

Scenario Analysis of Breakeven Molten Salt Fast Reactors (BeMFRs) for Spent Nuclear Fuel Management in Korea



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Contents

Introduction

Current Status of Nuclear Power Plants in Korea

BeMFR Sample

Verifying SNF Management Scenario

Conclusions

Introduction

Nuclear trilemma

- Enhancing the safety → Adopting the concept of MSFR
- Preventing accumulation of spent fuel → Reutilizing the spent fuel
- Securing uranium resources → Reutilizing the spent fuel

Energy potential

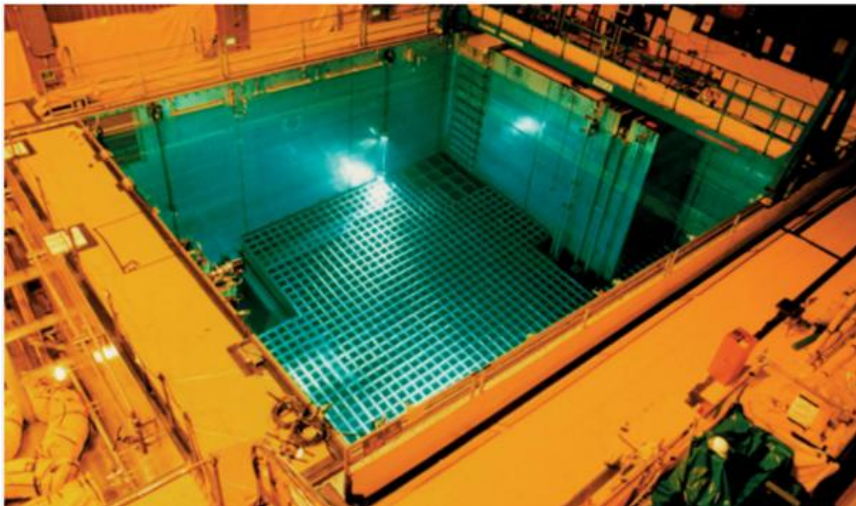
- Spent fuel in Korea: ~9,000 tons from LWR & ~9,400 tons from HWR
 - Equivalent to total electricity in Korea over 300 years
- Spent fuel in U.S.: ~90,000 tons from PWR and BWR
 - Equivalent to total electricity in USA over several hundreds years as well!



Accumulated amount of SNF and Saturation point of storage tank

Power plant	Expected SNF accumulation	Storage tank saturation point
Kori	12,290 FA	2032
Hanbit	13,051 FA	2030
Hanul	27,401 FA	2031
Saeul	15,660 FA	2066
Shin Wolsong	3,633 FA	2042
Wolsong	721,920 FA	2037

<Reference: Ministry of Trade, Industry and Energy>



Introduction

Breakeven Molten salt Fast Reactor (BeMFR)

– MSFR concept

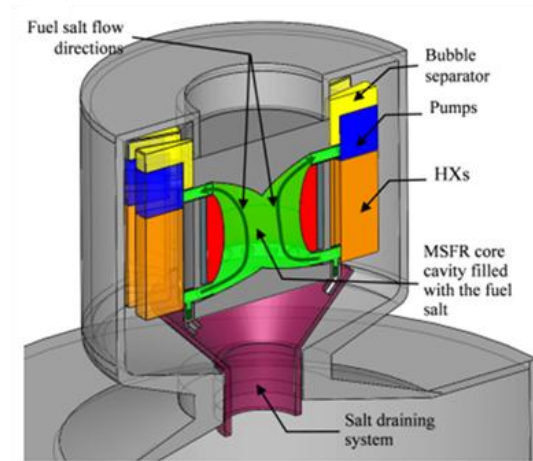
- Passive safety, convenient decay heat removal, atmospheric pressure operation
- Reduced spent fuel buildup, proliferation resistance

– Reutilizing the spent fuel as a energy resource

- Requiring U and TRU from spent fuel at the startup
- During operation, spent fuel is consumed as make-up fuel

– Other Properties:

- Enables long-term operation by spent fuel feeding
- Chloride salt → compact, high-density core
- Minimal pyro-processing (output: small fraction of TRU) → high proliferation resistance



