30th IAEA Fusion Energy Conference (FEC2025)
13-18 October, 2025, Chengdu, People's Republic of China

Experimental Study on Tritium Release from Li_2TiO_3 Pebbles as Tritium Breeder through International Collaboration between Korea and China

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한국핵융합에너지연구원
KOREA INSTITUTE OF FUSION ENERGY

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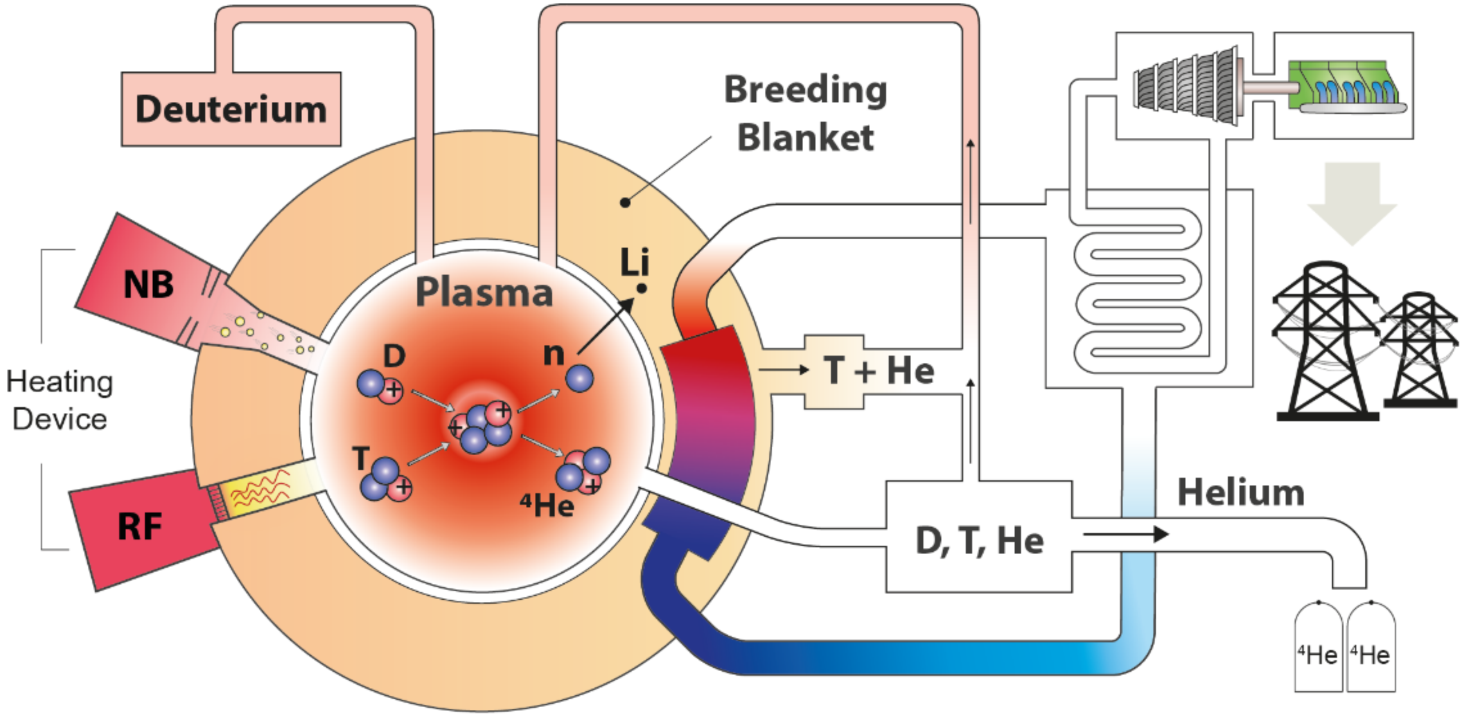
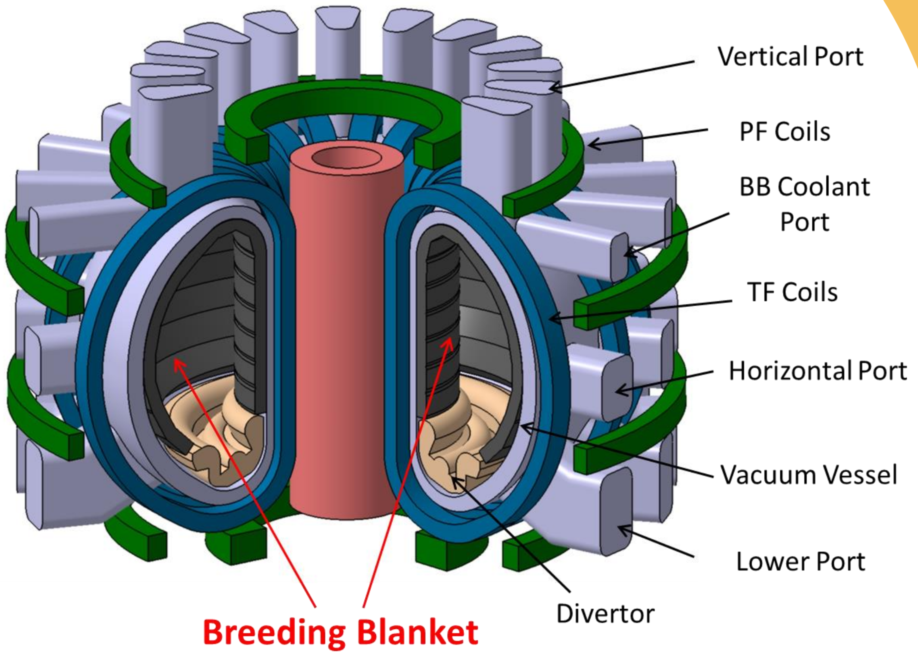
Background

Concept of Fusion Power Plant and Breeding Blanket





- in Fusion Core :

  D + **T** → 4 He + **n** + 17.6 MeV

- in Breeding Blanket :

  ^{6}Li + **n** → ^{4}He + **T** + 4.8 MeV

  ^{7}Li + n → ^{4}He + T + n' – 2.5 MeV

  ^{9}Be + n → ^{8}Be + 2n – 2.5 MeV

- Functions of Breeding Blanket
  - **Tritium Breeding** to ensure fuel self-sufficiency
  - **Heat Conversion and Extraction** for electricity generation
  - Neutron and Gamma-ray **Shielding**

Korean Breeding Blanket Concepts and Materials

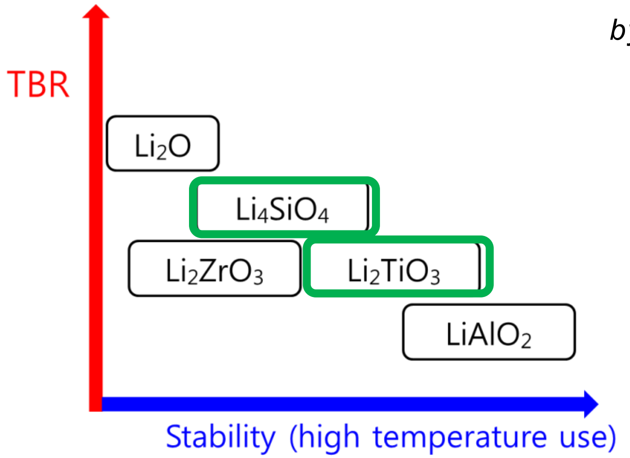
Parameters	HCCR ITER TBM	HCCP ITER TBM	HCCR DEMO	HCCP DEMO
FW Heat Flux	0.3 MW/m^2	0.3 MW/m^2	0.5 MW/m^2	0.5 MW/m^2
Neutron Wall Loading	0.78 MW/m^2	0.78 MW/m^2	1.5 MW/m^2	1.5 MW/m^2
Armor Material (Plasma Facing)	n/a	n/a	Tungsten	Tungsten
Structural Material	RAFM (ARAA)	RAFM (Eurofer/ARAA)	RAFM (ARAA)	RAFM (ARAA)
Tritium Breeder Material	Li_2TiO_3	Li_4SiO_4/Li_2TiO_3	Li_2TiO_3	Li_4SiO_4/Li_2TiO_3
Neutron Multiplier Material	Be	Be	Beryllide	Beryllide
Reflector Material	Graphite	n/a	Graphite	n/a
Max. dpa (Lifetime of blanket)	3	3	20 / 50	20 / 50
Primary Coolant	Helium	Helium	Helium	Helium
Coolant Inlet/Outlet Temperature	300/500 ^oC	300/500 ^oC	300/500 ^oC	300/500 ^oC
Coolant Pressure	8 MPa	8 MPa	8 MPa	8 MPa
Purge Gas	He with 0.1% H_2	He with 0.1% H_2	He with 0.1% H_2	He with 0.1% H_2
Enrichment (^6Li)	70%	70%	90%	90%

