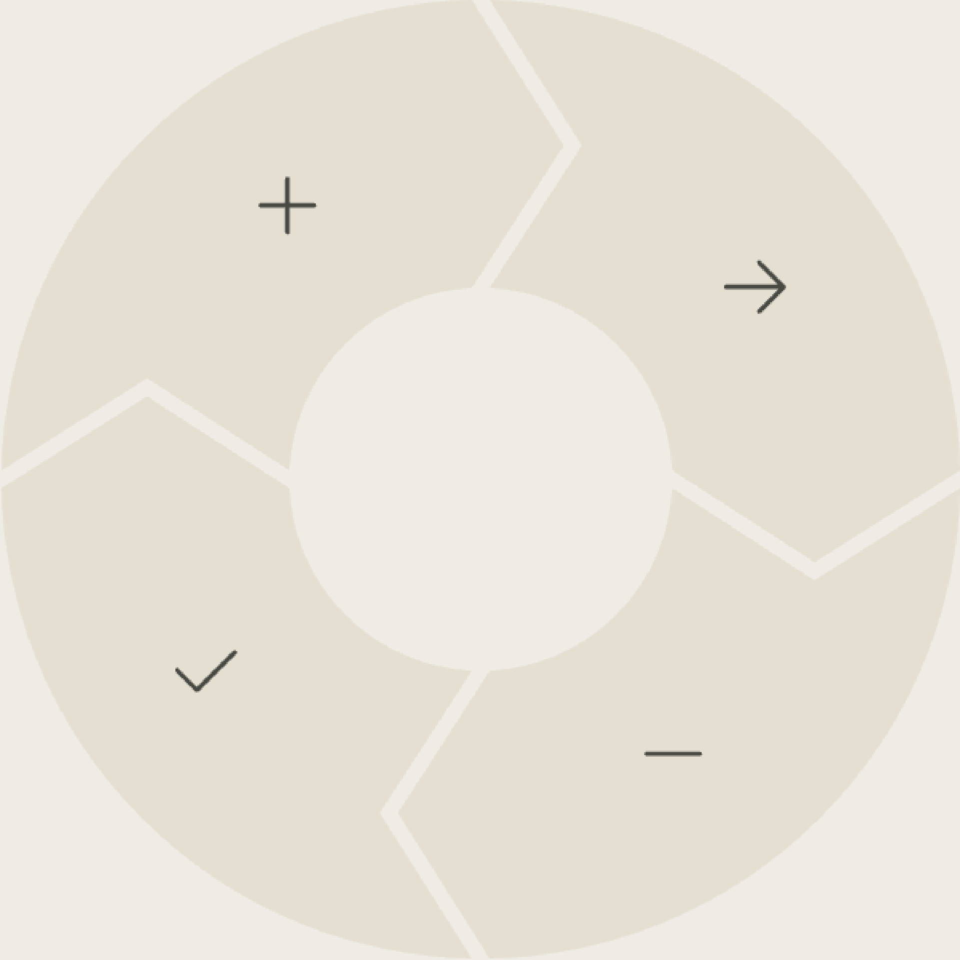
3 **Full Silicide Core (2003~2005)**

Complete transition to U_3Si_2-Al silicide fuel while maintaining the same uranium density.

4 **Equilibrium Silicide Core (2005~present)**

Stable 5/1 loading pattern established with consistent neutronic parameters.

Innovative 5 FEs/1 CE Fuel Loading Pattern (1)



1. Remove Spent Fuel

Discharge 5 FEs and 1 CE after reaching 56% burnup from fixed positions.

2. Shuffle Existing Fuel

Move FEs and CEs according to a predetermined (fixed) pattern, maintaining 8 burnup classes.