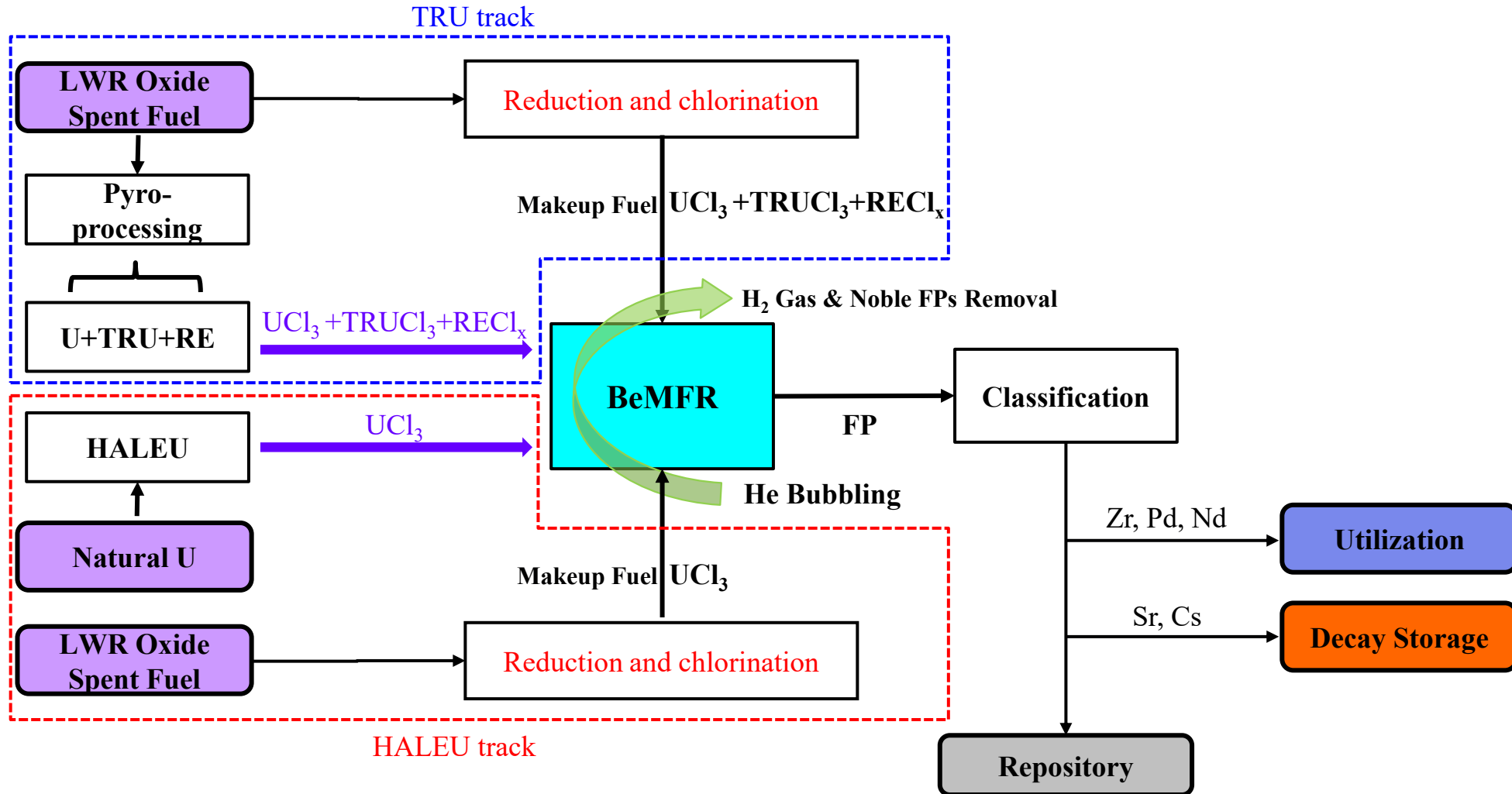
European MSFR

BeMFR pursues addressing nuclear trilemma though adopting MSFR concept and reutilizing spent fuel.

