International School of Fusion Tokamak Reactors
Erice, July 26 – August 1, 2004

Ceramic Breeder Technology

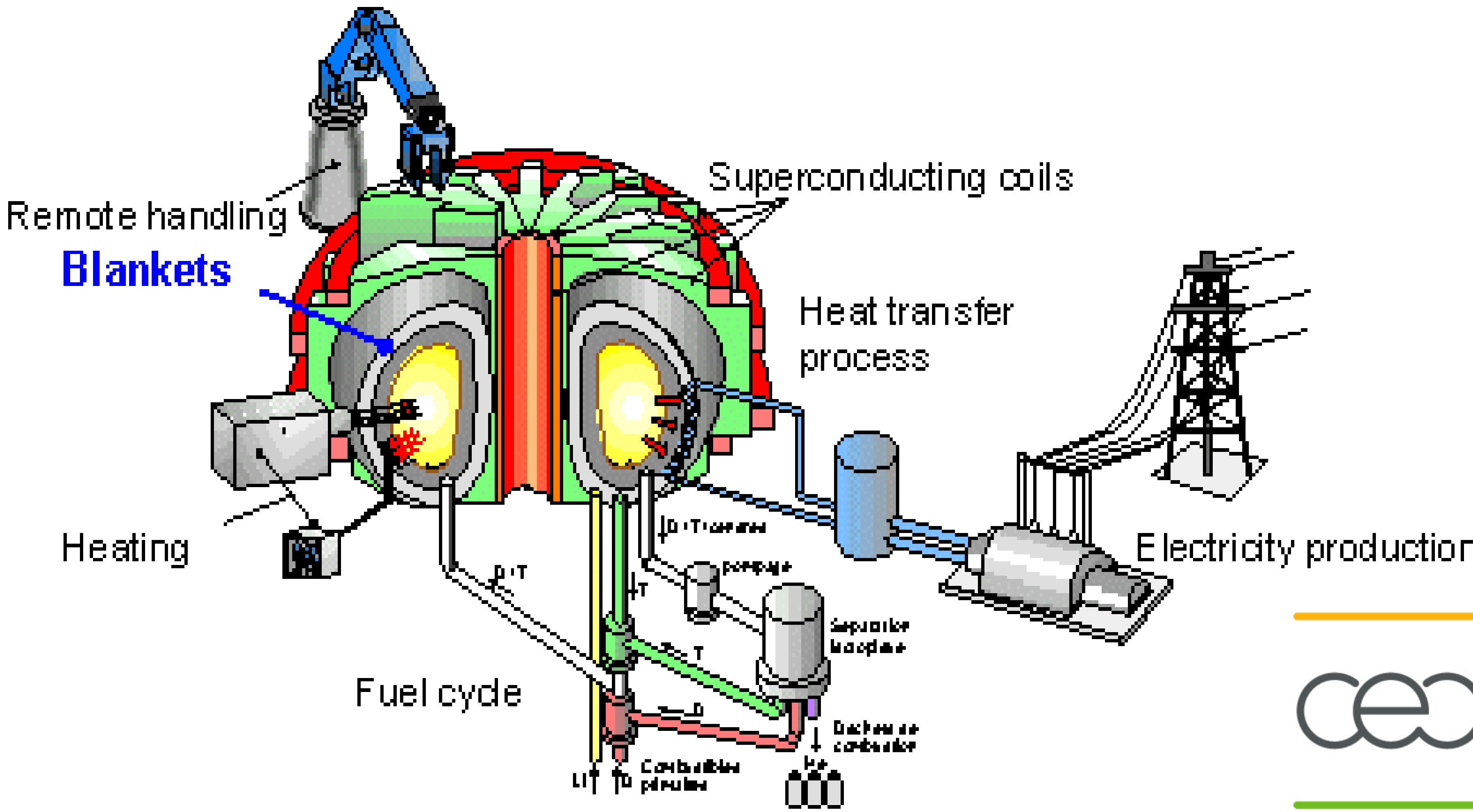
Sergio Casadio
ENEA CR Casaccia, uts MAT

LITHIUM CERAMIC BREEDERS
State of art after 20 years of R&D

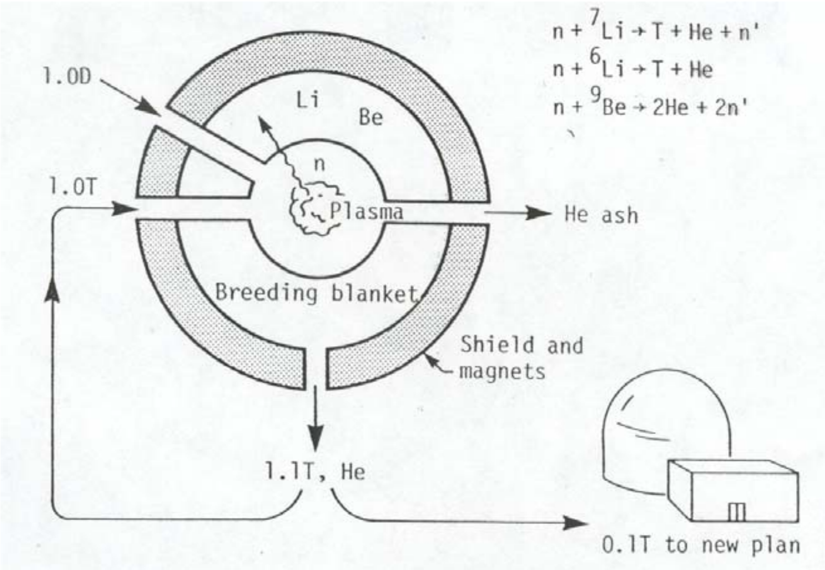
- Basic concepts
- Pellets functioning and radiation damage tested in fission reactors
- Pebbles fabrications
- Pebble beds testing in blanket modules

Breeding blanket primary functions

- 1 – tritium production
- 2 – heat generation
- 3 – neutron shielding

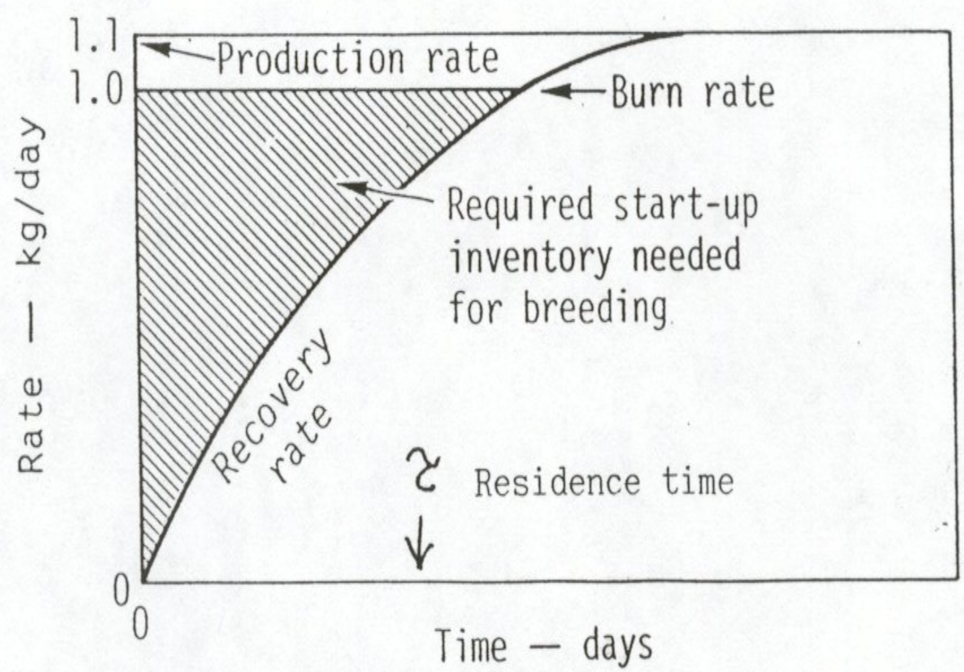


Tritium breeding diagram in a fusion power plant



- The tritium is mainly generated by the reaction
- $^6Li + n \rightarrow T(2.7\ MeV) + He(2.1\ MeV)$
- Neutrons are supplied by the D-T fusion
- $D + T \rightarrow He(3.52\ MeV) + n(14.1\ MeV)$