Tritium Breeder Ceramics

Candidates of Solid-type Tritium Breeders

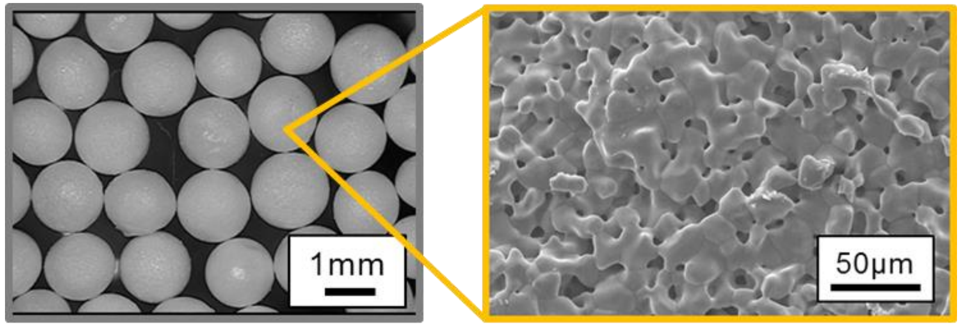
	Li_2O	Li_2AlO_2	Li_2ZrO_3	Li_4SiO_4	Li_2TiO_3
Li Vaporization (in additional H_2)	> 600˚C	> 900˚C	> 800˚C	> 700˚C	> 800˚C
Long period use (2 years)	Instability (Li vaporization)	Stability	Instability (crack)	Instability (Li vaporization)	Instability (Reduction of Ti)
Tritium release (easy release)	> 400˚C	> 400˚C	> 400˚C	> 350˚C	> 300˚C
Optimum operating temp.	400 - 600 ˚C	400 - 900˚C	400 - 800˚C	350 - 700˚C	300 - 800˚C
Tritium breeding ratio (TBR)	High	Lower	Middle	Middle	Middle
Thermal conductivity	High	Middle	Middle	Middle	Middle

by Dr. Hoshino, CBBI-16, 2011



Shape of Tritium Breeder Ceramics : **Pebble**

- Stress Distribution
- Packing Behavior
- Thermal Conductance
- Purge Gas Flow
- …



(Li_2TiO_3 Pebbles)

by Y.-H.Park et al, JNM 455 (2014), 106

02

Manufacturing of Tritium Breeder Pebbles

Manufacturing Process for Ceramic Materials (using Sintering)

Mixing

Shaping

Sintering

Manufacturing Process for Ceramic Pebble (using Sintering)

Mixing

- Raw Powder (Li_2TiO_3, Li_4SiO_4, Li-M-O, et. al.)
- Binder Materials
- Solvent

Shaping

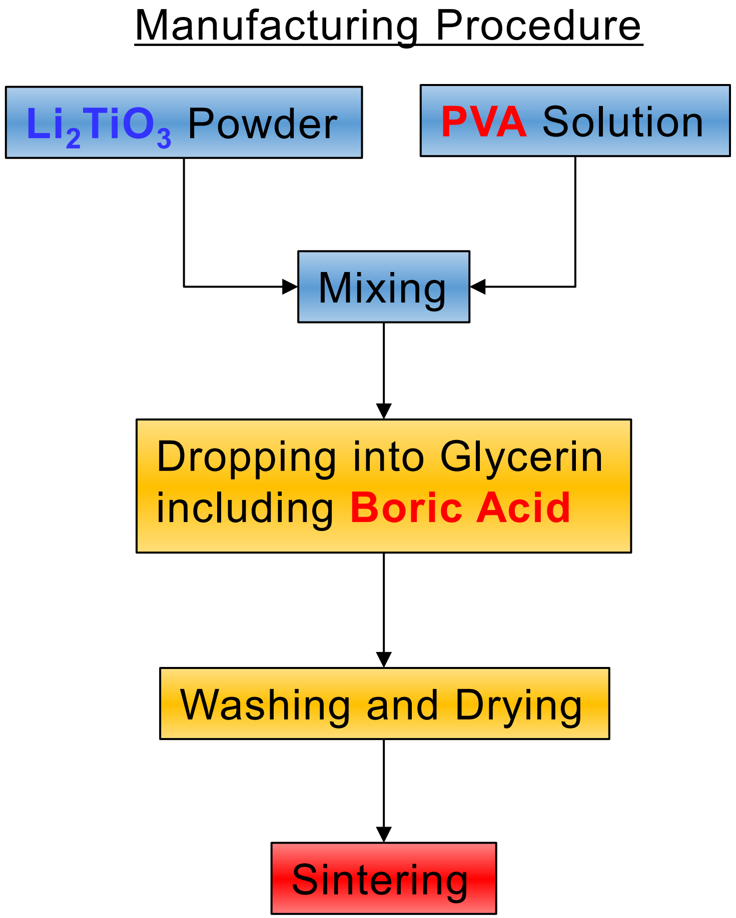
- Wetting Process (Dropping, Emulsion, …)
- Drying Process (PIM, CM, 3D Printing, …)

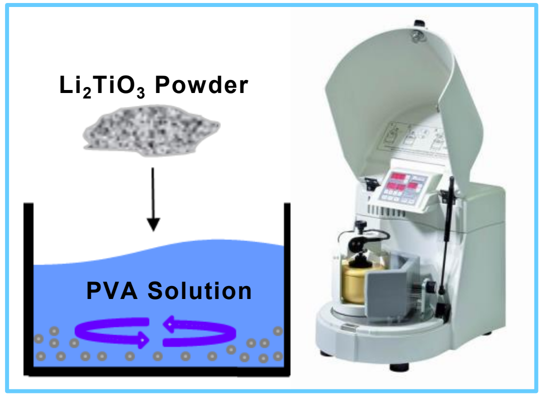
Sintering

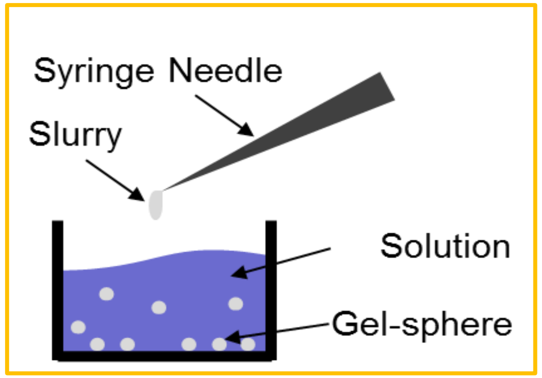
- Temperature
- Time
- Atmosphere

Development of Manufacturing Process for Li_2TiO_3 Pebbles

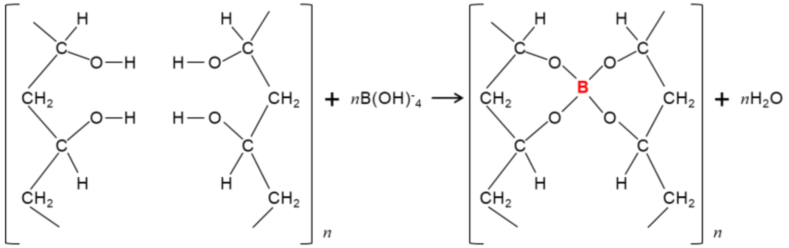
- **Slurry Droplet Wetting Method** based on the Cross-linking Reaction between PVA and Boric Acid