Introduction

Closed fuel cycle

- TRU track and HALEU track



Contents

Introduction

Current Status of Nuclear Power Plants in Korea

BeMFR Sample

Verifying SNF Management Scenario

Conclusions

Current Status of Nuclear Power Plants in Korea

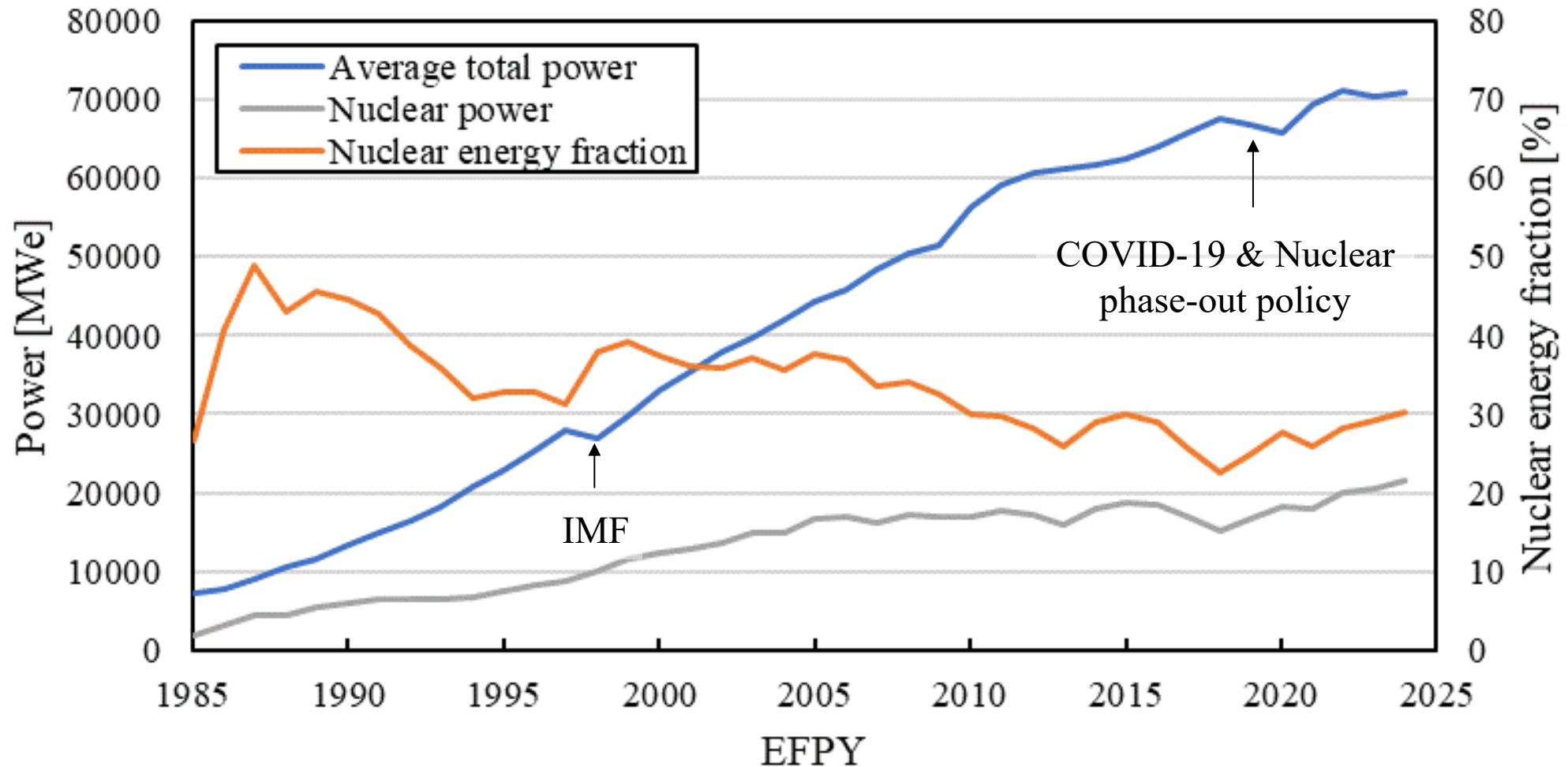
Nuclear power plants in Korea

Black: LWR Blue: HWR : Permanent shutdown * 2024

Location	Name	Model	Electric power [MWe]	Thermal power [MWth]	Capacity factor	Operation start date	Permanent shutdown date	Total energy production [MWth-d]
Gijang-gun	Kori-I	WH 60	562	1,729	75.8%	1978-04-29	2017-06-18	6.190E+06
Gijang-gun	Kori-II	WH F	621	1,882	83.6%	1983-07-25	-	7.718E+06
Gijang-gun	Kori-III	WH F	948	2,912	83.5%	1985-09-30	-	1.144E+07
Gijang-gun	Kori-IV	WH F	949	2,912	84.7%	1986-04-29	-	1.144E+07
Gijang-gun	Shin-kori-I	OPR-1000	995	2,825	77.0%	2011-02-28	-	3.938E+06
Gijang-gun	Shin-kori-II	OPR-1000	996	2,825	84.2%	2012-07-20	-	3.879E+06
Ulju-gun	Saeul-I	APR-1400	1,413	3,983	81.4%	2016-12-20	-	3.479E+06
Ulju-gun	Saeul-II	APR-1400	1,413	3,983	83.8%	2019-08-29	-	2.405E+06
Gyeongju-si	Wolsong-I	CANDU 6	631	2,061	79.2%	1983-04-22	2019-12-24	5.845E+06
Gyeongju-si	Wolsong-II	CANDU 6	646	2,061	89.2%	1997-07-01	-	5.860E+06
Gyeongju-si	Wolsong-III	CANDU 6	655	2,061	85.3%	1998-07-01	-	5.500E+06
Gyeongju-si	Wolsong-IV	CANDU 6	649	2,061	91.1%	1999-10-01	-	5.560E+06
Gyeongju-si	Shin-wolsong-I	OPR-1000	995	2,825	82.0%	2012-07-31	-	3.800E+06
Gyeongju-si	Shin-wolsong-II	OPR-1000	991	2,825	84.1%	2015-07-24	-	2.945E+06
Yeonggwang-gun	Hanbit-I	WH F	938	2,787	84.5%	1986-08-25	-	1.111E+07
Yeonggwang-gun	Hanbit-II	WH F	934	2,787	84.0%	1987-06-10	-	1.084E+07
Yeonggwang-gun	Hanbit-III	OPR-1000	976	2,825	82.8%	1995-03-31	-	8.558E+06
Yeonggwang-gun	Hanbit-IV	OPR-1000	970	2,825	84.9%	1996-01-01	-	7.603E+06
Yeonggwang-gun	Hanbit-V	OPR-1000	984	2,825	80.2%	2002-05-21	-	6.586E+06
Yeonggwang-gun	Hanbit-VI	OPR-1000	987	2,825	84.8%	2002-12-24	-	6.798E+06
Uljin-gun	Hanul-I	France CP1	939	2,775	85.8%	1988-09-10	-	1.072E+07
Uljin-gun	Hanul-II	France CP1	940	2,775	87.0%	1989-09-30	-	1.055E+07
Uljin-gun	Hanul-III	OPR-1000	985	2,825	84.6%	1998-08-11	-	8.213E+06
Uljin-gun	Hanul-IV	OPR-1000	989	2,825	84.8%	1999-12-31	-	7.643E+06
Uljin-gun	Hanul-V	OPR-1000	994	2,825	87.2%	2004-07-29	-	6.530E+06
Uljin-gun	Hanul-VI	OPR-1000	995	2,825	88.9%	2005-04-22	-	6.406E+06
Uljin-gun	Shin-hanul-I	APR-1400	1,420	3,983	80.9%	2022-12-07	-	9.908E+05
Uljin-gun	Shin-hanul-II	APR-1400	1,416	3,983	90.6%	2024-04-05	-	4.208E+05

Current Status of Nuclear Power Plants in Korea

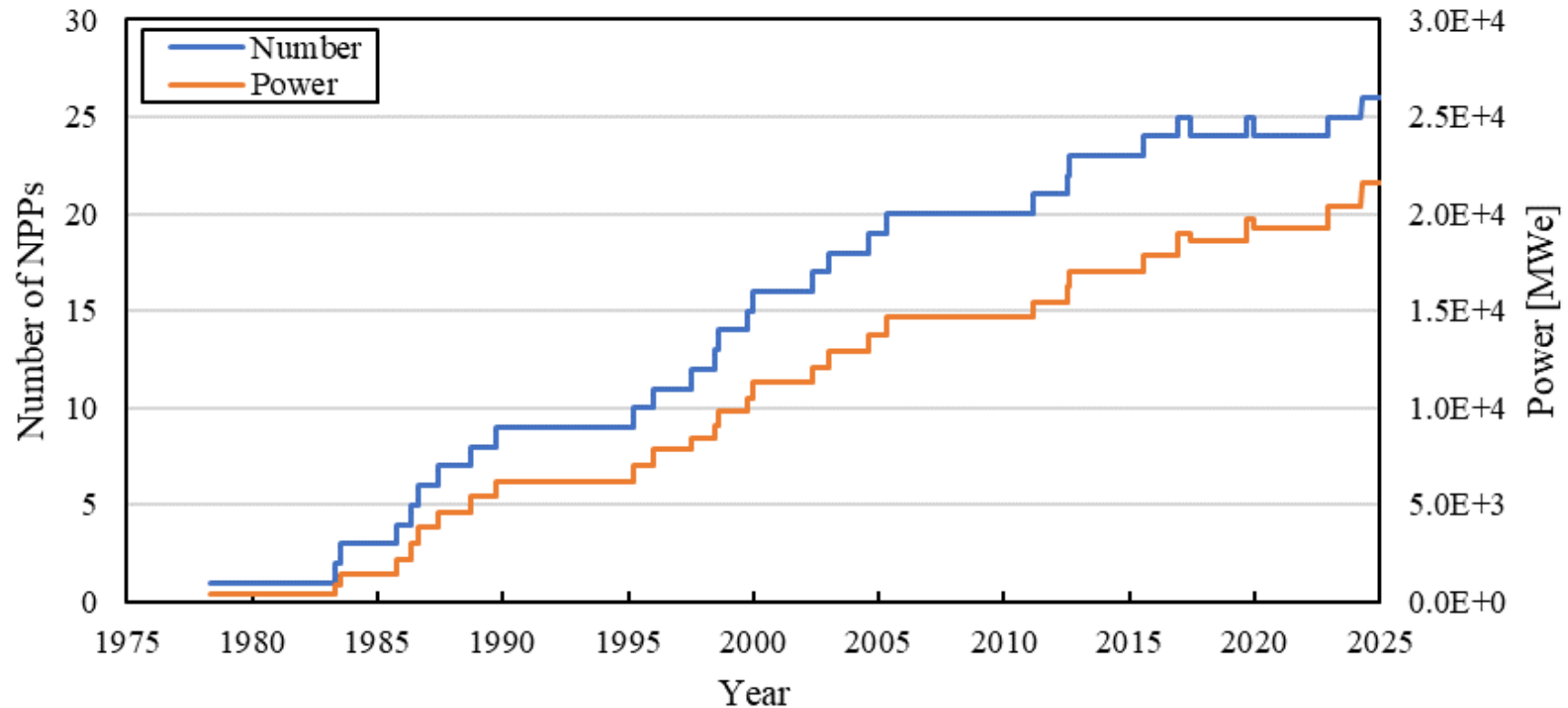
Total and nuclear power production and nuclear power fraction since 1985