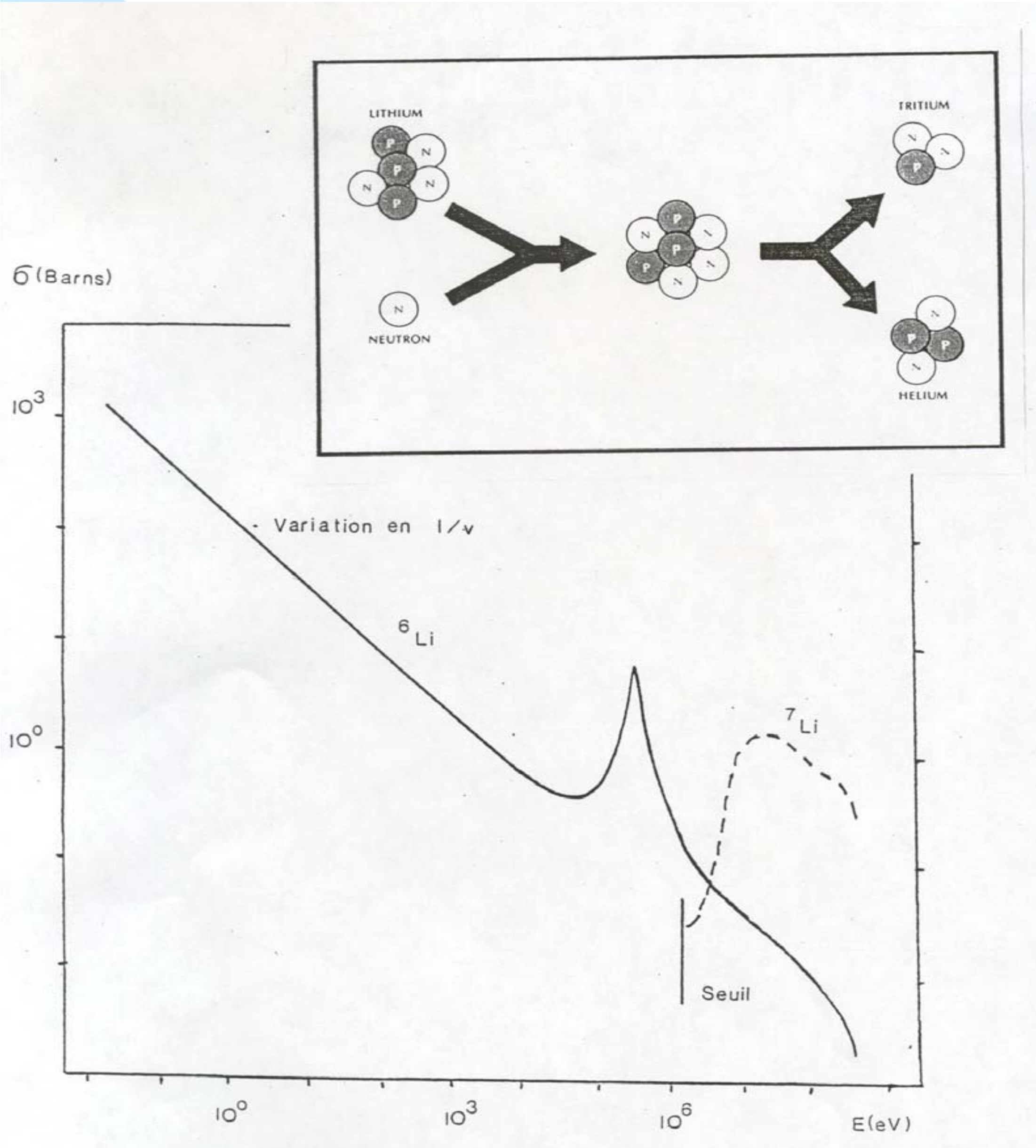
- tritium generation rate **G** and its recovery rate **R** must satisfy self-breeding and start-up of other reactors, **TBR > 1;**
- **Be** as (n.2n) **neutron multiplier** must be largely employed.
- Tritium inventory **I = ∫(G-R)dt**
- Tritium residence time **τ = I/G**



Dimension of a 1000 MW Fusion Power Plant CONSUMPTION

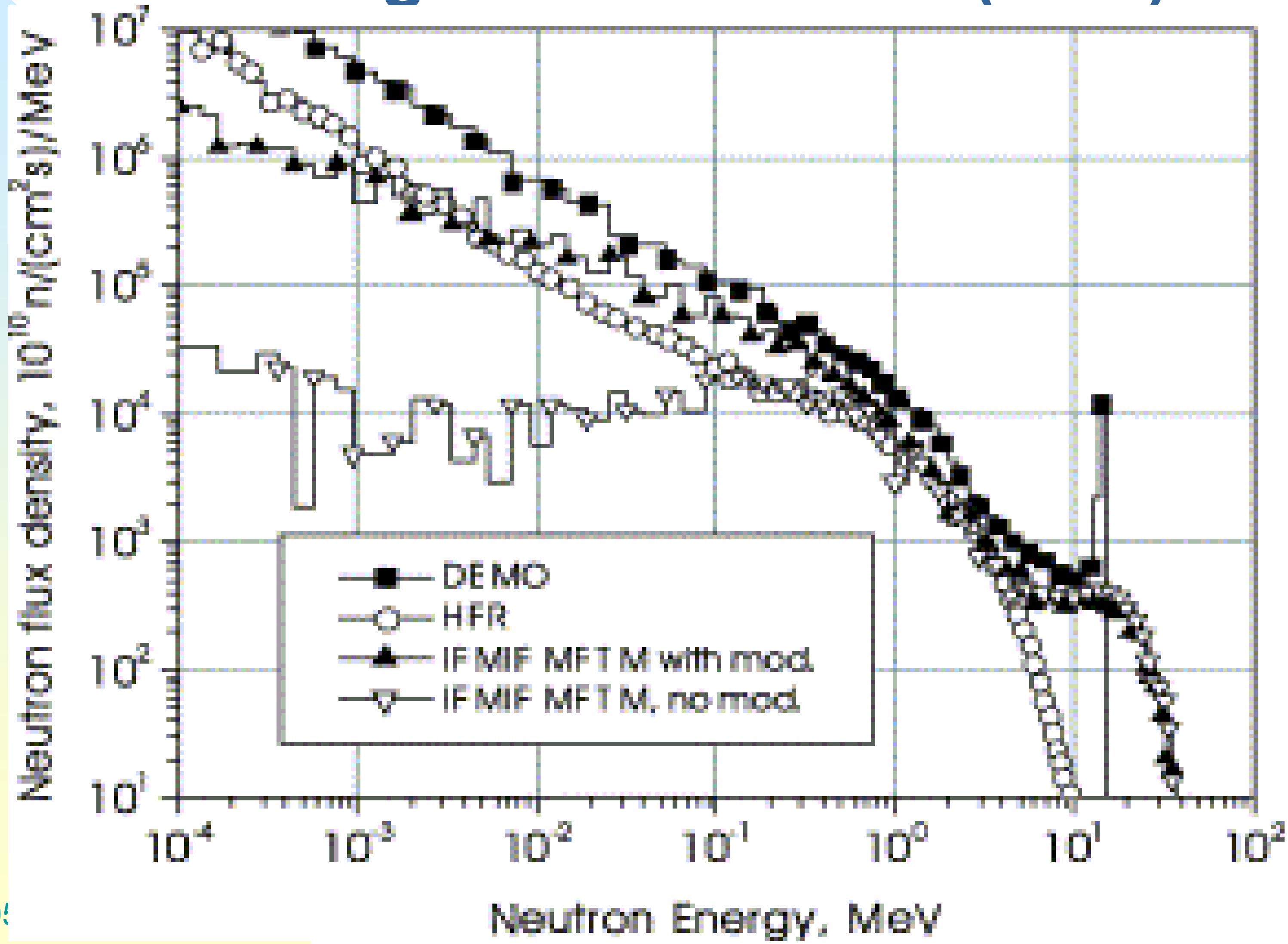
- Deuterium D_2: ~0.7 Kg/day
- Tritium T_2: ~ 1 Kg/day
- ^{6}Li isotope: ~ 2 Kg/day
- Inside the blanket during its life (4 years)
  - ^{6}Li ~ 24,000 Kg
  - As fully enriched Li_2O ~ 56,000 Kg
  - To be transformed in T_2O