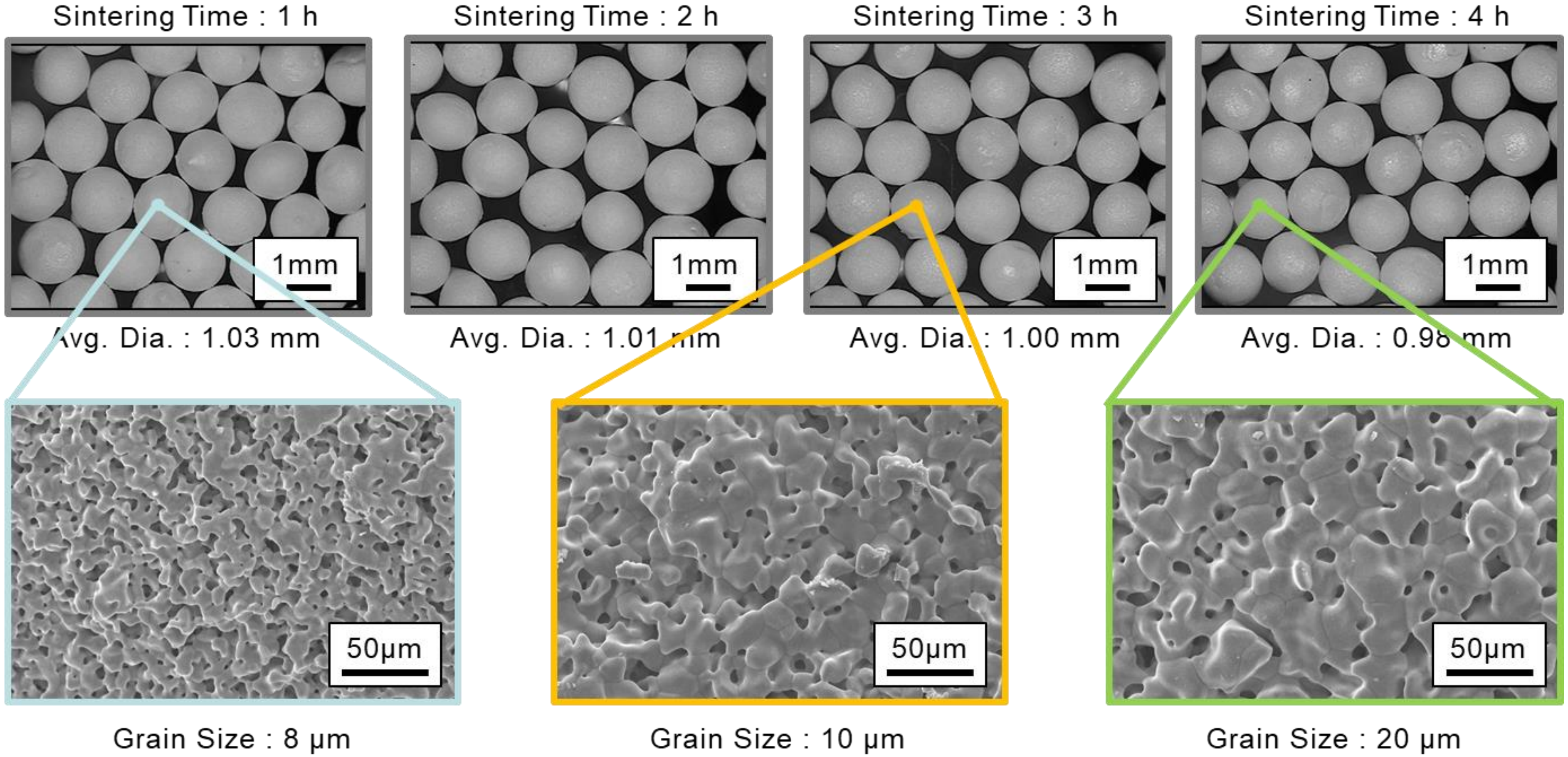


Cross-linking Reaction :



Parametric Study on Sintering Conditions for Li_2TiO_3 Pebbles

- Effect of Sintering Time (1200 ^oC, Air atmosphere)



- Grain size was increased with increasing sintering time.
- The whole pore of the sintered pebble was open type.
- The open porosity was about 10 %. (Sintering Time : 3 h)

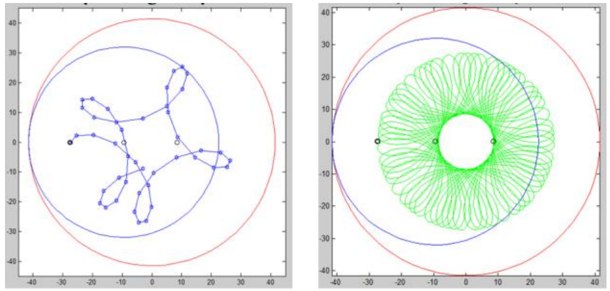
Mass-production System for Slurry Droplet Wetting Method

- Automatic Slurry Dispensing System

Dispensing Unit

; for instillation of

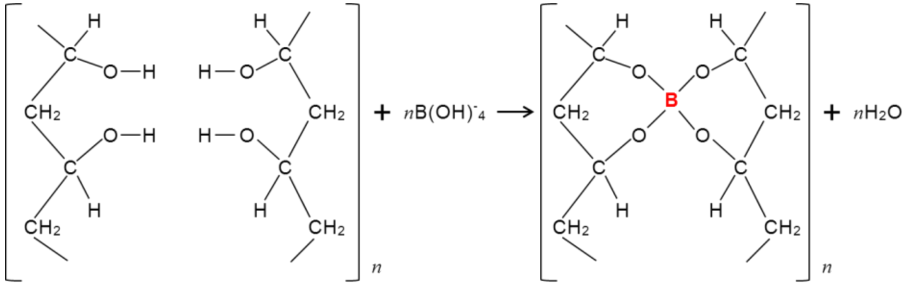
Li_2TiO_3 slurry

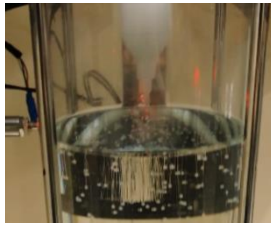


Trace of Drop Point through the Moving Needle

Glycerin Bath

; for hardening of droplets





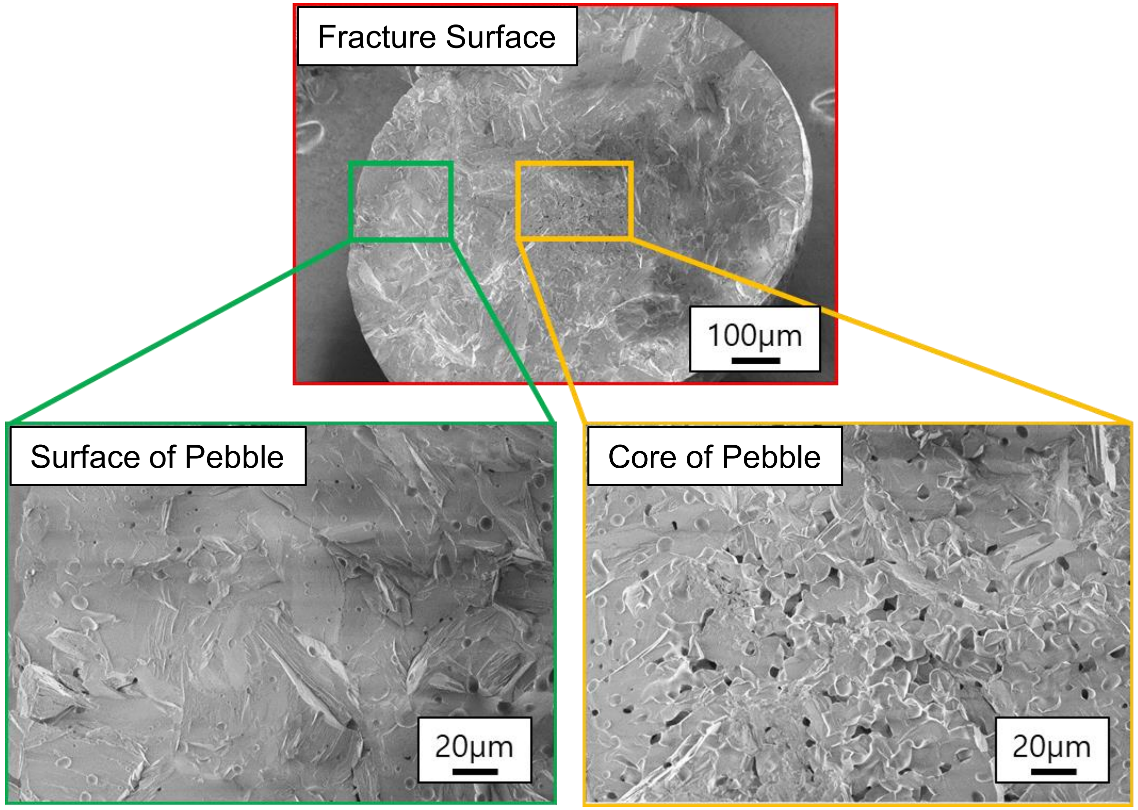
Automatic maintaining Unit

; for constant distance between

syringe needle and glycerin surface

Shortcoming of Droplet Wetting Method for Mass-production

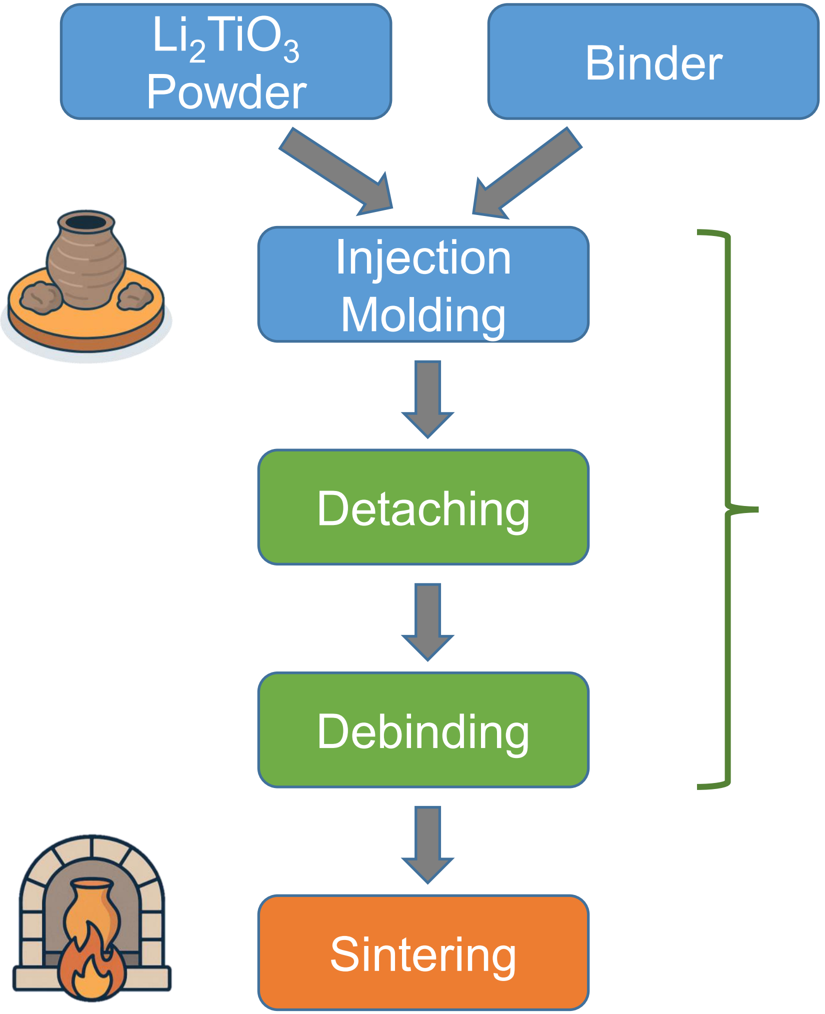
- **Non-uniform Microstructure** in Sintered Pebbles caused by Changing Concentration of Boric Acid
  - Decrease in the concentration of boric acid due to its consumption in the cross-linking reaction
  - Difference in hardening speed between the surface and the core of the droplets

