Recent Irradiation Trends of Materials R&D (2020~2025)

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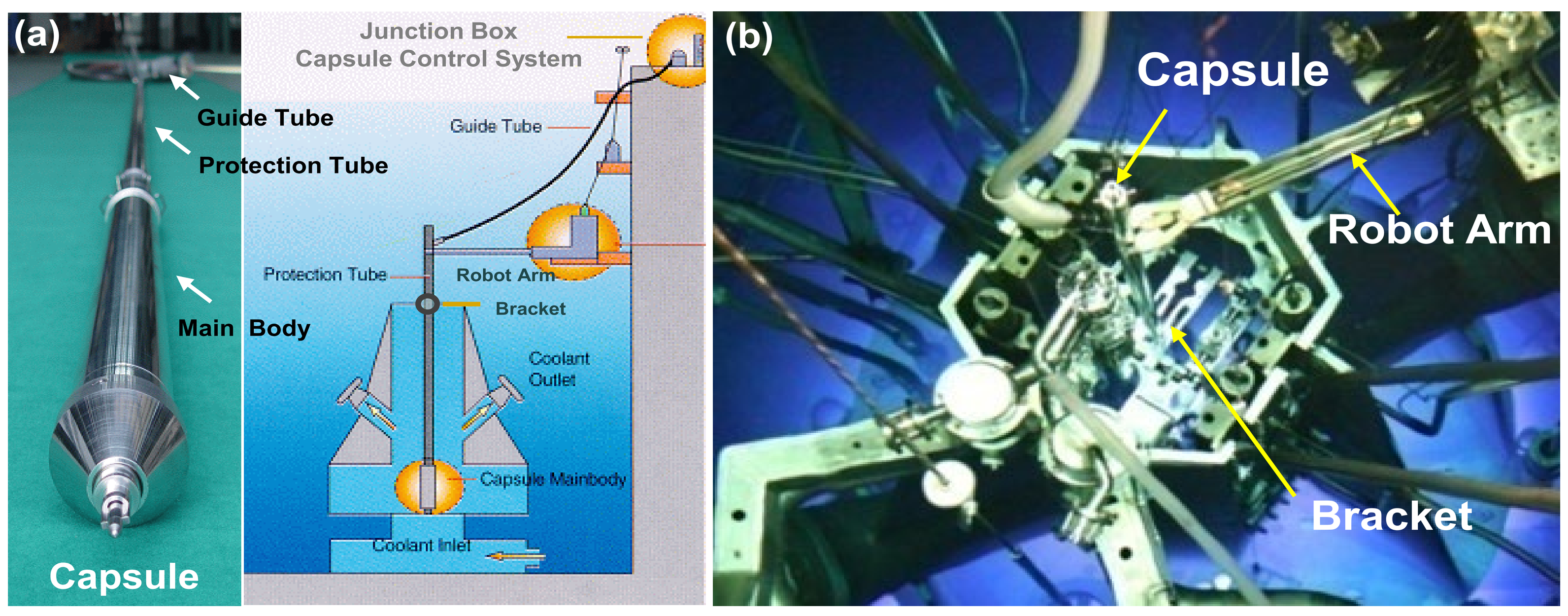
◆ Introduction

- ✓ As worldwide old research reactors have been shut down and new facility programs have been delayed, effective utilization HANARO becomes more important at these days.
- ✓ As Gijang research reactor is due to start up in 2027, HANARO will specialize more on irradiation research of nuclear fuels and materials. Recent irradiation trends of material R&D at the worldwide RRs will be valuable to the future planning of HANARO.