$^6Li(n,\alpha)T$ transmutation

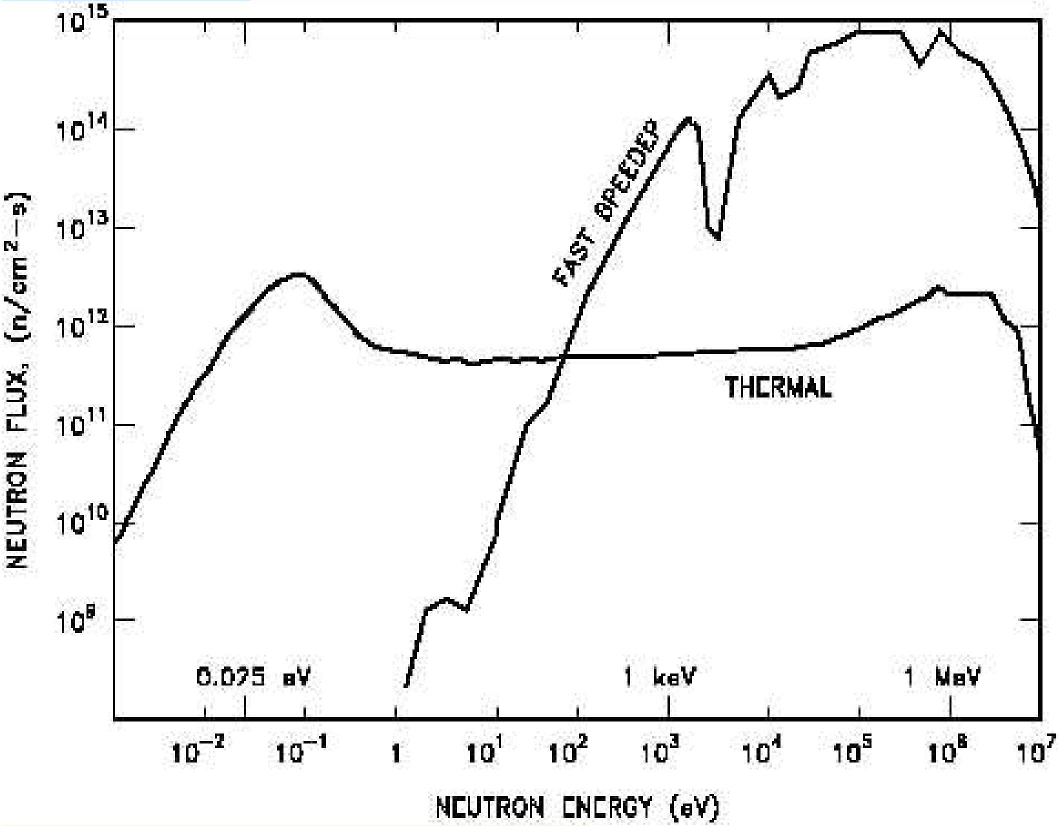


- Tritium generation rate **G =** $\int_V \int_E \varphi \, \rho \, \sigma$
- Where $\varphi(E)$ = neutron flux density; $\sigma(E)$ = ^{6}Li cross section (decreasing with ~ $\sqrt{E}$); ρ = ^{6}Li density; integrated over the energy E and the space coordinates V
- Energy given per captured neutron: 4.8 MeV
- For each $\varphi(E)$, **G** (and its power generation **P**) can be tailored by adjusting ρ with appropriate ^{6}Li enrichment.
- **Slow and fast neutron Fission reactors may reproduce the G and P values of DEMO power plant breeding blankets**

DEMO neutron flux density as compared to those of the future D-Li stripping source (IFMIF) and of the existing fission reactor (HFR).



Li-ceramics testing in fission experimental reactors



Tritium and heat generation rate in Li-ceramics can be examined in fission neutron sources.

In fast-reactors the blanket fusion n-environment is reasonably reproduced for ^{6}Li-tailored (enriched) oxides below 2MeV.

High Flux Fission Reactors may give ^{6}Li transmutation rate (G) and amount (^{6}Li depletion or Li-burn-up (BU)) comparable to those of a DEMO-blanket.

The radiation damage (rate and dose) cannot be simultaneously and exactly reproduced

A combination of differently tailored n-spectra and ^{6}Li concentrations may help to reproduce the fusion breeding blanket radiation damage

Li-CERAMICS RADIATION DAMAGE

From L.R. Greenwood (PNNL), "Radiation damage calculations for the FUBR and BEATRIX irradiations of Li-compounds in EBR-II and FFTF". Fusion Materials, Semiannual Progress Report for period ending in June 30, 1999.

The recoiling of α and T from the $^6Li(n,\alpha)T$ reaction create a cascade of secondary recoil atoms from their interaction with atoms in the ceramics.

Fast neutron interactions can also cause primary recoil atoms that also lead to a cascade of secondary recoil atoms.

Both these processes lead to radiation damage characterized by the total number of displacements per atom (DPA).

The Li transmutation leads to creation of Li-vacancies and build-up of He and T_2O, as measured by the Li burn-up (BU).

BU effects might be more significant than stable products dpa in the evolution of property changes.