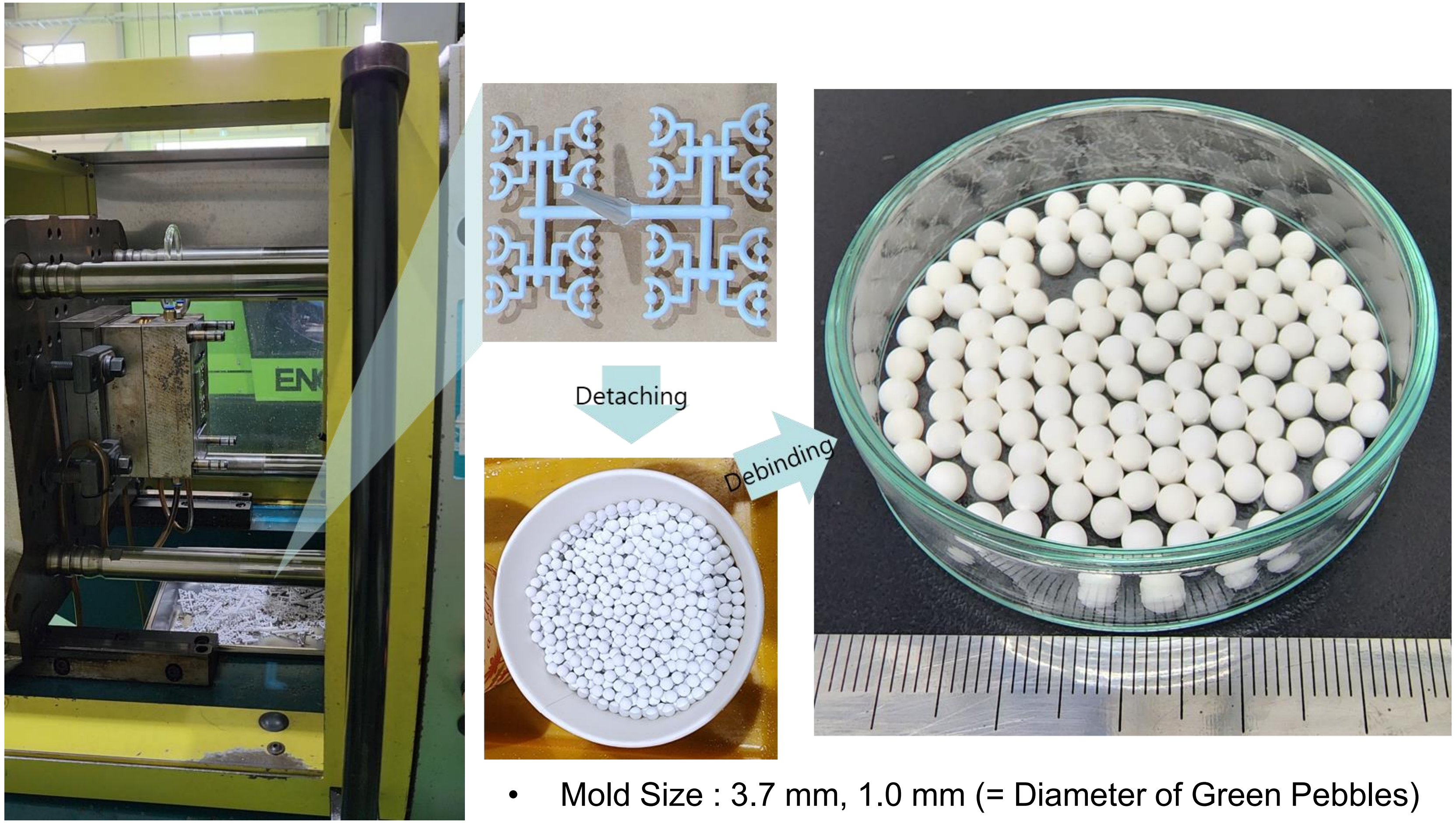


[Microstructure of Sintered Li_2TiO_3 Pebble after Crush Test]

Development of Manufacturing Process for Li_2TiO_3 Pebbles

- Li_2TiO_3 pebbles have been successfully manufactured using **Powder Injection Molding (PIM) process**

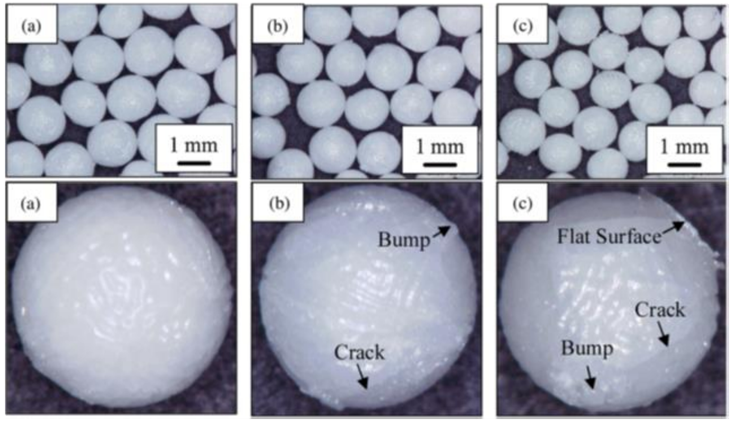




- Mold Size : 3.7 mm, 1.0 mm (= Diameter of Green Pebbles)
- Amount of Binder : 48 %
- Debinding Conditions : 800 ^oC, 1 h

Improvement of Sintering Process for Mass-production

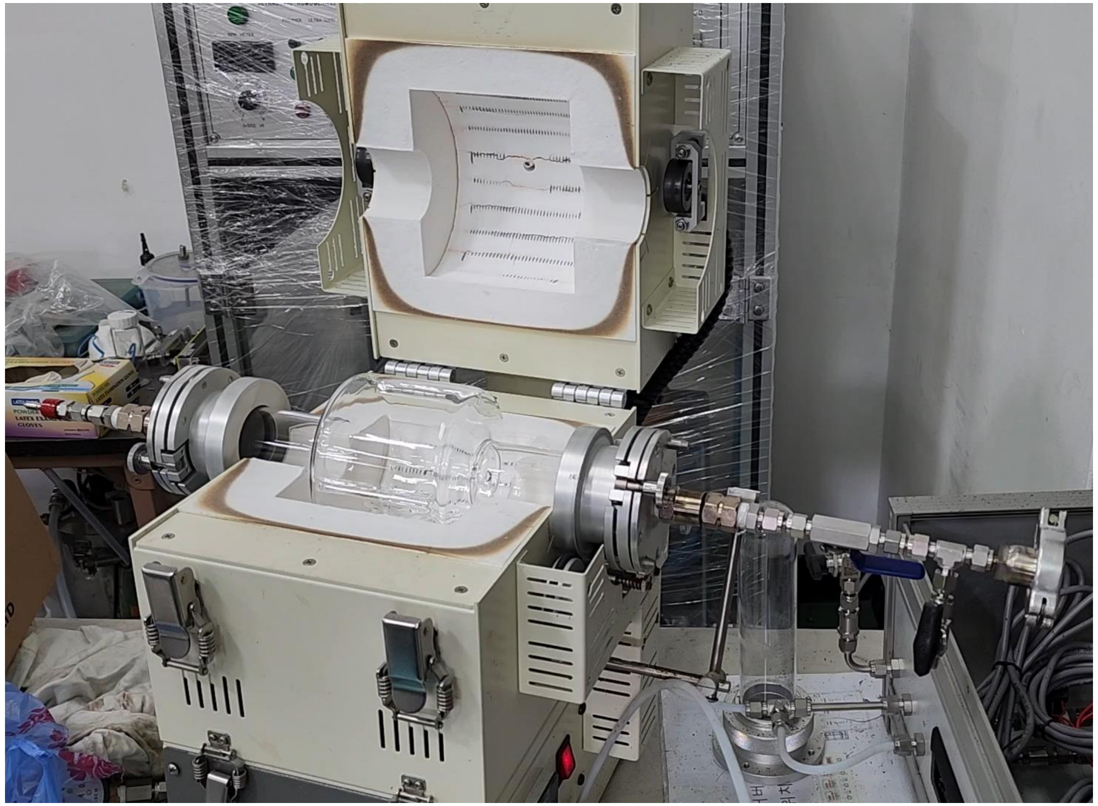
- **Formation of Defects** caused by Batch Process
  - Sintering between the contacted neighboring pebbles
    → Crack, Bump, Flatted Spot, and so on.