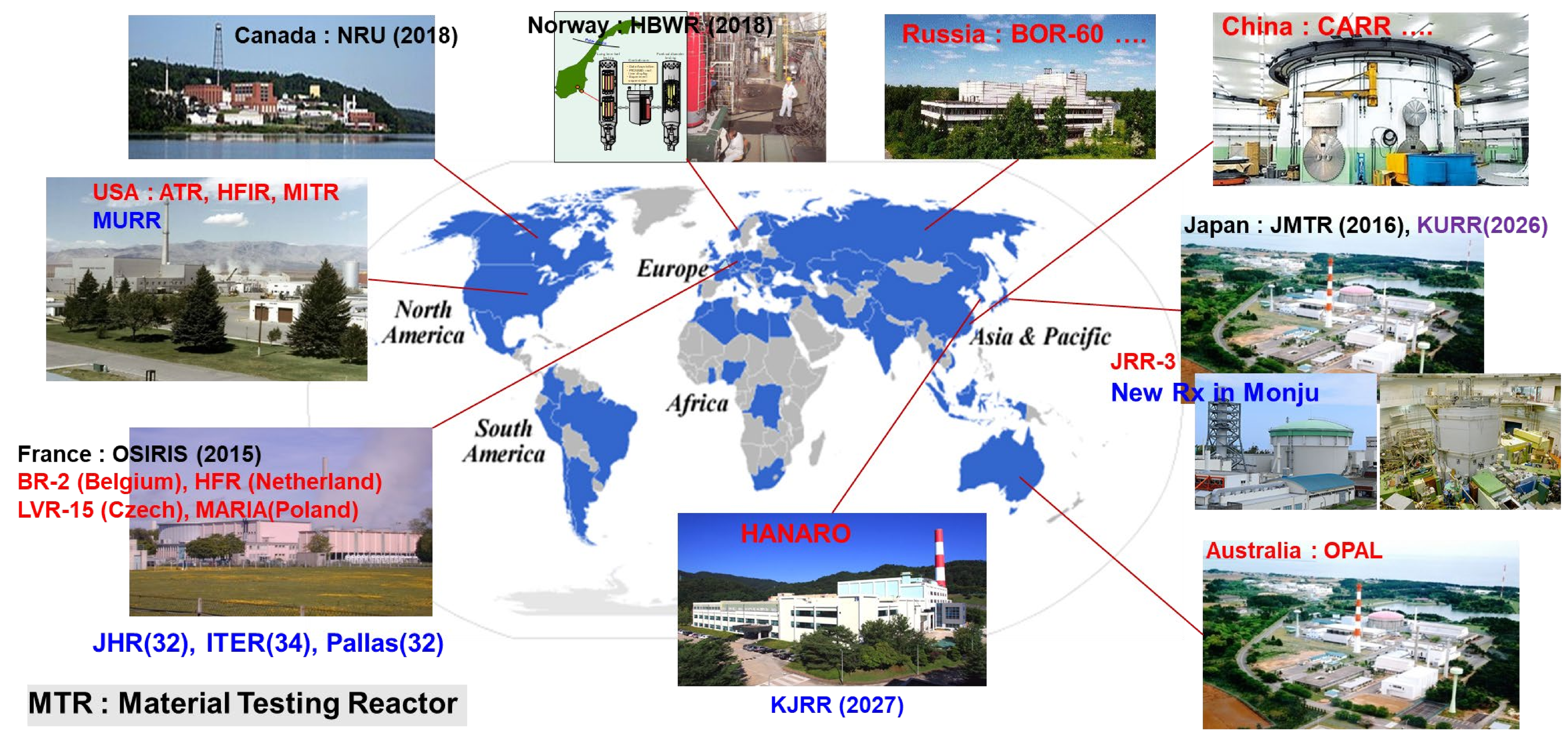
◆ HANARO Irradiation Capsule Systems



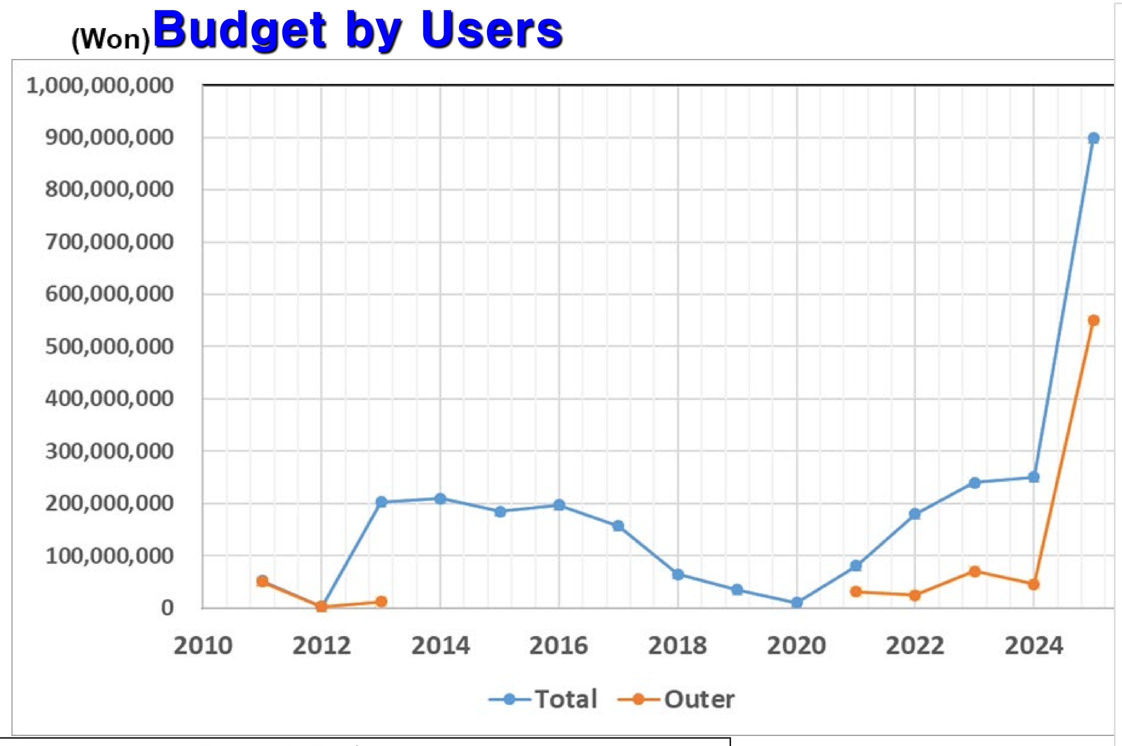
1) Status of RRs & Trends of Materials R&D