^{6}Li-tailoring allows a reasonable reproduction of BU-DPA in high flux experimental fission reactors (much better if Fast Neutron Reactors (EBR-II and FFTF)) as envisaged to occur in a Fusion-DEMO breeding blanket

Neutron spectrum and predicted radiation damage (DPA – BU combination) for Li-ceramics in DEMO

Li-6 density is near the same for the different oxides

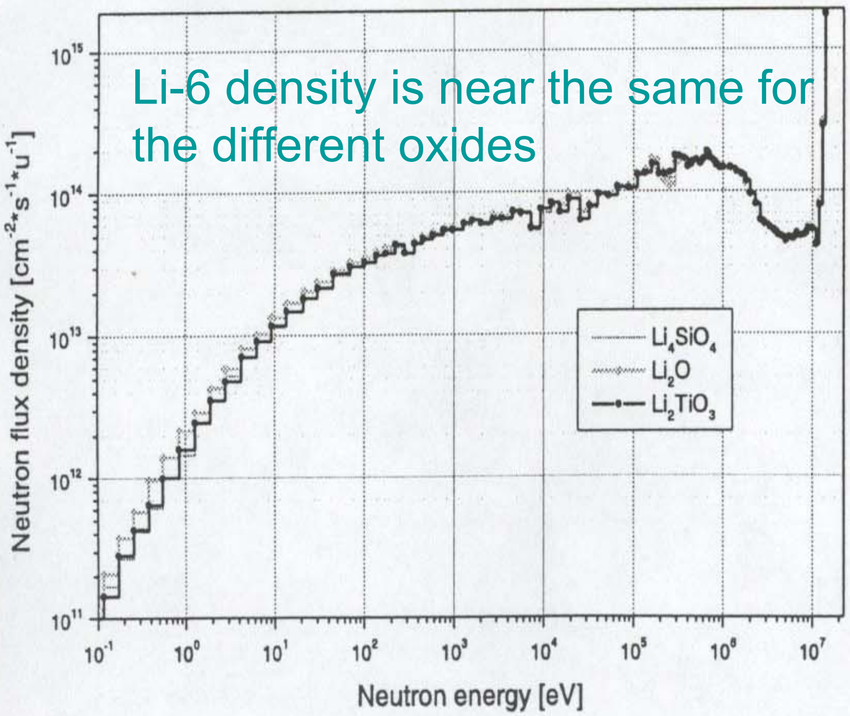


Fig. 5. HCPB Demo blanket: neutron flux spectra in Li_2O, Li_4SiO_4 and Li_2TiO_3.

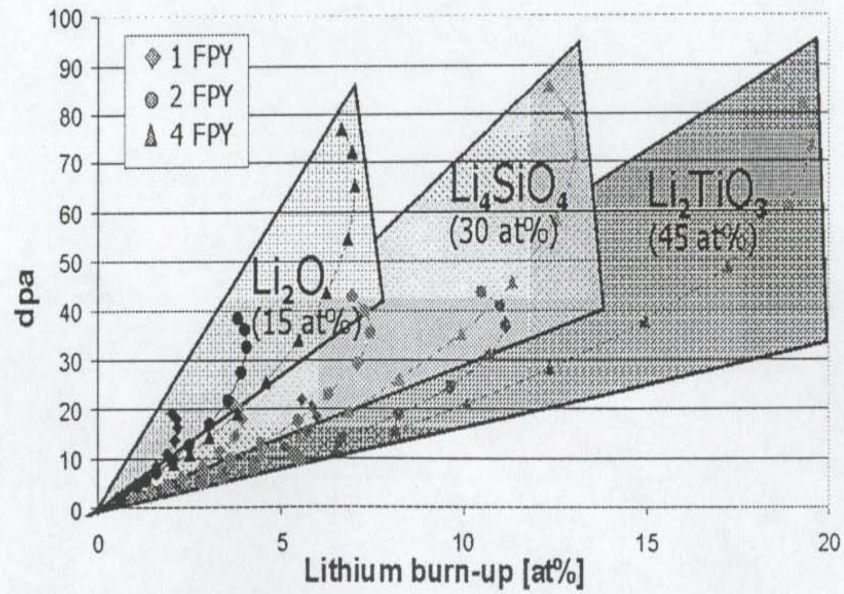


Fig. 6. DPA accumulation vs. lithium burn-up for the breeder materials Li_2O, Li_4SiO_4 and Li_2TiO_3 in the HCPB Demo blanket.

DPA – BU combinations acievable (for both n-spectra and isotope tailored Li-ceramics) in high flux fission neutron reactors

160 U. Fischer et al. / Journal of Nuclear Materials 280 (2000) 151–161

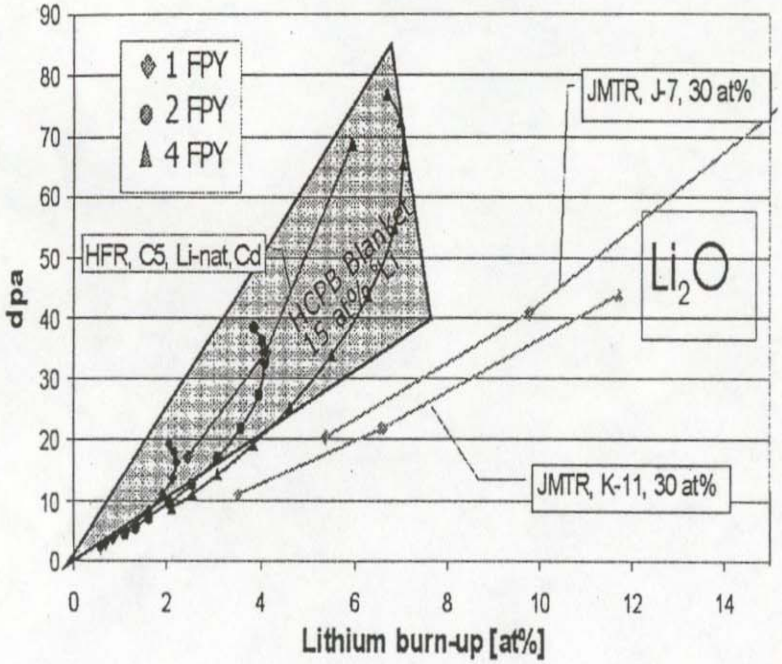


Fig. 11. Dpa accumulation vs. lithium burn-up for Li_2O.

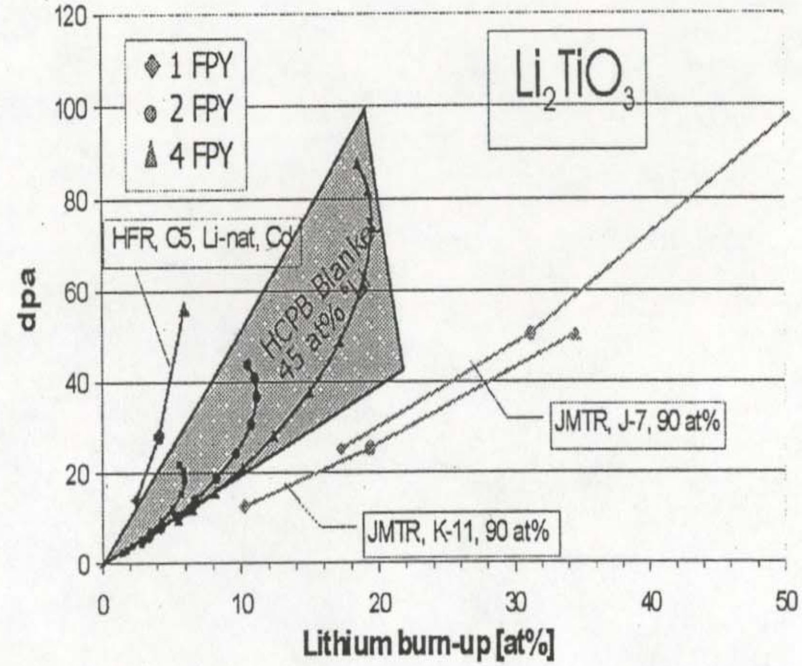
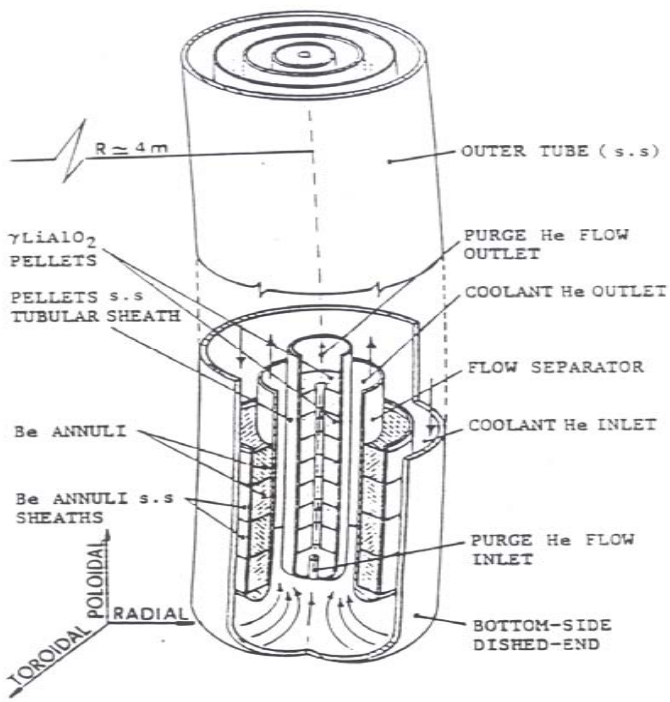