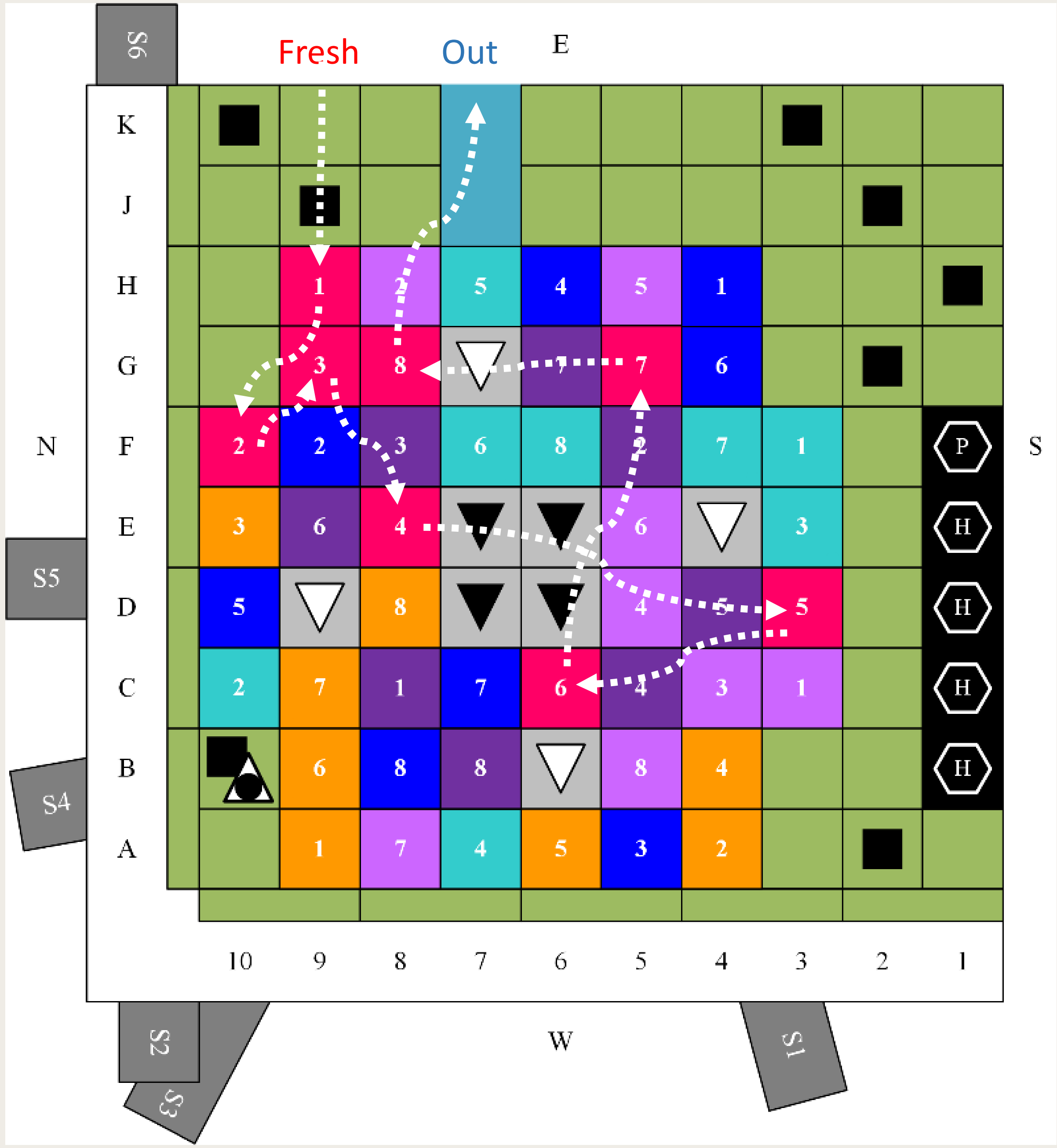
3. Add Fresh Fuel

Insert 5 FEs and 1 CE at designated (fixed) positions.

4. Verify Parameters

Confirm core reactivity and safety parameters remain within limits.