1) Research Reactors : Old facilities used by the material R&D programs have been shut down (OSIRIS, JMTR, NRU, HBWR). And new facility programs (ITER, JHR, NRR) have been delayed. Therefore, effective utilization of the existing RRs becomes more important at these days.
2) HANARO : The user request is increasing sharply from 2025 due to the shut-down of the old research reactors, recent global crisis, and active response to the user requirements.
3) Materials R&D Trends : HANARO is recommended to extend its limited utilization (concentrated to fission reactor researches) up to the future reactors including fusion reactor and non-nuclear advanced materials.

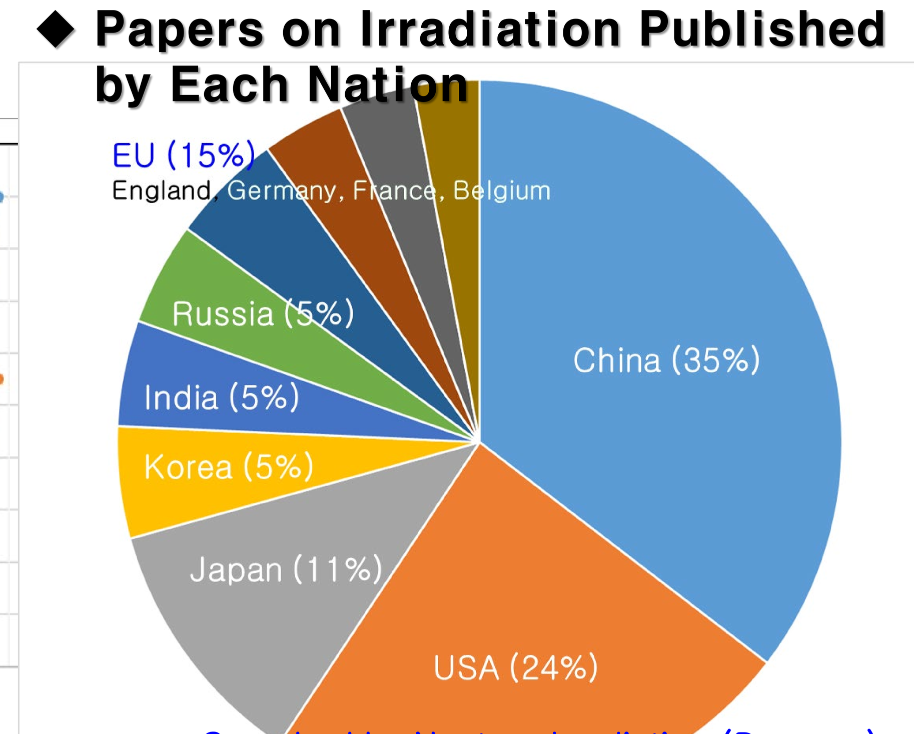
◆ Worldwide Research Reactors



◆ Trend of HANARO Annual Irradiation Budget by Users



◆ Papers on Irradiation Published by Each Nation



Searched by Neutron Irradiation (Damage) (Science Direct)

(Irradiation Research Topics of Major Nuclear Countries)