Current Status of Nuclear Power Plants in Korea

Number of NPPs and total nuclear power from 1978 to 2024

- The power of each plant is assumed to be the average value of the total period power and considered constant over the entire period.



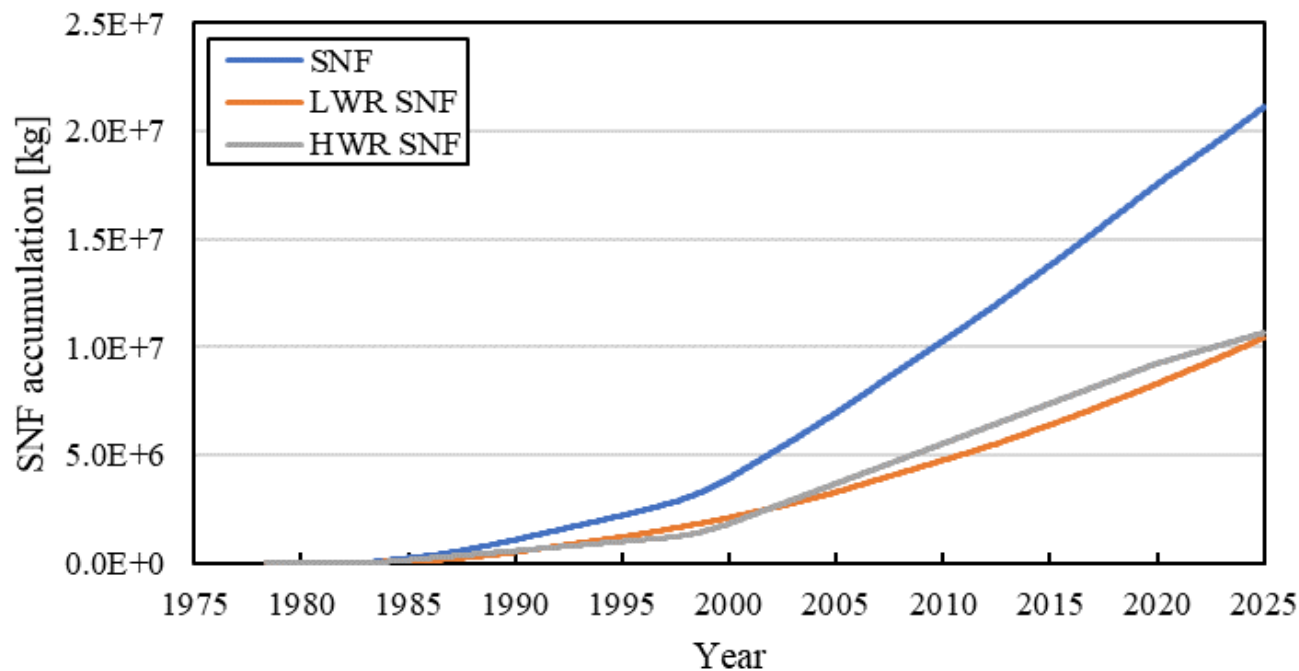
As of the end of 2024, there are a total of 26 plants with a combined power output of approximately 21,500 MWth.

Current Status of Nuclear Power Plants in Korea

Total SNF accumulation from 1978 to 2024

- A discharge burnup of 45 MWd/kgU is assumed for PWRs, and 7 MWd/kgU for HWRs.
- The mass of structural materials is excluded.

$$\text{Annual SNF production} = \frac{P \times 365.2425 \times CF}{\epsilon \times BU}$$



By the end of 2024, about 20,600 tons of spent nuclear fuel are accumulated.