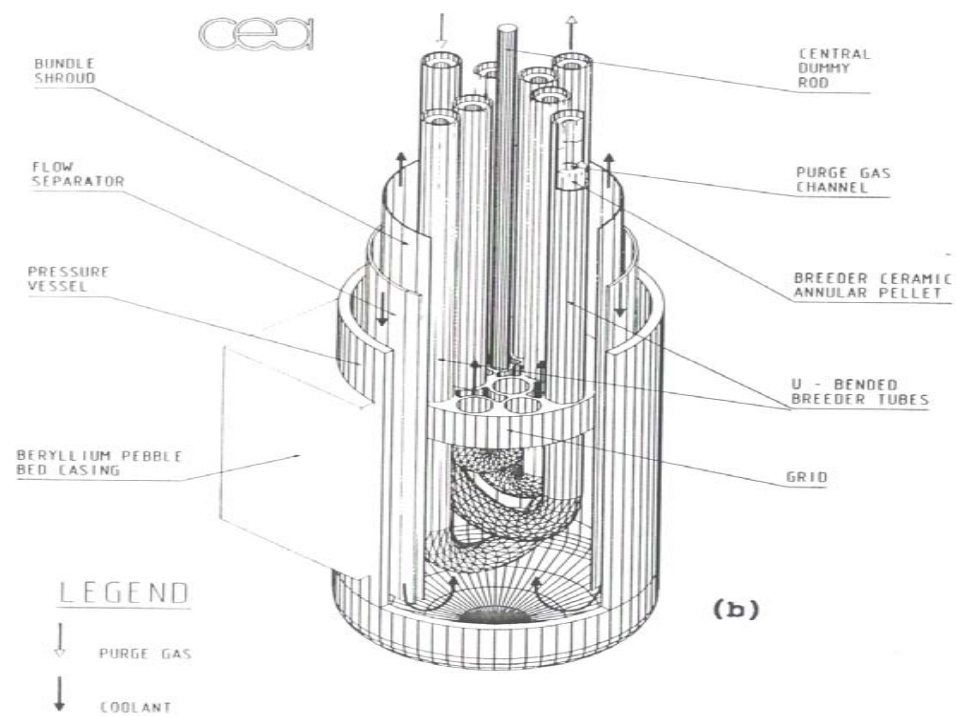
Fig. 12. Dpa accumulation vs. lithium burn-up for Li_2TiO_3.

Gray triangles refer to the DEMO fusion reactor

PELLETS are suitable forms to….

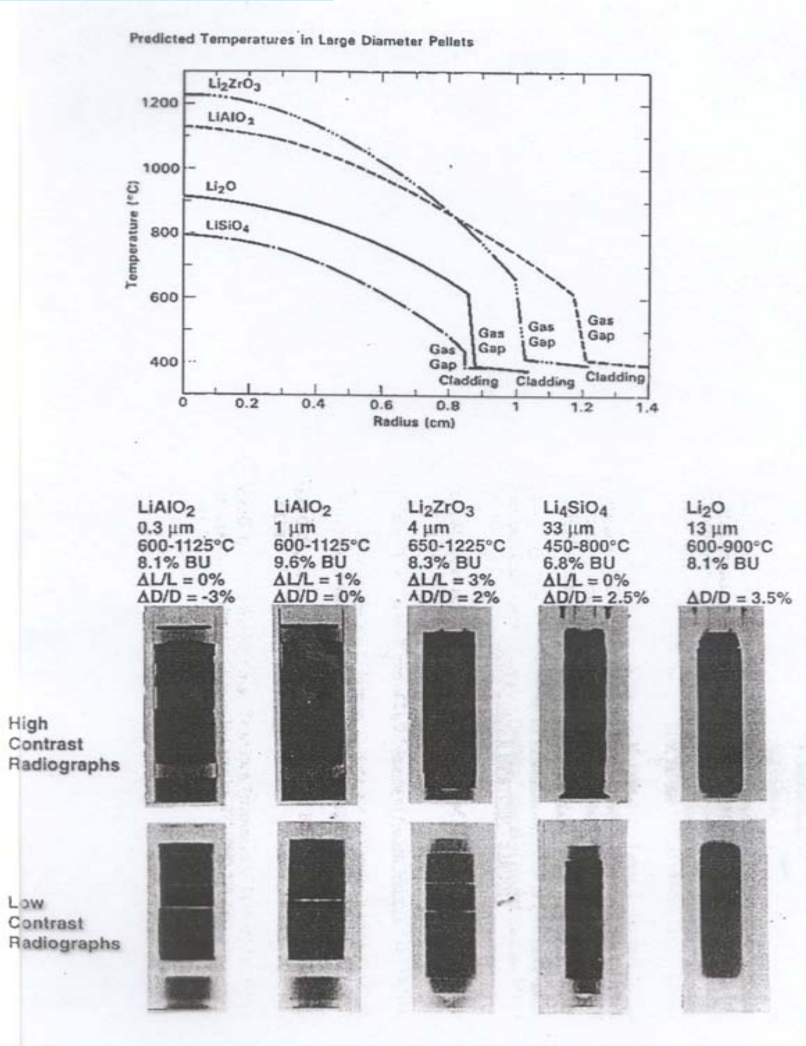
- …investigate material properties (disks, rods, rings, etc.);
- … be irradiated as cladded in instrumented fission reactor tubes/capsules,
- … be used as tested in “Breeder In Tube” blanket concepts
- *Pellets were candidate forms for the ENEA-CEA BIT- POLOIDAL He cooled European Blanket (1990-1995).*