Nation	Facility	Research Topics
China	Computer Simulation	- He/neutron damage
		- High entropy alloy (HEA), GaN, SiO2/4H-SiC swelling with MD
		- W defects with MC method
		- Dislocation dynamics (DD)
		- Zr-Nb, SS, SiO2, TCAD simulation
	CSNS	- Single event burnout (SEB) in SiC power MOSFETs
		- S/Dram, High-voltage semiconductor devices (thyristors)
		- Neutron-sensitive microchannel plate (nMCP) for neutron imaging
		- InGaAs p-i-n photodetectors
		- Charge coupled detectors (CCDs)
	CARR	- Irradiation test of fuels and materials, NTD
		- Tritium breeder for ITER & nuclear detectors
	Others	- Be/W/high-entropy alloy/ceramic(HEA/HEC)/ODS for Fusion, MSR
		- Fe/RPV/SS/W/Zr-Nb/Ti/G, SiC/AlN, SiC/C fiber for Nuclear App.
		- PIN diode, 4H-SiC junction barrier Schottky (JBS) diodes in CFBR-II
		- Si/SiC heterojunction detector for Space, RTG, Spintronics
		- 3C/6H-SiC, GaN, BN, ZnO, YBCO conductor, Graphene, Solar cells
		- Diamond/SiPMs/CZT/CMOS Detectors, SPND, Magnet
		- Mo-S-Pb-Ti amorphous films: lubricating materials, Resin/BN
		- $Ge_2Sb_2Te_5$ (GST) memory and data storage technologies
		- Piezoelectric surface acoustic wave (SAW) extreme sensor
		- Alumina/TiAlN Coating, Annealing, Welding, Defect Eng.
		- Al, T extraction in CMRR
		- Plasma-facing material (PFM) in IFMIF
USA	Computer Simulation	- RPV for Life extension, GB segregation
		- Fe/WB/Be by DFT/MD calculations for Fusion
		- Ni-Inconel/Incoloy Heterostructures by MD
	ATR	- Alloy625/690, FeCrAl/ODS ATF cladding, SS316, T91, Zircaloy-2
		- ZrB2 ultra-high temperature ceramic(UHTC), WB for Fusion
		- Graphite for HTR/Annealing, PM-HIP alloys
		- U-Mo/U-Zr/TRISO fuel
	HFIR	- Inconel718/FeCr(Al)/SS304/Ti-MAX, Annealing, Welding Repair
		- SiC ATF cladding, Al-6061, Duplex SS
		- W/Eurofer for Fusion, G/Ta/UPS for advanced NRs
		- Al_2O_3 extreme sensor, silica optical fibers
	MITR	- ZrH_2 Metal hydrides for SMRs
		- T behavior in Fluoride molten salt
		- Corrosion of SiC
	Others	- RPV, HEA, Zry-4 in WSUR, I718, SS 347/304, T91/HT9 in BOR-60
		- Fe-Cr, FeCrAl ATF cladding, Zr-Nb, HEC, U-Si/MOX fuel
		- W/Lithium silicates, T/Li transport for Fusion
		- ABN(Lightweight mat.) for Space, Local chemical ordering (LCO)
		- Dosimeter, SPND, scintillator, Semiconductor Detectors
		- Laser-based inertial fusion energy (IFE) reactor
		- GaN, GaAs, SiC, graphene, AlN, NAND flash in MURR
		- Silica and Sapphire fibers
		- Molten chloride salt in Ohio State University RR (OSURR)

Nation	Facility	Research Topics
EU	JHR (France)	- ITER : Under Construction by 2034
		- JHR : Under Construction by 2032
	BR2 (Belgium)	- RPV, VVER RPV
		- Development of Advanced Technology Fuel claddings
		- Materials for Fusion, SMRs, GEN 3+ and GEN 4
		- W, RAFM steel, CuCrZr for Fusion
	HFR (Netherlands)	- HTR fuel, AGR C creep
		- Molten fluoride salt for MSR
		- W, Be/TiBe for Fusion
	LVR-2 (Czech)	- Concrete, SS, F/M(RAFM) steel
		- Pb-Li, Be fatigue for Fusion
		- U Oxide/U-Si fuel
		- YBCO and GdBCO/Ag superconductors
	MARIA (Poland)	- Graphene on 4H-SiC Detector
		- Poly-ethylene gasket for space
Japan	JRR-3	- Fuel/materials of light water/fast breeder/Fusion reactors
		- RPV steel for APWR
	KUR	- Tritium release behavior of Li_2TiO_3/Li_4SiO_4 for Fusion
		- FLiNaBe blanket material for Fusion
		- Optical lenses of ZnSe and ZnS for Fusion
		- Fe-Cu in RPV
	Others	- FeCrAl ODS steel/W for future fission/Fusion reactors (in JOYO)
		- Be/V/W/F82H steel, Cu oxide/Nb3Sn superconductors for Fusion
		- Fluoride molten salts such as FLiBe and FLiNaBe for Fusion
		- HEA, SiC, Oxies for APWR/Fusion
		- RPV/Recovery, 316SS, Concrete, Zr-Nb, Ti-6Al-4V alloy in MARIA
		- Zr-based/SiC cladding in HRP
		- TRISO fuel/ZrC coating for HTGR in WWR-K reactor
		- BGaN, AlN, Si-IGBT, InGaP solar cell for Detector
		- Thermoluminescence (TL) materials in KINKI reactor
		- Ti-$LiGaO_2$/Eu-doped LiBr scintillator
		- Photoluminescence Er_2O_3, Diamond sensor
		- Graphite for HPHT Condition