Contents

Introduction

Current Status of Nuclear Power Plants in Korea

BeMFR Sample

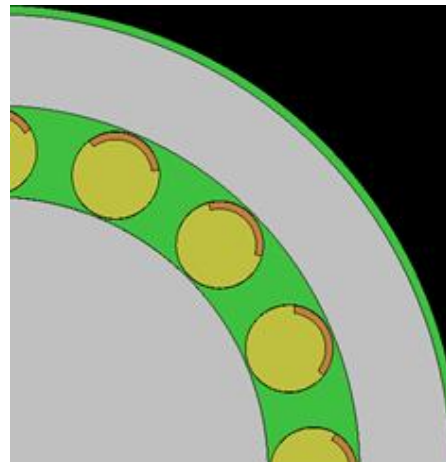
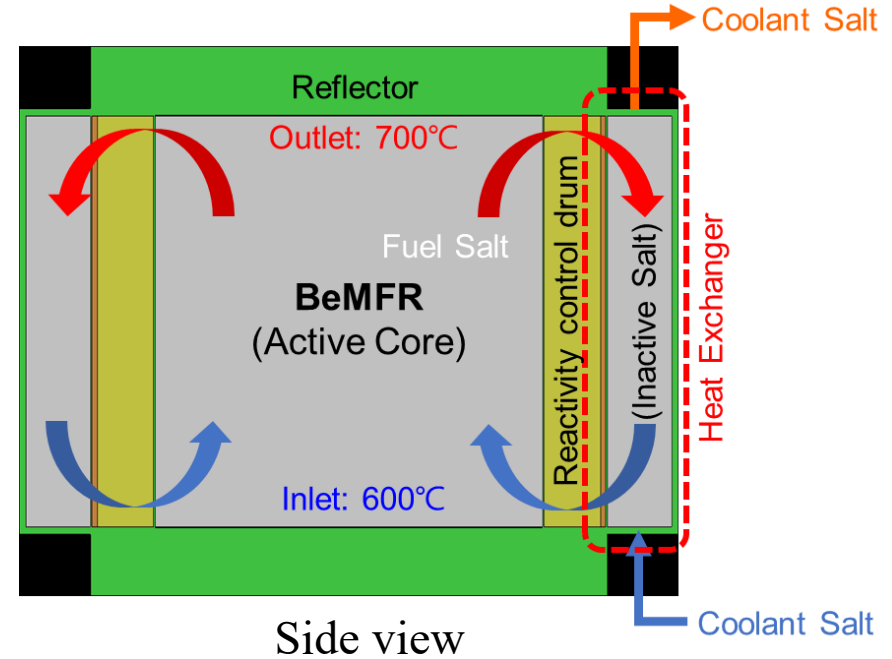
Verifying SNF Management Scenario

Conclusions

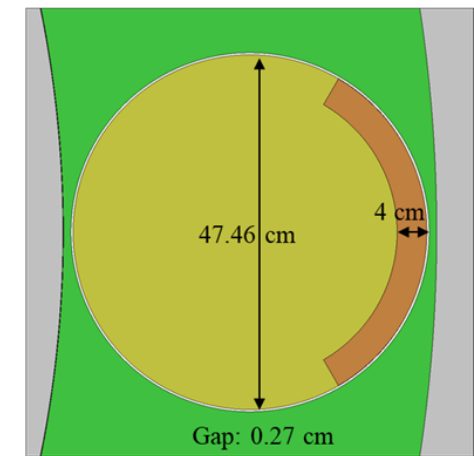
BeMFR Sample

Reactor Layout

- Power: 3,000 MWth
 - Active core: cylindrical geometry
 - Diameter = Height
- Reflector:
 - Stainless steel of 50 cm
- Inactive salt is placed around reflector
 - $V_{\text{inactive}} = 15 \text{ m}^3$
- Reactivity devices in reflector
- Operating temperature: 650°C



Top view (1/4)



Reactivity control device

BeMFR Sample

Design parameters of a BeMFR sample

	Reactor A
Power	3,000 MWth
KCl-TRUCl ₃ -UCl ₃ -RECl ₃	46.00-8.48-38.22-7.30
Cl-37 enrichment	99 at.%
Fuel density at 650°C	3.676 g/cm ³
Active core diameter	3.3 m
Active core height	3.3 m
Active core volume	28.22 m ³
Inactive salt volume of initial core	15.00 m ³
U mass	66.8 ton
TRU mass	14.9 ton
RE mass	7.5 ton

E. Lee, T. Oh, & Y. Kim, Neutronic Feasibility of Breakeven Molten Salt Fast Reactor Based on a Closed Fuel Cycle, Transactions of the American Nuclear Society Annual Conference, June 15–18, 2025, Chicago, IL