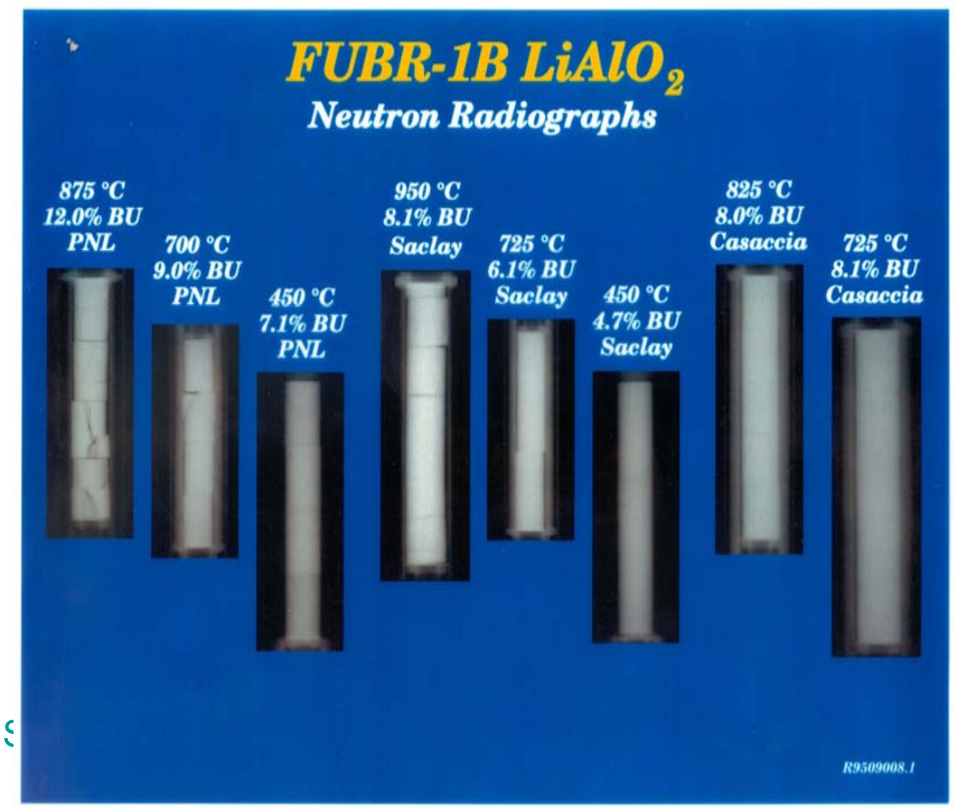




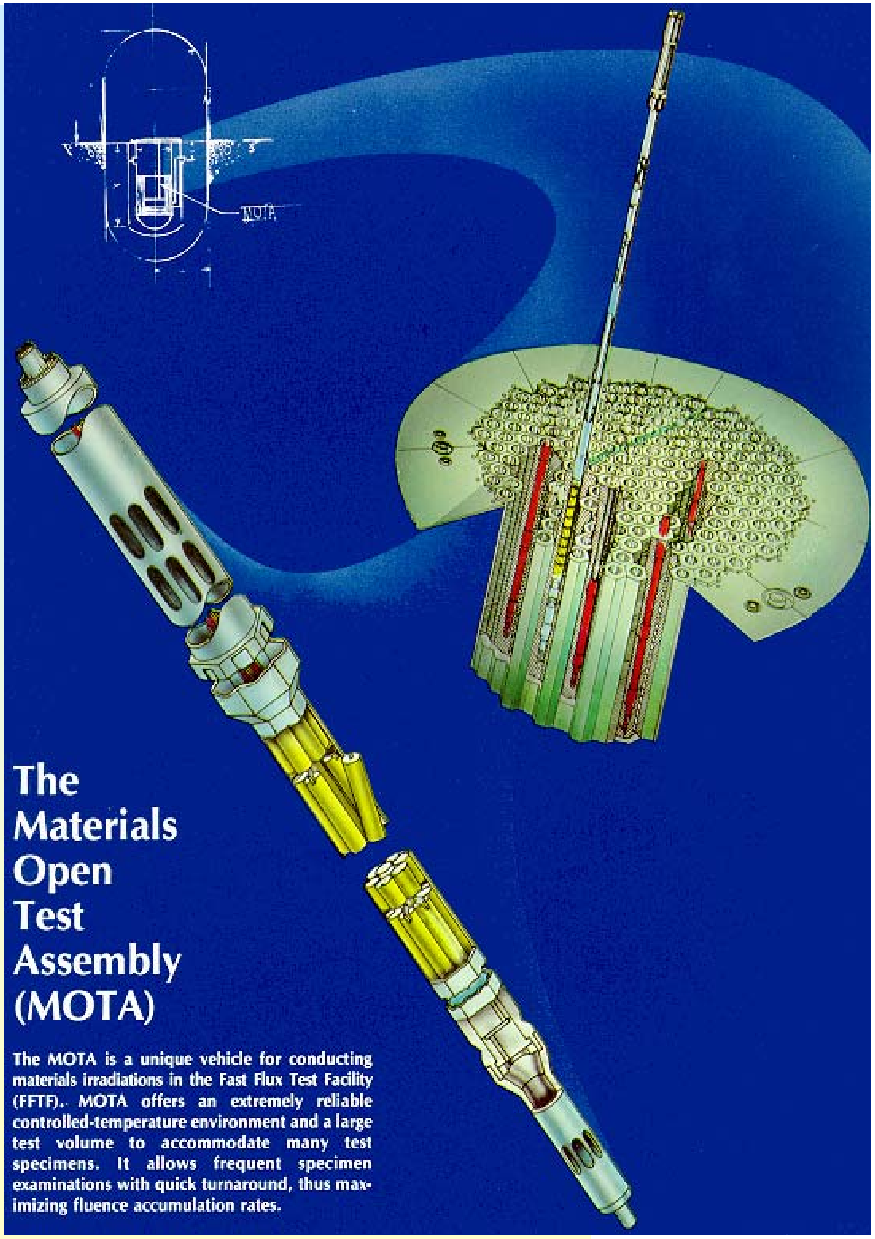
BEATRIX-I. Irradiation of Li-ceramic pellets in high flux fast neutron experimental reactor EBR-II

- Integrity and dimensional stability of pellets was tested
- Large pellets irradiated under high termal gradients (~50 W/cm³)
- Small and large pellets up to high Li-BU





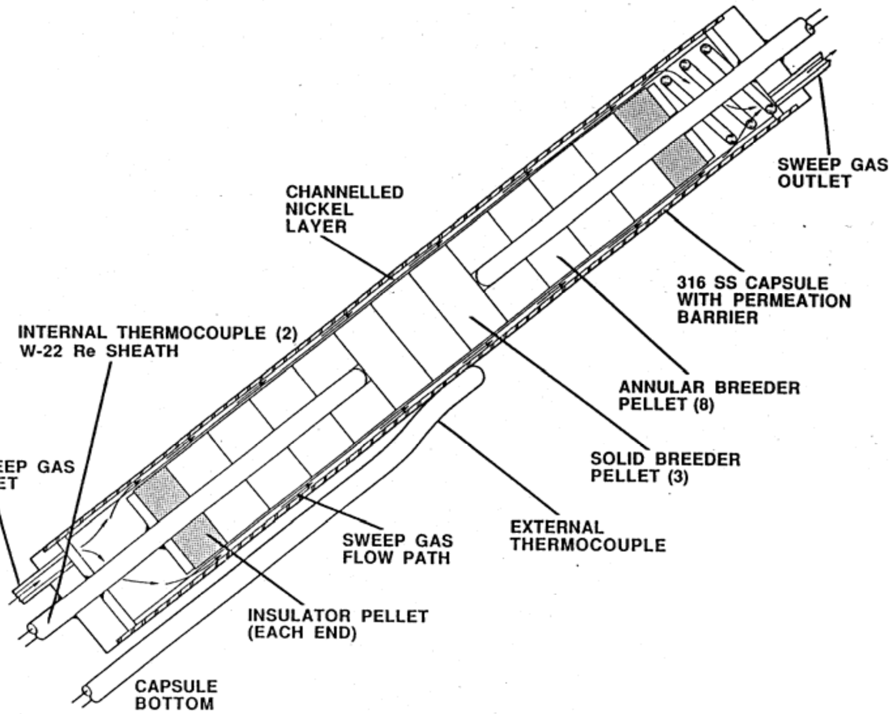
BEATRIX-II: irradiations in the Fast Flux Test Facility FFTF (1990-1994)