(HANARO Irradiation Requested by Users)

Year	Date	User	Title	Amount (Won)	Total
2020	09-14	Inner	High Density U-Mo Target (1)	10,000,000	
2020					10,000,000
2021	07-12	Inner	High Density U-Mo Target (2)	50,000,000	
2021	09-30	Outer	Co SPND (USERS Co. (1))	18,000,000	
2021	09-29	Outer	Co SPND (UJIN Co.)	13,000,000	
2021					81,000,000
2022	03-08	Inner	Neutron Absorber (1)	50,000,000	
2022	10-06	Inner	Neutron Absorber (2)	55,000,000	
2022	10-07	Inner	Accident Resistant Nuclear Fuel (1)	50,000,000	
2022	10-05	Outer	Co SPND (USERS Co. (2))	25,000,000	
2022					180,000,000
2023	05-24	Inner	Accident Resistant Nuclear Fuel (2)	50,000,000	
2023	09-22	Inner	Thermal Embrittlement Resistant Stainless Steels (1)	70,000,000	
2023	11-29	Inner	i-SMR Fuels/Materials (1)	50,000,000	
2023	10-12	Outer	Thermal Embrittlement Resistant S/Steels (UNIST)	70,000,000	
2023					240,000,000
2024	06-27	Inner	Accident Resistant Nuclear Fuel (3)	50,000,000	
2024	07-23	Inner	Thermal Embrittlement Resistant Stainless Steels (2)	50,000,000	
2024	08-26	Outer	i-SMR Fuels/Materials (UNIST)	45,454,550	
2024	10-21	Inner	Low-Alloy Steels, Electron Beam Welded (1)	55,000,000	
2024	11-22	Inner	SMR Austenitic Structural Materials (1)	50,000,000	
2024					250,454,550
2025	01-02	Outer	i-SMR Burnable Absorber Candidate Materials (KNF)	550,000,000	
2025	04-29	Inner	SPND Burn-up Performance/Safety	6,000,000	
2025	05-09	Inner	Thermal Embrittlement Resistant Stainless Steels (3)	40,000,000	
2025	07-22	Inner	Accident Resistant Nuclear Fuel (4)	50,000,000	
2025	07-25	Inner	LEU+/ATF Nuclear Fuel (1)	80,000,000	
2025	10-23	Inner	SPND for i-SMR	8,000,000	
2025	11-24	Inner	Fission Moly (FM) Mini Target	72,600,000	
2025	12-12	Inner	Spent Fuel Dry Storage Cask	38,800,000	
2025	12-16	Inner	i-SMR RPV (2)	53,000,000	
2025					898,400,000
2026	1-06	Outer	i-SMR Burnable Poison material (KNF)	924,000,000	

◆ Conclusion

- ✓ Considering the several construction delays of large-scale test facilities such as ITER and JHR, in addition to the new constructions of multi-purpose reactor (MPR) in China, Japan, and Korea, MPR seems to be a major research reactor model. HANARO is the best example of the MPR.
- ✓ The utilization of HANARO is increasing sharply due to worldwide shut-down of old research reactors, global crisis, and active response to the user requirements.
- ✓ HANARO seems to have about 7 years before the start-up of the new large-scale test facilities. During that times it should secure its original utilization plan including a role relocation due to the start-up of new Gijang research reactor.
- ✓ HANARO is recommended to extend its limited utilization (concentrated to fission reactor researches) up to the future reactors including fusion reactor and non-nuclear advanced materials. And it seems to be necessary to cooperate with foreign users, especially with Japanese users using other foreign reactors.