Contents

Introduction

Current Status of Nuclear Power Plants in Korea

BeMFR Sample

Verifying SNF Management Scenario

Conclusions

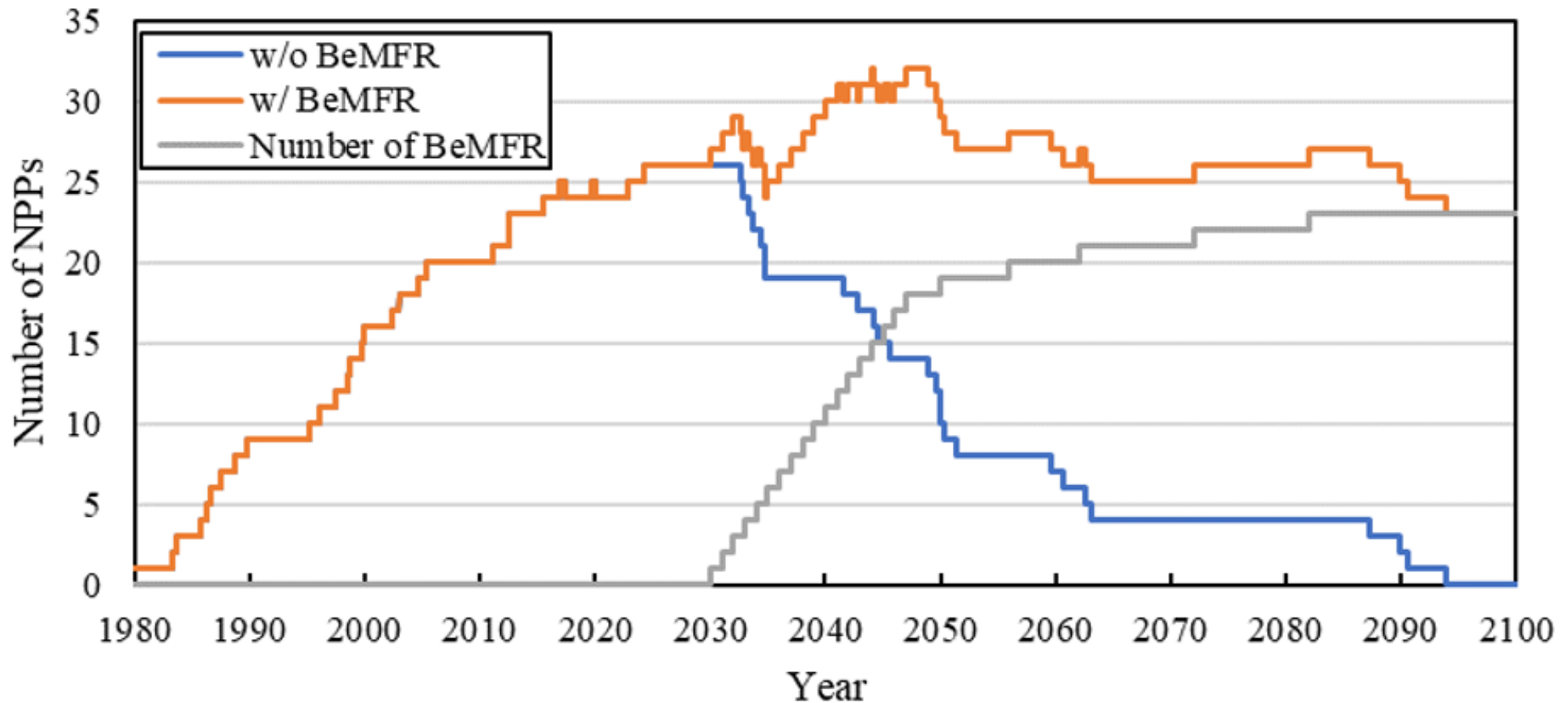
Verifying SNF Management Scenario

Assumptions

- The operational lifetime of existing NPPs:
 - 40 years divided by the capacity factor (except APR-1400)
 - 60 years divided by the capacity factor (APR-1400)
- No additional LWRs or HWRs are assumed to be constructed after 2025.
- SNF Requirements for one BeMFR construction (Reactor A):
 - U: 66.8 tons, TRU: 14.9 tons, RE: 7.5 tons
- BeMFR construction condition:
 - First construction: 2030
 - Before TRU depletion: BeMFRs are built annually.
 - After TRU depletion: A BeMFR is added whenever 15 tons of TRU generate from existing NPPs
- BeMFR operation condition:
 - Thermal power: 3,000 MWth
 - Thermal efficiency: 40 %
 - Capacity factor: 0.85
 - Operational lifetime: unlimited
 - The daily SNF consumption: 3.121 kg multiplied by CF

Verifying SNF Management Scenario

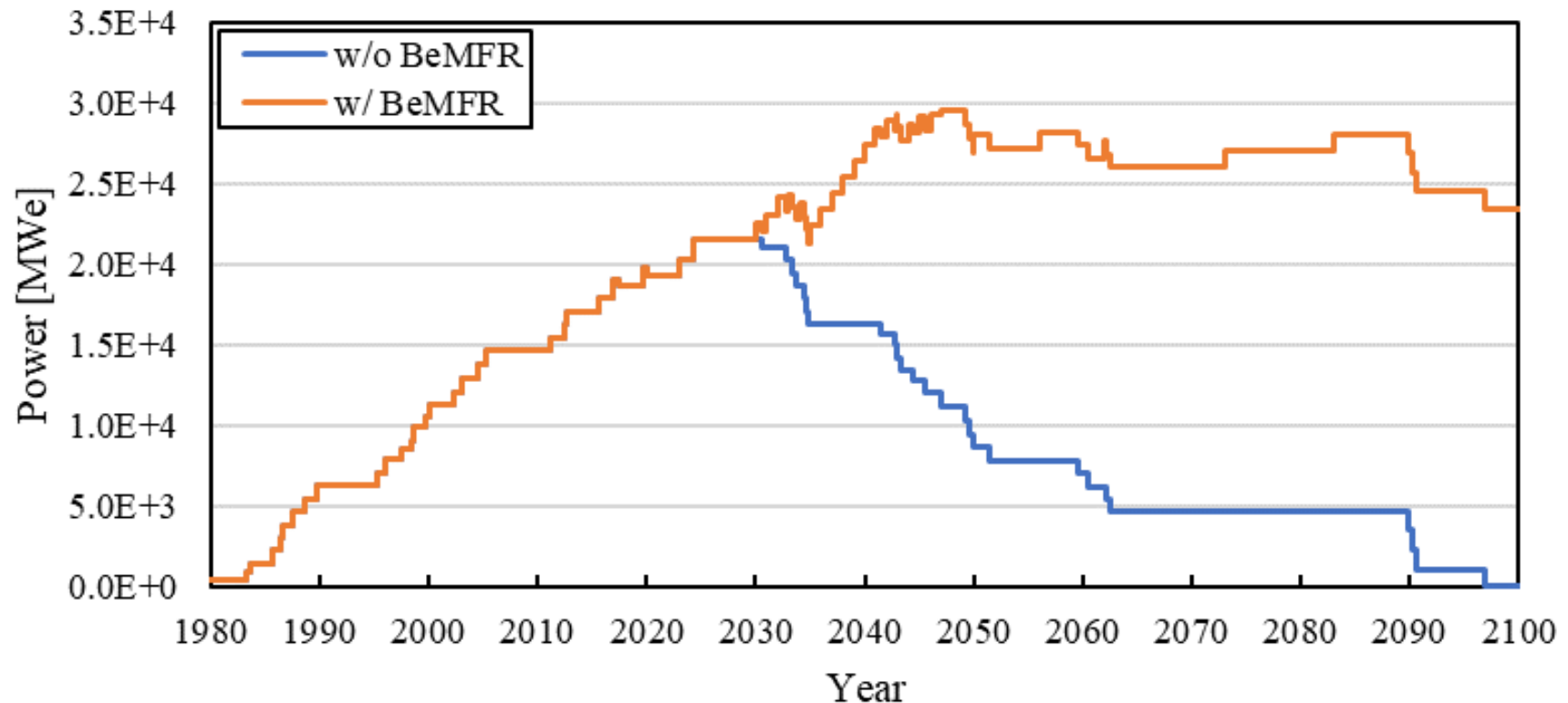
Total number of nuclear plants in the BeMFR scenarios



With no new PWR or CANDU and using only spent fuel, about 23 BeMFRs can be built by 2100.