Innovative 5 FEs/1 CE Fuel Loading Pattern (2)



From	To	From	To	From	To
fresh	A-9	fresh	C-3	fresh	H-9
A-9	A-4	C-3	H-8	H-9	F-10
A-4	E-10	H-8	C-4	F-10	G-9
E-10	B-4	C-4	D-5	G-9	E-8
B-4	A-6	D-5	H-5	E-8	D-3
A-6	B-9	H-5	E-5	D-3	C-6
B-9	C-9	E-5	A-8	C-6	G-5
C-9	D-8	A-8	B-5	G-5	G-8
D-8	out	B-5	out	G-8	out
fresh	F-3	fresh	H-4	fresh	C-8
F-3	C-10	H-4	F-9	C-8	F-5
C-10	E-3	F-9	A-5	F-5	F-8
E-3	A-7	A-5	H-6	F-8	C-5
A-7	H-7	H-6	D-10	C-5	D-4
H-7	F-7	D-10	G-4	D-4	E-9
F-7	F-4	G-4	C-7	E-9	G-6
F-4	F-6	C-7	B-8	G-6	B-7
F-6	out	B-8	out	B-7	out

- Eight burnup classes (1 ~ 8)
  - 1 : New fuel (fresh)
  - 8 : Discharge fuel (out)
- Shuffling pattern is fixed (color shows individual FE shuffling history)
- Core quadrant power share (balancing)

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Core Neutronics Parameters Comparison

Parameter	Energy per cycle (MWd)	Total CR worth (%)	Excess reactivity (%)	Shutdown margin (%)	Core Burnup BOC (%)	Core Burnup EOC (%)
TWC with oxide fuel (1998 ~ 1999) 6/1 or 6/2						
Average	525.4	-11.1	6.9	-1.6	22.3	28.8
σ	3.4%	-22.0%	8.7%	-21.8%	1.6%	2.9%
Mixed oxide silicide fuel core (1999 ~ 2003) 5/1						
Average	565.1	-12.7	8.0	-2.9	22.7	28.8
σ	9.6%	-6.6%	11.0%	-14.5%	2.3%	1.5%
Full silicide fuel core (2003 ~ 2005) 5/1						
Average	627.3	-12.6	7.4	-3.4	24.6	31.3
σ	2.0%	-4.3%	5.7%	-8.2%	2.9%	2.2%
Equilibrium silicide fuel core (2005 ~ 2007) 5/1						
Average	657.6	-12.8	7.6	-3.3	25.0	31.9
σ	6.0%	-0.8%	1.6%	-3.2%	1.6%	1.9%
Recent equilibrium silicide fuel core (2018 ~ 2019) 5/1						
Average	625.2	-13.0	7.1	-4.1	24.0	30.5
σ	0.1%	-1.0%	1.3%	-4.5%	0.2%	0.2%

σ : Variation (Standard Deviation)

Benefits of Equilibrium Core Strategy

Simplified Management

Operators follow clear loading guidelines without intensive reactivity calculations for each cycle.