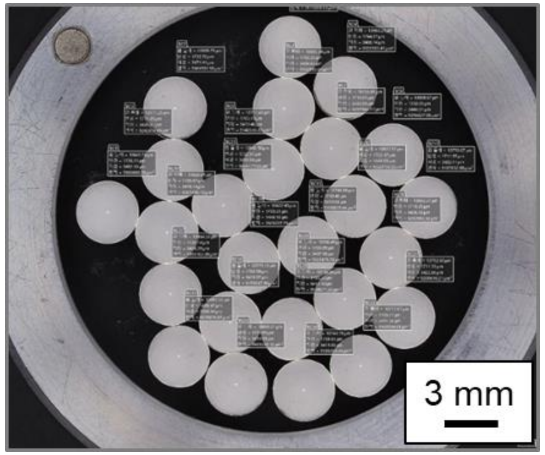
by Y.-H.Park et al, FED 109-111 (2016), 443

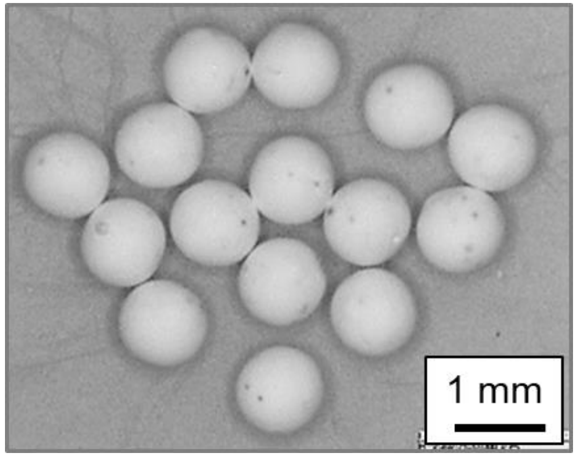
Improvement

- **Rotating Sintering System** was adopted to prevent the sintering between neighboring pebbles in the crucible.

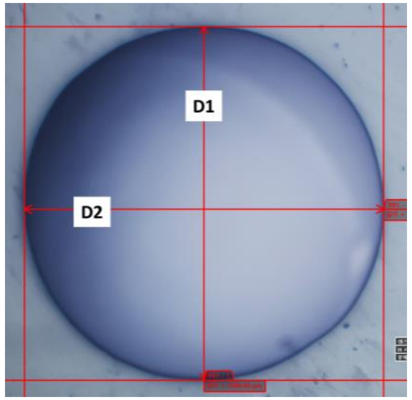


Morphology of Li_2TiO_3 Pebbles manufactured using PIM Process





Sphericity = D1 / D2, (D1 > D2)

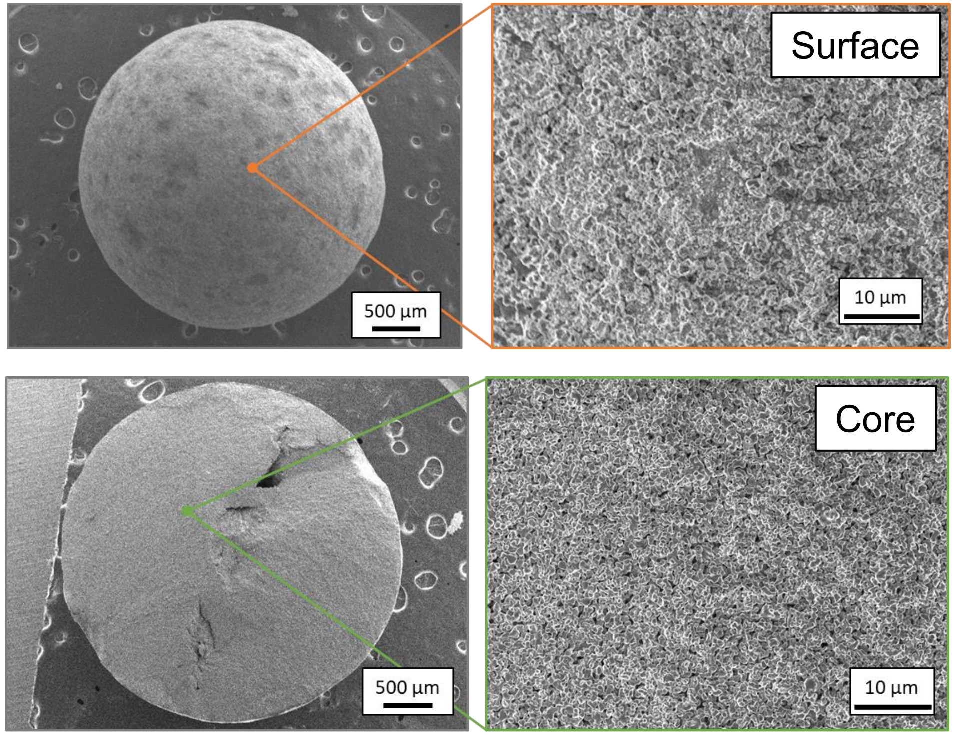


Value	Item	Value
3.70 mm	Mold Size	1.00 mm
3.43 mm	Average Diameter	0.96 mm
< 1.01	Average Sphericity	< 1.01
16 %	Volume Shrinkage Ratio	15 %

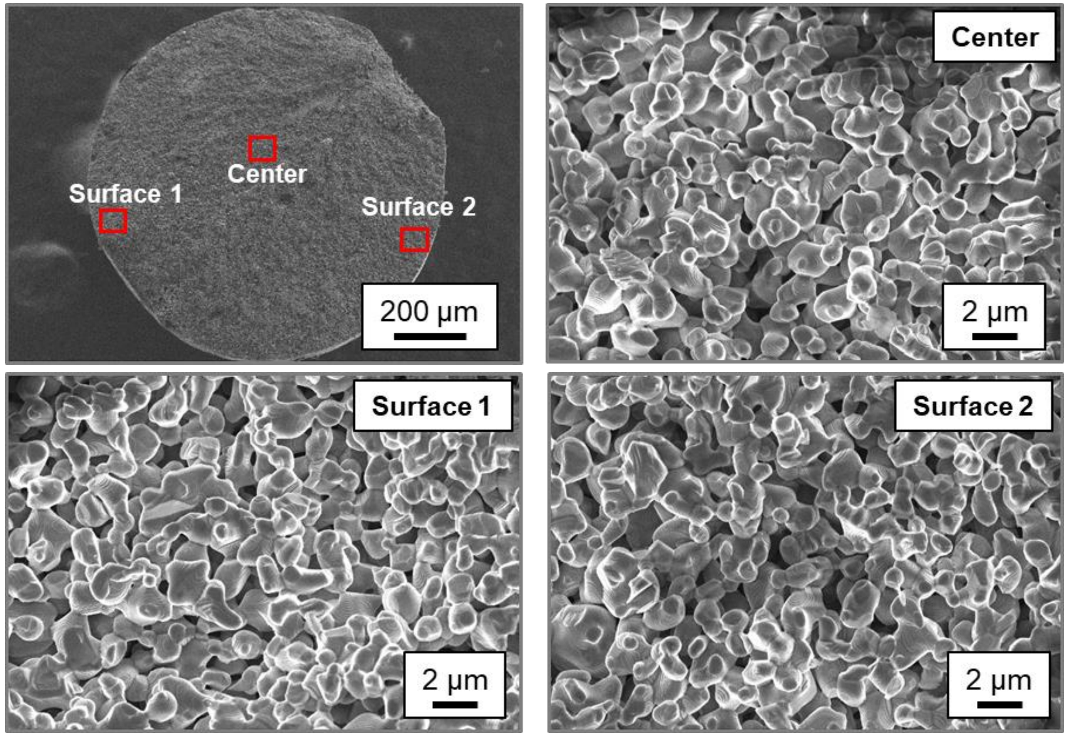
- Combined pebbles were not observed due to the pebble moving in the rotating tube during sintering process.
  - Defects (crack, bump, flatted surface, and so on) were not formed at the surface of sintered pebbles.
- The shrinkage ratio can be used as a parameter to design the mold in order to control the pebble diameter.