Verifying SNF Management Scenario

Total nuclear plant thermal power in BeMFR scenarios



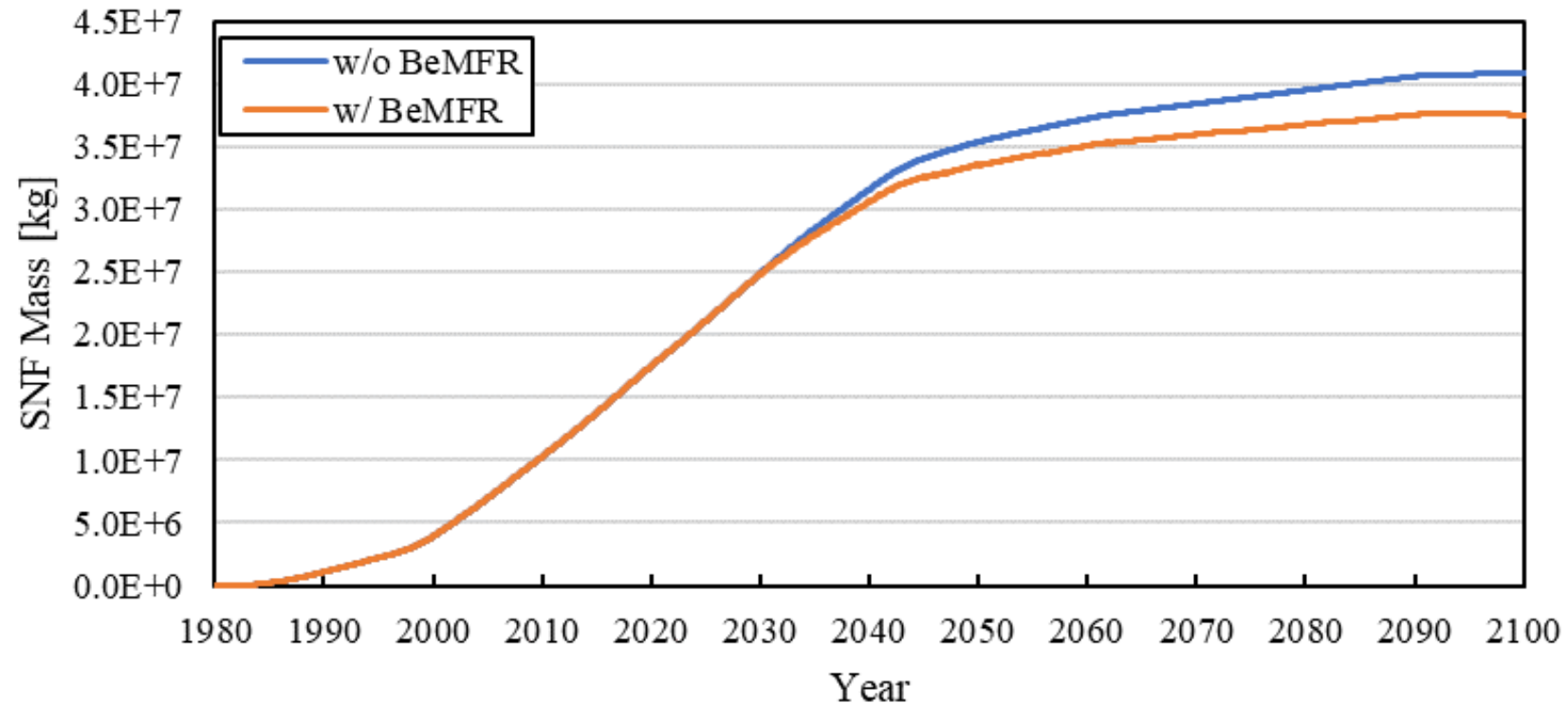
Late 2040s: coexistence of BeMFR, PWR, and CANDU yields up to 30,000 MWe.

All existing plants replaced by BeMFRs yield 23,000 MWe.

After 2050, additional plants such as BeMFRs fueled with HALEU can be required.

Verifying SNF Management Scenario

SNF accumulations in BeMFR scenarios



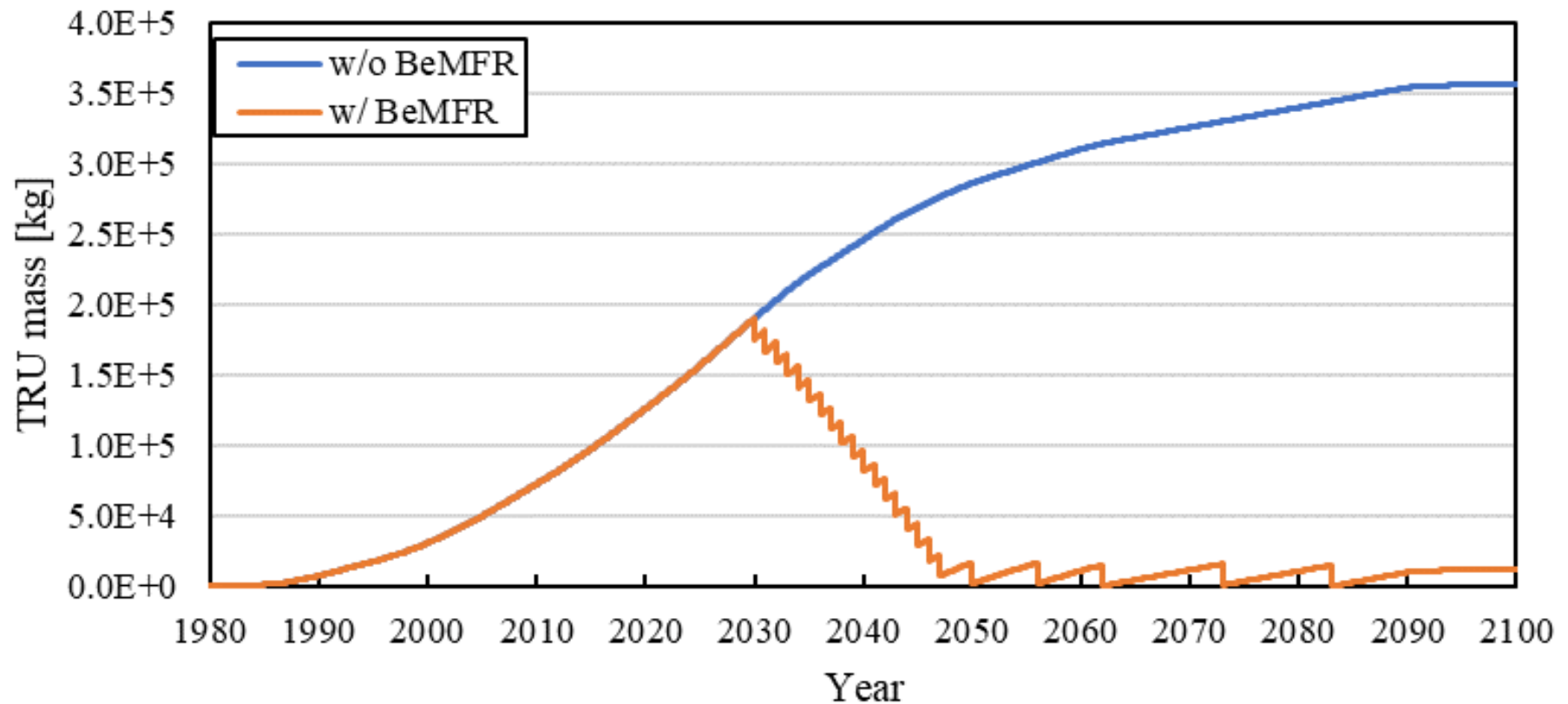
Even without additional PWR construction, a repository capable of storing twice the currently accumulated spent nuclear fuel is required.