Optimized Fuel Utilization

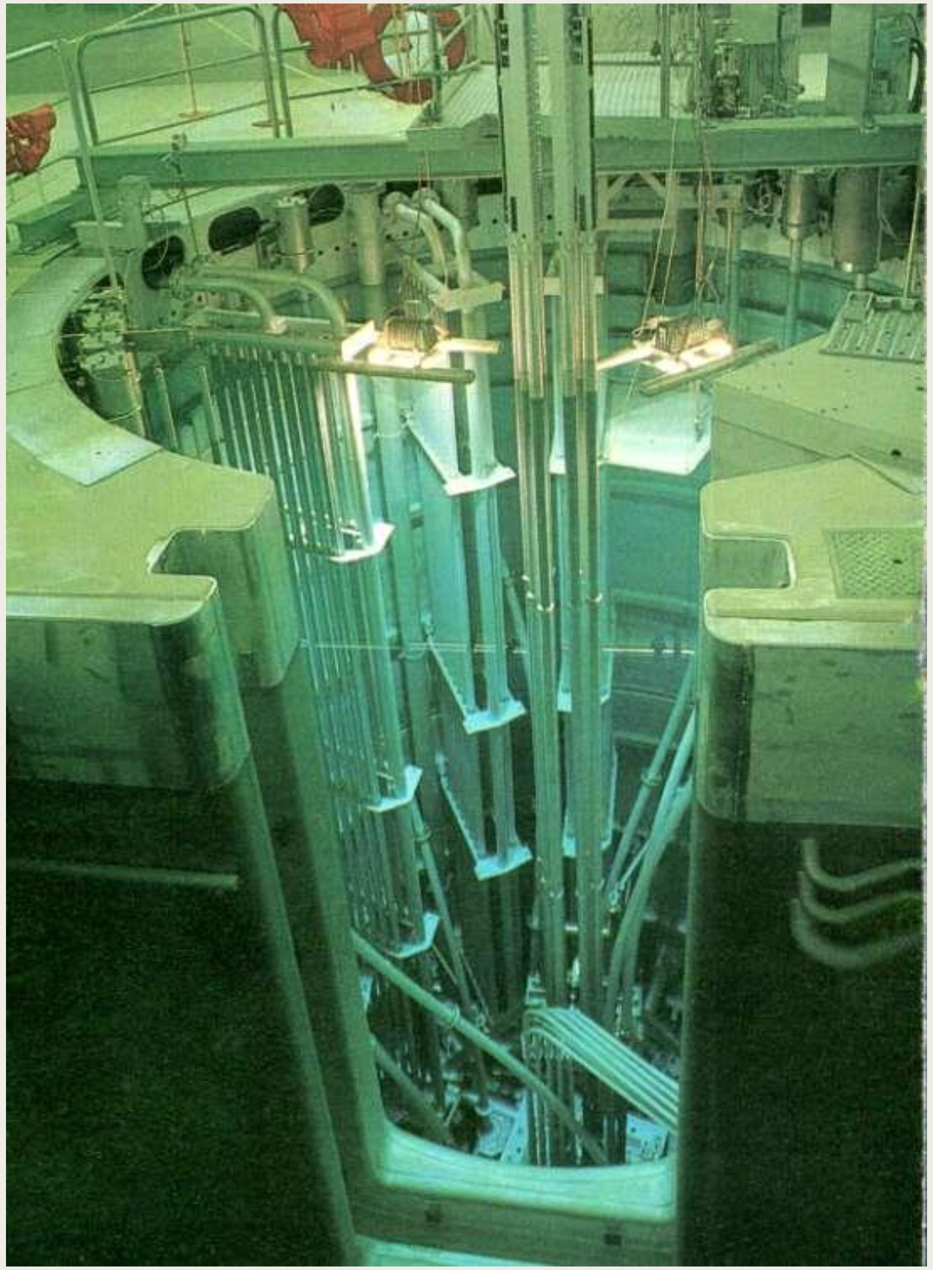
All discharged fuel reaches target 56% burnup, maximizing resource efficiency.

Enhanced Safety

Consistent neutronic parameters ensure predictable reactor behavior and stable operation.

Validated Performance

Measurements confirm agreement with calculations within Safety Analysis Report limits.



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Closing Remarks and Future Work

Successful Achievement of Silicide Equilibrium Core

- Oxide to silicide core conversion program:
  - New equilibrium silicide with 5/1 loading pattern
  - Same uranium density with oxide fuel
- Higher uranium density of silicide fuel:
  - Irradiation of miniplate silicide fuels with higher uranium density (3.55 and 4.8 g/cm^3) was completed.
  - Post Irradiation Examination (PIE) was also completed, showing promising results.

Future Work and Challenges

- Licensing for the silicide core with higher uranium density (3.55 g/cm^3).
- New trends in MTR fuel technology:
  - U-Mo fuel.
- Measures against reactor aging:
  - Evaluation of SSC related to reactor safety.
  - Replacement and/or modernization of SSC.

Thank You!

ご清聴ありがとうございました。

Terima Kasih!

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