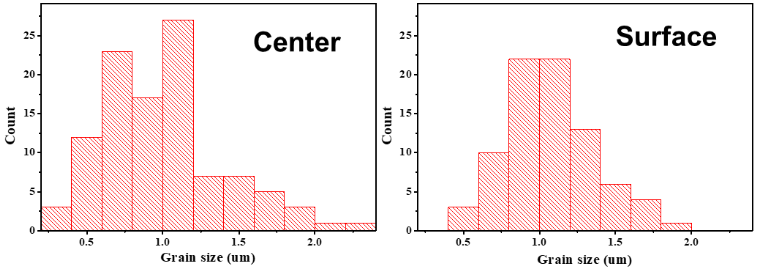
Microstructure of Li_2TiO_3 Pebbles manufactured by PIM Process

Diameter : 3.43 mm

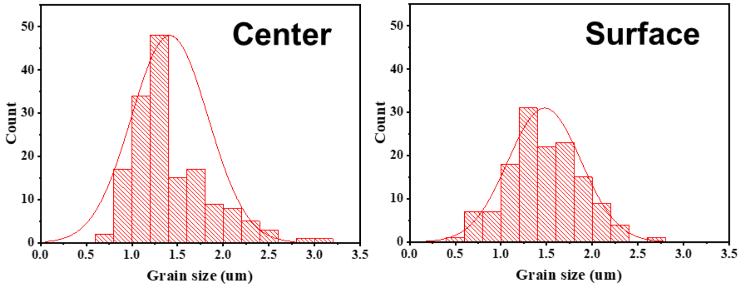


Diameter : 0.96 mm



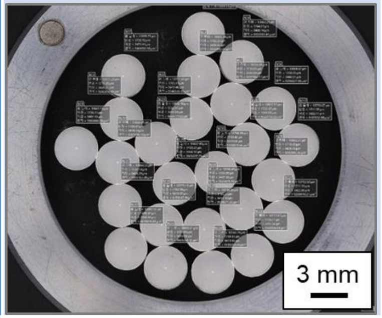
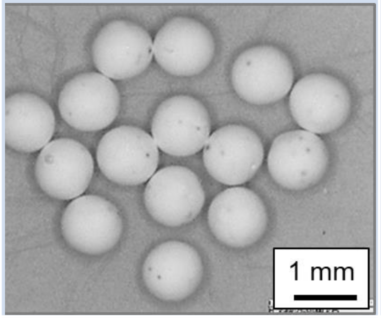
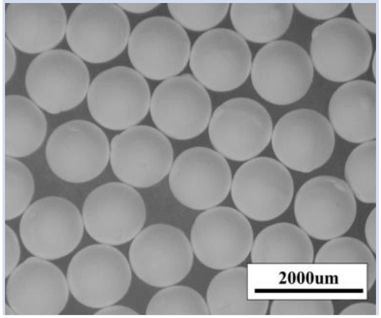
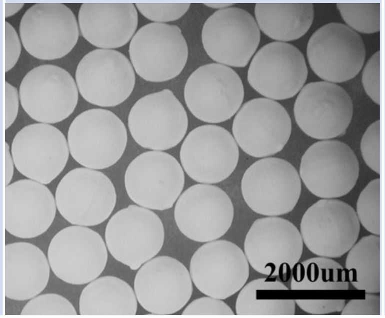
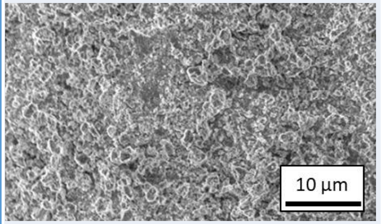
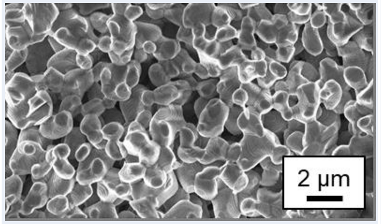
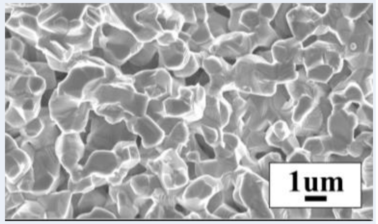
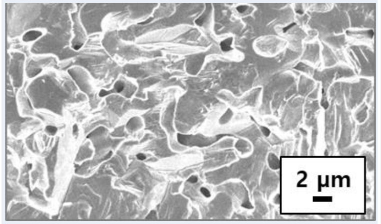


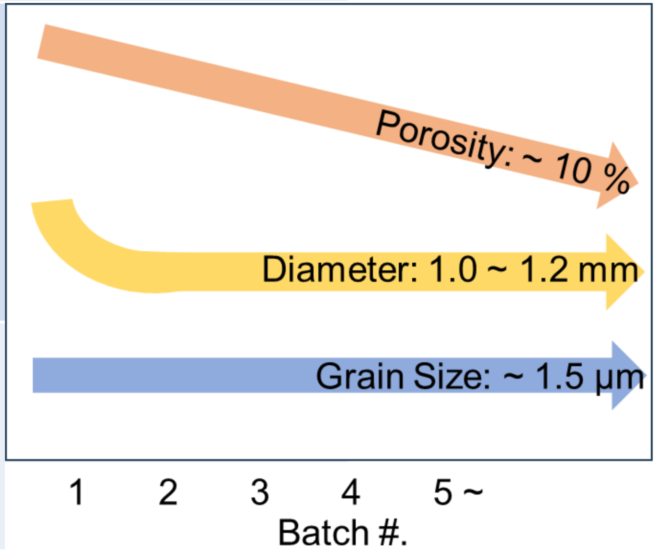
Value	Item	Value
1.00 µm	Grain Size	1.35 µm
39.7 %	Porosity	34.2 %



- A uniform microstructure with open pores in the surface and the core of sintered pebbles was confirmed.

Manufacturing Status of Li_2TiO_3 Pebbles based on Drying Process

Batch #	# 1	# 2	# 3	# 4	# 5 ~ (target)
Diameter	3.43 mm	0.96 mm	1.19 mm	1.19 mm	1.00 ~ 1.20 mm
Porosity	39.7 %	34.2 %	32.6 %	25.9 %	~ 10 %
Pore Type	Open	Open	Open	Open + Closed	Open
Grain Size	1.00 μm	1.35 μm	1.35 μm	-	1.00 ~ 1.50 μm
Shaping Proc.	PIM	PIM	PIM	PIM	PIM or 3DP
Manuf. Status	Done	Done	Done	Done	On-going
Morphology					
Microstructure					



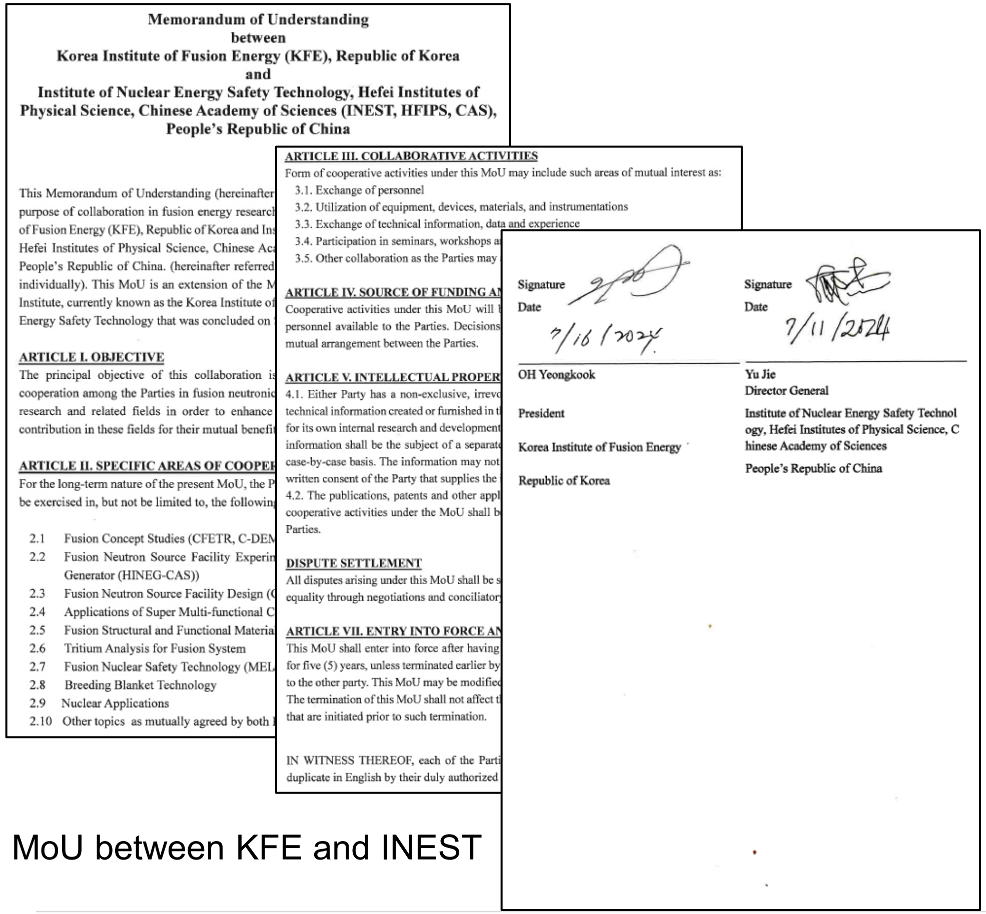
03

Neutron Irradiation Test and Tritium Release Test of Breeder Pebbles

한국핵융합에너지연구원
KOREA INSTITUTE OF FUSION ENERGY

Breeding and Release Research under KO-CN International Collaboration Program

- Neutron Irradiation and Tritium Release of Li_2TiO_3 Pebbles using D-T Fusion Neutron Source Facility
  - Phase 1 : 2021.10 ~ 2023.10
  - Phase 2 : 2024.12 ~ 2026.12