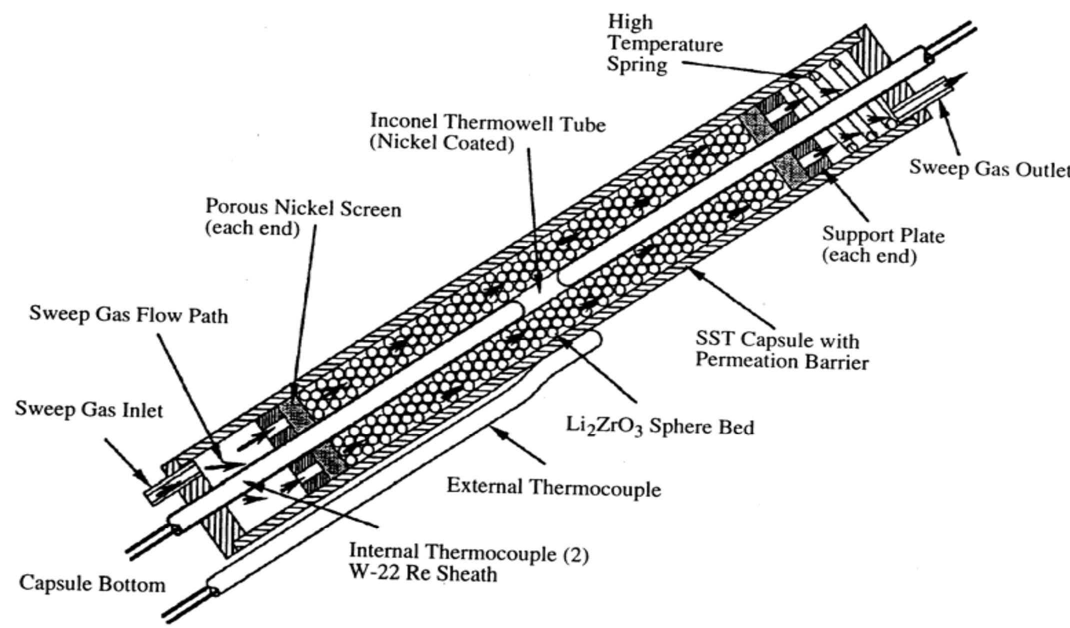
- Li_2O pellets generated tritium at a rate G=1.2 10^{14} atom/cm^3/s and power P = 100 w/cm^3 during irradiation exposure of 300 + 203 effective full power days (EFPD, phase-I + phase-II).
- Tritium recovery rate and temperature gradients were found stable up to 4.2% B.U., Data are directly applicable to the performance of Li_2O at EOL conditions
- During phase-II a Li_2ZrO_3 pebble bed was tested succesfully (1994).

- *BEATRIX-II, Phase-I and II: Reports: PNNL-10279 and 11148, UC-404 O.D. Slagle and G.W. Hollemberg, January 1995 and May 1996 Richland, Washington 99352*

BEATRIX-II irradiations in FFTF



- Phase-I: thermal gradient under fast-flux irradiation of large Li_2O pellets was of 400 to 1000°C.
- Phase-II: a Li_2ZrO_3 pebble bed canister was tested in similar conditions, the thermal gradient was of 440 to 1100°C



BEATRIX-II phase II

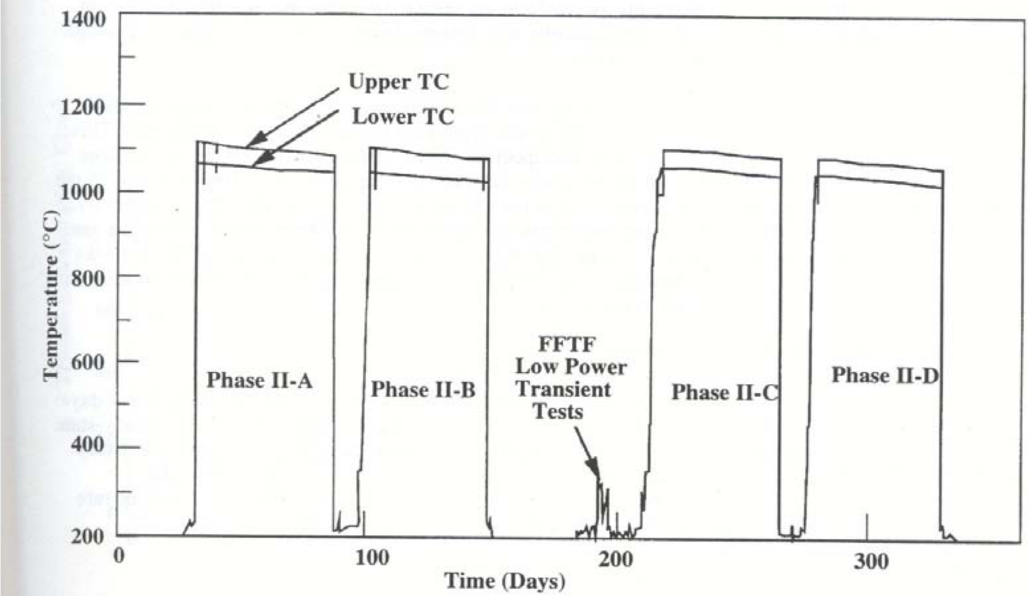


Figure 5.10. Center Temperatures of the Phase II Temperature-Gradient Canister for the Four Irradiation Cycles