The reduction of spent nuclear fuel begins in the 2090s, when the last PWR is retired.

Without new BeMFRs, spent fuel alone allows ~1,400 years of additional operation.

Verifying SNF Management Scenario

TRU accumulations in BeMFR scenarios



If one BeMFR is built each year starting in 2030, a total of 18 units can be constructed by 2047.

Construction intervals lengthen, stopping after five more units.

HALEU-fueled BeMFRs needed.

Contents

Introduction

Current Status of Nuclear Power Plants in Korea

BeMFR Sample

Verifying SNF Management Scenario

Conclusions

Conclusions

- BeMFRs' purpose: addressing key nuclear challenges: **sustainable fissile supply** and **SNF management**.
- Utilizing SNF as startup fuel enables a closed fuel cycle, reducing SNF accumulation.
 - However, that rely on the reducing number of existing nuclear power plants
- Initial deployment can rely on TRU from existing spent fuel; later expansion may use HALEU.
- **Accumulated SNF** alone could be used for nearly **unlimited operation**.
- Reduces the burden on spent fuel storage and contributes to sustainable nuclear power development.
- Further research is needed on fuel cycle optimization, long-term safety, economics, and integration with current infrastructure.

Contents

Introduction

Current Status of Nuclear Power Plants in Korea

BeMFR Sample

Verifying SNF Management Scenario

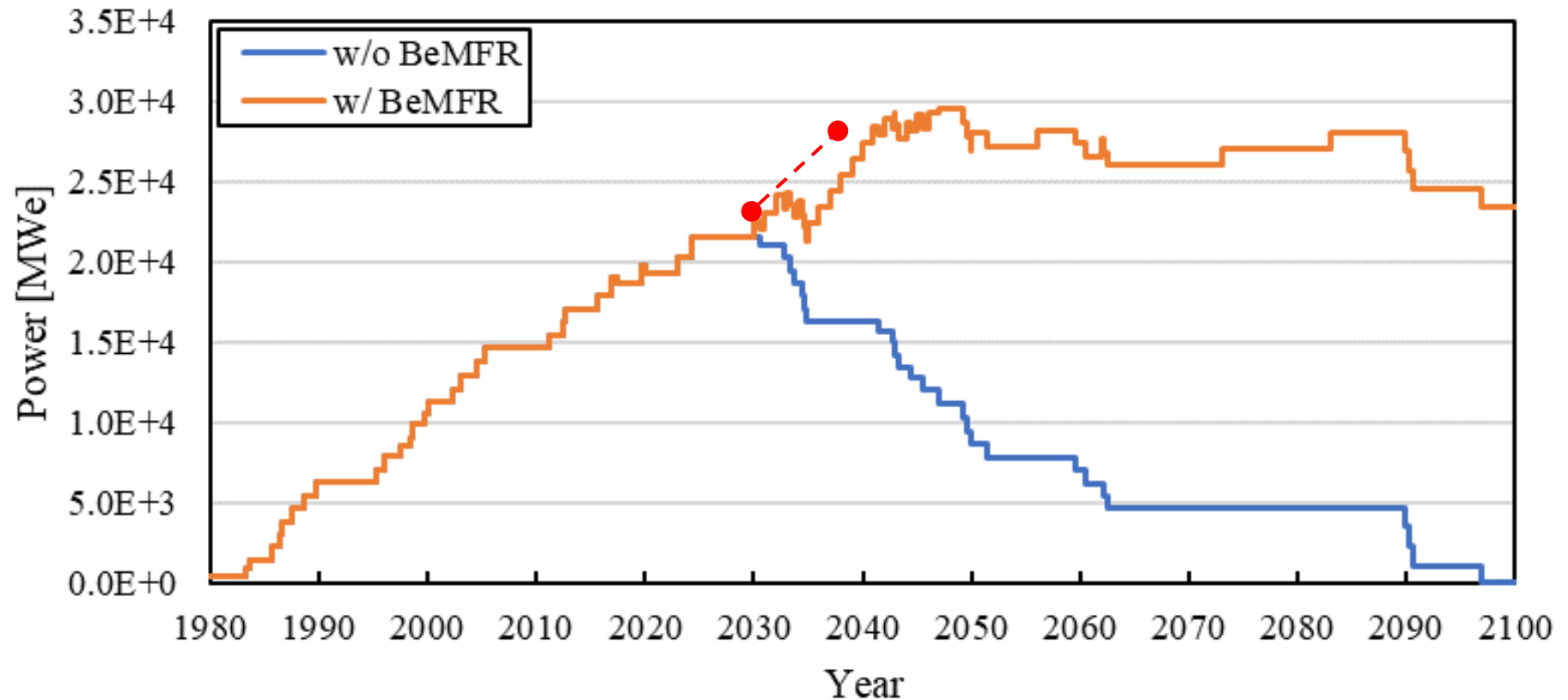
Conclusions

Backup Slides

Backup Slides

11th Electricity Supply and Demand Plan

Year	Nuclear share	Power production	Power
2030	31.8 %	204.2 TWh	23,295 MWe
2038	35.6 %	249.7 TWh	28,485 MWe



Backup Slides

Spent fuel composition

- From the depletion calculation of APR1400 lattice by Serpent 2.1
- Burnup: 50,000 MWd/MTU, Cooling period: 10 years