Memorandum of Understanding
between
Korea Institute of Fusion Energy (KFE), Republic of Korea
and
Institute of Nuclear Energy Safety Technology, Hefei Institutes of Physical Science, Chinese Academy of Sciences (INEST, HFIPS, CAS), People's Republic of China

This Memorandum of Understanding (hereinafter
purpose of collaboration in fusion energy researc
of Fusion Energy (KFE), Republic of Korea and Ins
Hefei Institutes of Physical Science, Chinese Ac
People's Republic of China. (hereinafter referred
individually). This MoU is an extension of the M
Institute, currently known as the Korea Institute of
Energy Safety Technology that was concluded on

ARTICLE I. OBJECTIVE
The principal objective of this collaboration is
cooperation among the Parties in fusion neutronic
research and related fields in order to enhance
contribution in these fields for their mutual benefi

ARTICLE II. SPECIFIC AREAS OF COOPER
For the long-term nature of the present MoU, the P
be exercised in, but not be limited to, the following

2.1 Fusion Concept Studies (CFETR, C-DEM
2.2 Fusion Neutron Source Facility Experin
Generator (HINEG-CAS))
2.3 Fusion Neutron Source Facility Design (
2.4 Applications of Super Multi-functional C
2.5 Fusion Structural and Functional Materia
2.6 Tritium Analysis for Fusion System
2.7 Fusion Nuclear Safety Technology (MEL
2.8 Breeding Blanket Technology
2.9 Nuclear Applications
2.10 Other topics as mutually agreed by both

ARTICLE III. COLLABORATIVE ACTIVITIES
Form of cooperative activities under this MoU may include such areas of mutual interest as:
3.1. Exchange of personnel
3.2. Utilization of equipment, devices, materials, and instrumentations
3.3. Exchange of technical information, data and experience
3.4. Participation in seminars, workshops a
3.5. Other collaboration as the Parties may

ARTICLE IV. SOURCE OF FUNDING AN
Cooperative activities under this MoU will
personnel available to the Parties. Decisions
mutual arrangement between the Parties.

ARTICLE V. INTELLECTUAL PROPER
4.1. Either Party has a non-exclusive, irrevo
technical information created or furnished in t
for its own internal research and development
information shall be the subject of a separat
case-by-case basis. The information may not
written consent of the Party that supplies the
4.2. The publications, patents and other appl
cooperative activities under the MoU shall b
Parties.

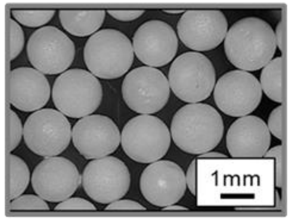
DISPUTE SETTLEMENT
All disputes arising under this MoU shall be s
equality through negotiations and conciliatory

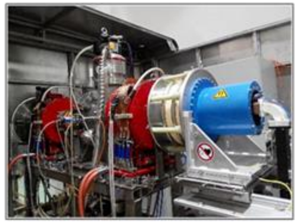
ARTICLE VII. ENTRY INTO FORCE AN
This MoU shall enter into force after having
for five (5) years, unless terminated earlier by
to the other party. This MoU may be modified
The termination of this MoU shall not affect t
that are initiated prior to such termination.

IN WITNESS THEREOF, each of the Parti
duplicate in English by their duly authorized

Signature	Signature
Date 7/16/2024	Date 7/11/2024
OH Yeongkook	Yu Jie
President	Director General
Korea Institute of Fusion Energy	Institute of Nuclear Energy Safety Technology, Hefei Institutes of Physical Science, Chinese Academy of Sciences
Republic of Korea	People's Republic of China

MoU between KFE and INEST





Irradiation Exp. Data

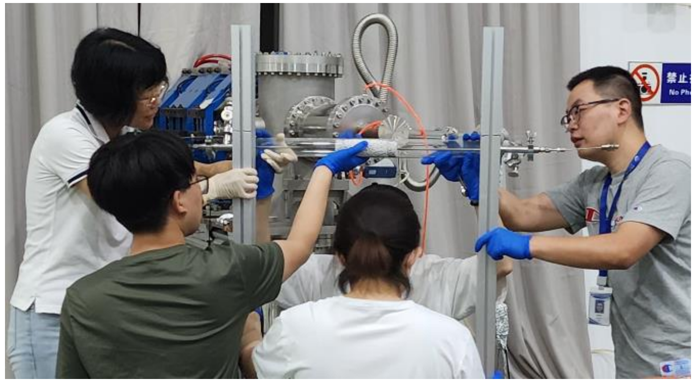
(KFE) Li_2TiO_3 Breeder Pebbles
- Synthesis of Li_2TiO_3 Raw Powder
- Fabrication of Li_2TiO_3 Breeder Pebbles
- Evaluation of un-irradiated Li_2TiO_3 Pebbles

(HFIPS) D-T Neutron Source
- Neutron Irradiation on Li_2TiO_3 Pebbles
- Measurement of Bred Tritium
- Evaluation of irradiated Li_2TiO_3 Pebbles

Li_2TiO_3 Breeder Pebbles

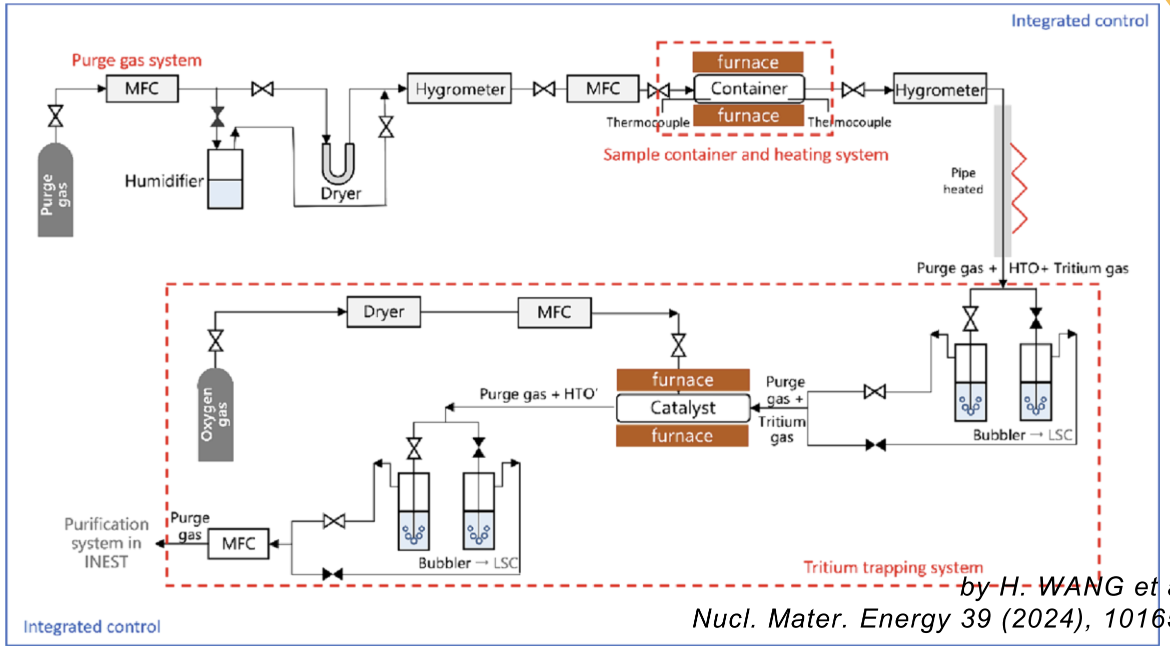
1st Neutron Irradiation Test on Li_2TiO_3 Pebbles

- Date : 2023.06
- Neutron Source : HINEG-CAS
  - Neutron Energy : 14.1 MeV
  - Neutron Yield : ~ 10^{12} n/s
- Irradiation Test Conditions
  - Duration Time : 6 h
  - Total Number of Neutron : 1.104 x 10^{15} n
  - Neutron Fluence at Pebble : 9.96 x 10^{11} n/cm^2
- Tritium Breeder Sample
  - Material : Li_2TiO_3 Pebbles
  - Diameter : 3.43 mm
  - Sphericity : < 1.01
  - Porosity : 39.7 %
  - Amount : 274 g



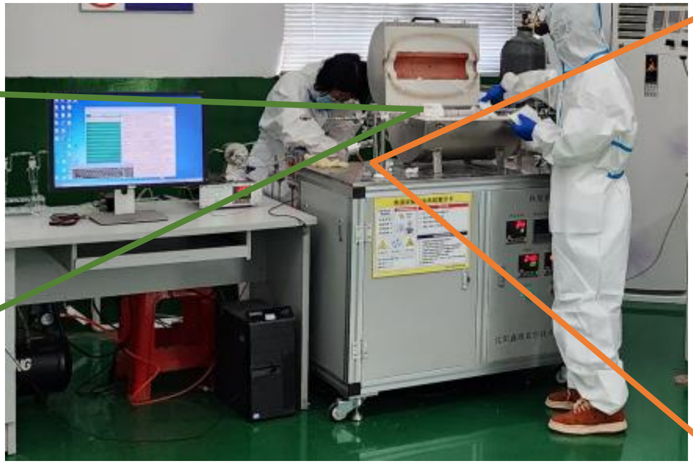
Tritium Release Test of Irradiated Li_2TiO_3 Pebbles

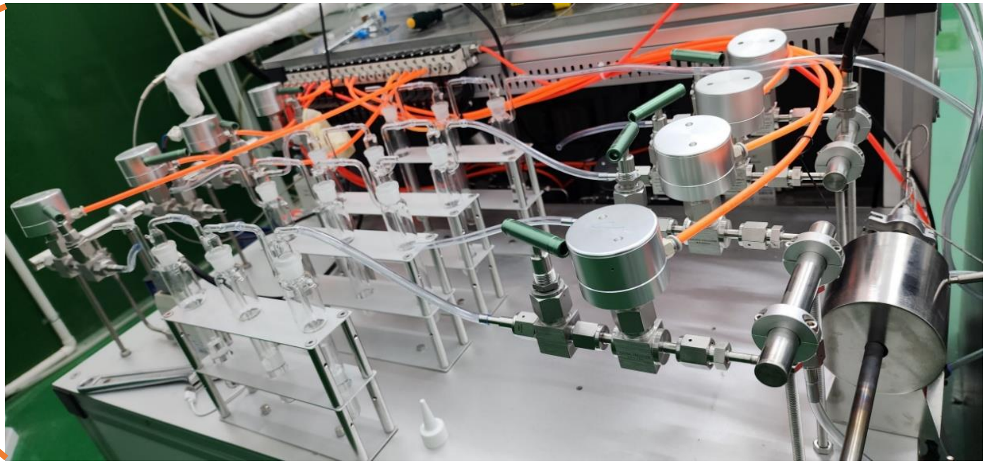
- Test Conditions
  - Purge Gas : He + 1 % H_2
  - Flow Rate of Purge Gas : 100 ml/min
  - Humidity Level : < 15 ppm
  - Tritium Release Temperature : R.T. ~ 800 ^{o}C
  - Catalyzer to change HT → HTO : Pt/SDB
  - Tritium Measurement : LSC Method
    (Lower Detection Limit : 0.7 Bq/L)



by H. WANG et al, Nucl. Mater. Energy 39 (2024), 101653


<Irradiated Pebble Assembly>


<Tritium Release System>


<Bubblers to trap HTO>

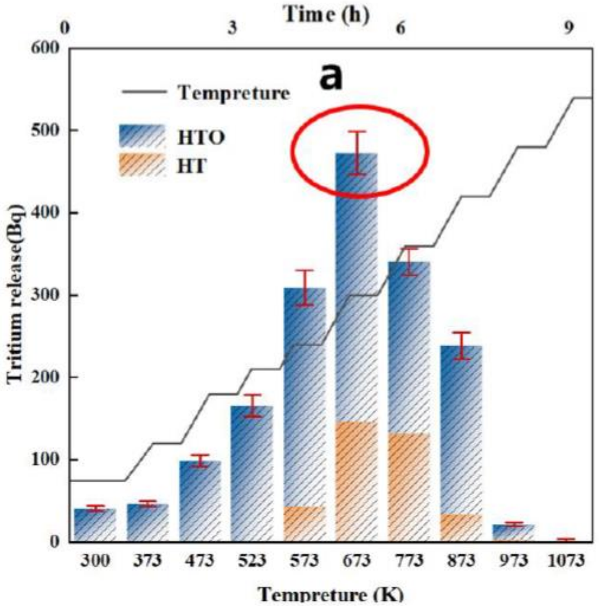
1^{st} Tritium Release Test Results from Irradiated Li_2TiO_3 Pebbles

<Tritium Radioactivity in Bubblers>

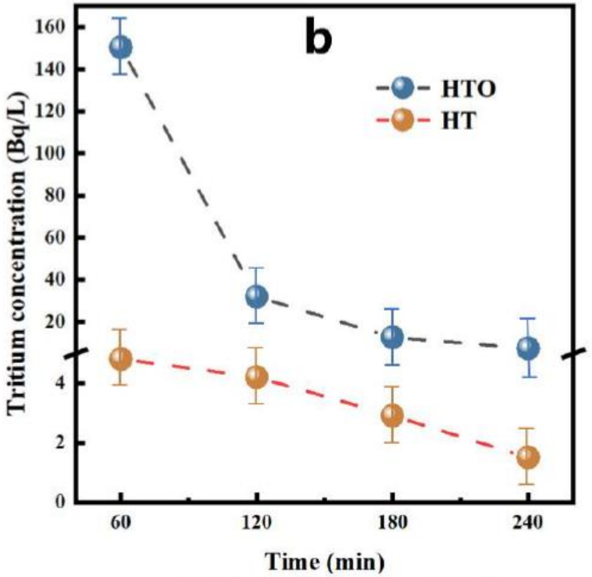
T(K)	Radioactivity (Bq)					
	1#	2#	3#	4#	5#	6#
RT	39.1	0.1		1.2	0.1	
373	46.0	0.1		0.2	0.1	
473	98.8	0.2		0.1	0.1	
523	163.9	0.6		1.1	0.1	
573	264.1	0.9	BG	43.8	0.1	BG
673	325.2	1.5		145.6	0.5	
773	208.0	0.8		131.4	0.6	
873	204.0	0.9		33.5	0.1	
873′	22.2	0.1		3.5	0.1	
Total	HTO: 1376.5 Bq			HT: 362.2 Bq		

*BG: Background

by W. Wu et al,
Int. J. Hydrogen Energy 68 (2024), 1393



Distribution curves of tritium release at different temperature



Tritium measurement results at 1073 K for 4 h

- Before heating (during irradiation): A certain amount of HTO (54.4 Bq) and HT (23.6 Bq) was released from the surface of Li_2TiO_3 pebbles.
- At elevated temperature: Tritium release peaked at 400 ^oC, with the release ratio of HTO to HT being approximately 79.3 % to 20.7 %.
- At 800 ^oC: The tritium concentration decreased to background levels, indicating no residual tritium retention in the pebbles after 4 h.

04

Summary

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Summary

- Li_2TiO_3 pebbles with high sphericity for tritium breeder material were successfully fabricated using Slurry Droplet Wetting process and Powder Injection Molding (PIM) process.
  - In the PIMed Li_2TiO_3 pebbles, a uniform microstructure was observed both at the surface and the core of the sintered pebbles, while no defects resulting from sintering between neighboring pebbles were detected.
- Tritium production and release experiments were conducted on Li_2TiO_3 pebbles with 14.1 MeV fusion neutron source HINEG-CAS and tritium release system.
  - The total radioactivity of tritium released from the irradiated Li_2TiO_3 pebbles with a weight of 274 g was approximately 1,866.4 Bq.
  - The tritium release peaked at 400 ^{o}C, with the release ratio of HTO to HT being approximately 79.3 % to 20.7 %.
- *Future Works;*
  - Validate the performance of oxidizers in tritium release system
  - Investigate the effects of purge gas composition
  - Compare the influence of breeder pebble properties

Thank you for your kind attention !!!

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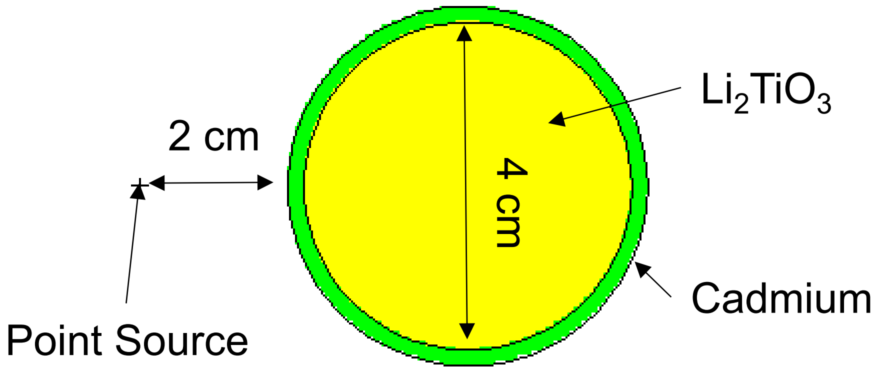
MCNP Result of Tritium Production

- MCNP Model
  - Source : 14.1 MeV Point Source
  - Material : Li_2TiO_3 (Natural Lithium)
  - Cd Thickness : 2 mm
  - Weight of Li_2TiO_3 : 274 g



- Results
  - T Production (with Cd) : 3,787 Bq (2.24×10^{12}) regarding neutron fluence
  - T Production (w/o Cd) : 4,146 Bq (2.33×10^{12}) regarding neutron fluence
  - Neutron Spectrum