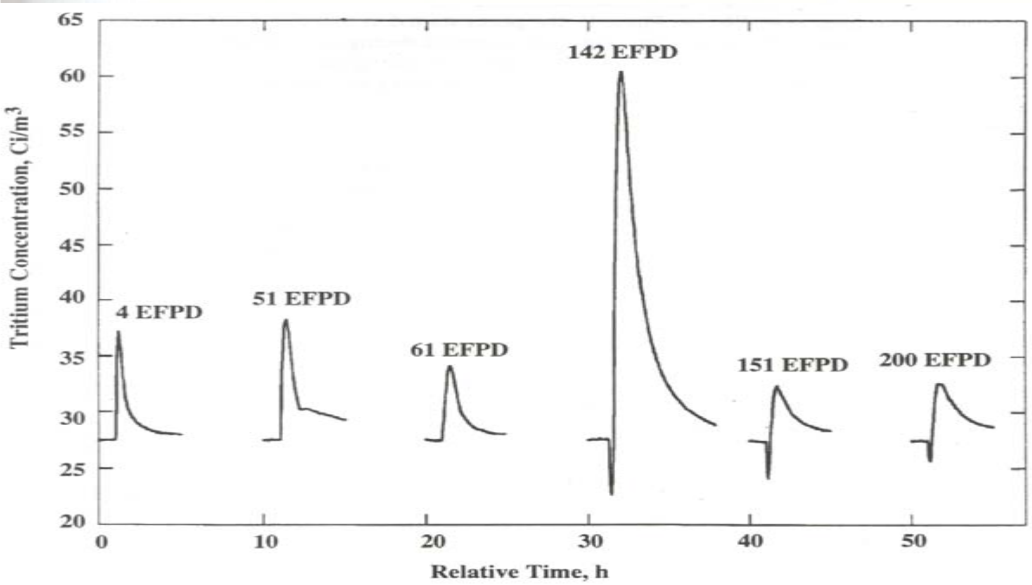


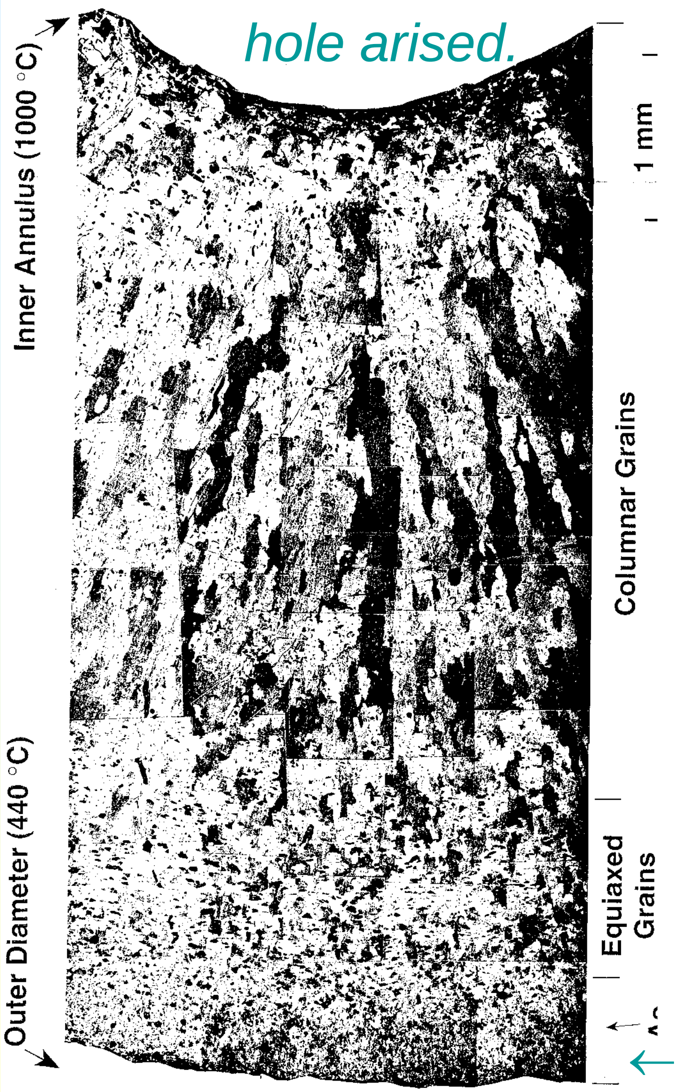
Figure 5.5. Tritium-Recovery Peaks for Temperature Transient 530 to 640°C at 4, 51, 61, 142, 151, and 200 EFPD

- Main results for Li_2O big pellets (thermal gradient canister)
- Top temperatures inside the canister decrease slowly with BU and show stable gradient.
- Tritium release spikes as induced by thermal steps 530→640°C on thin annular pellets.
- This property remains good up to the EOL

PIE of Li_2O pellets irradiated in FFTF

A central hole arised.

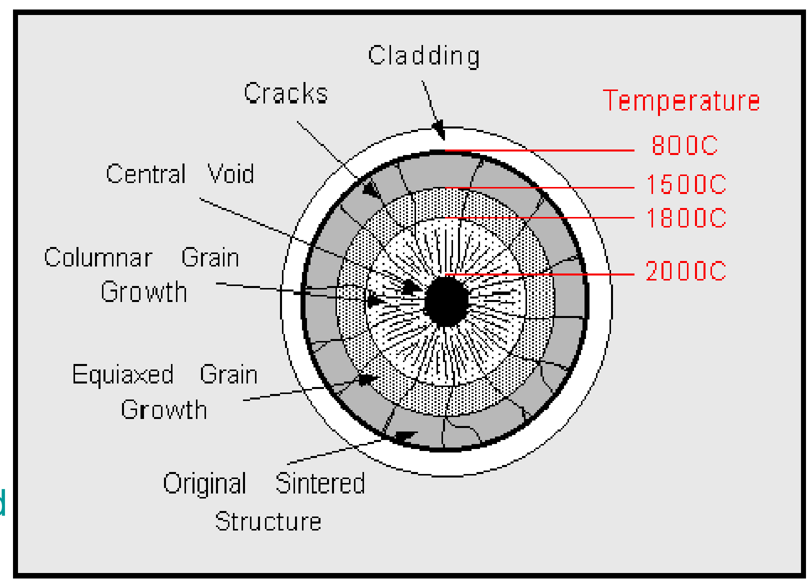
Composite photomicrograph of the post-irradiation temperature gradient specimen (BEATRIX-II, Phase I, 4.2 % Li burnup), radial section.



Grains were found to grow as columnar (where the gradient is maximum) and as equiaxed (near the cold surface)

← As fabricated microstructure

A situation similar to that of UO_2 fission fuel rod-pin section (~200 W/cm^3) at its End of Life (BU max)



TRITIUM RECOVERY FROM Li-CERAMICS

- Pellets or pebbles are swept by He flowing during the reactor operation.
- Tritium in gaseous forms are carried by the He purge, adding H_2 (as isotope swamping) to He the removal rate is improved
- T_2, DT (or HT in the experiments) are preferred to water vapor condensable forms T_2O or DTO (or HTO).
- He doped with D_2 (0.1% as H_2 in the experiments) is the "reference" purge gas to get tritium in DT (or HT) form

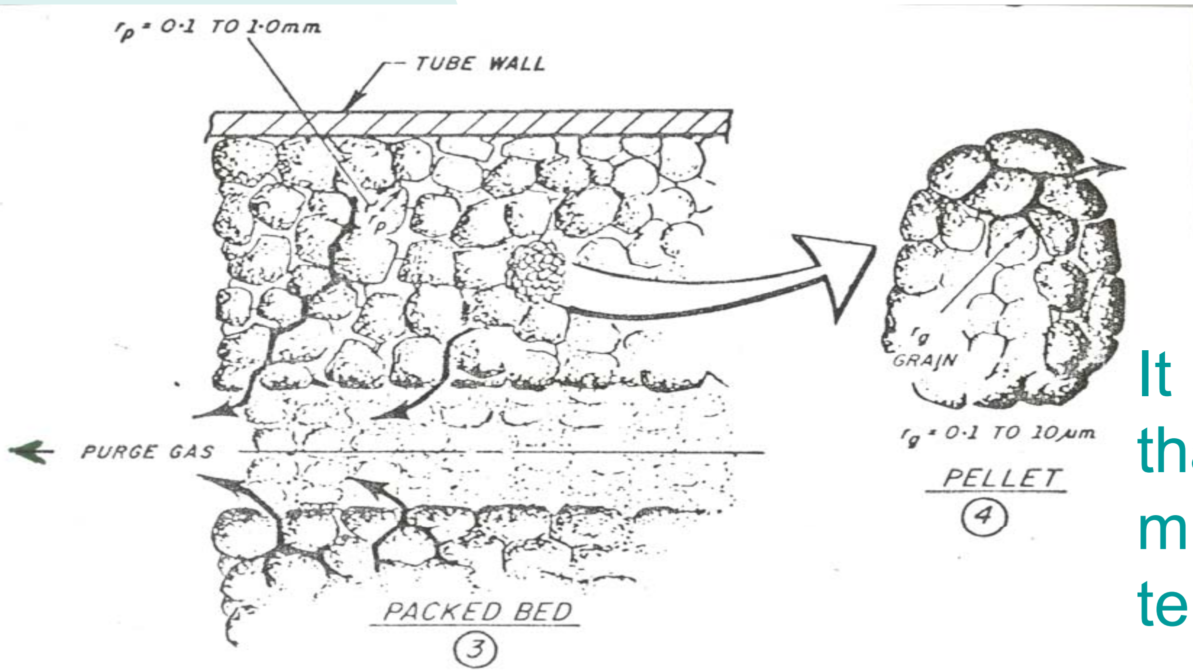
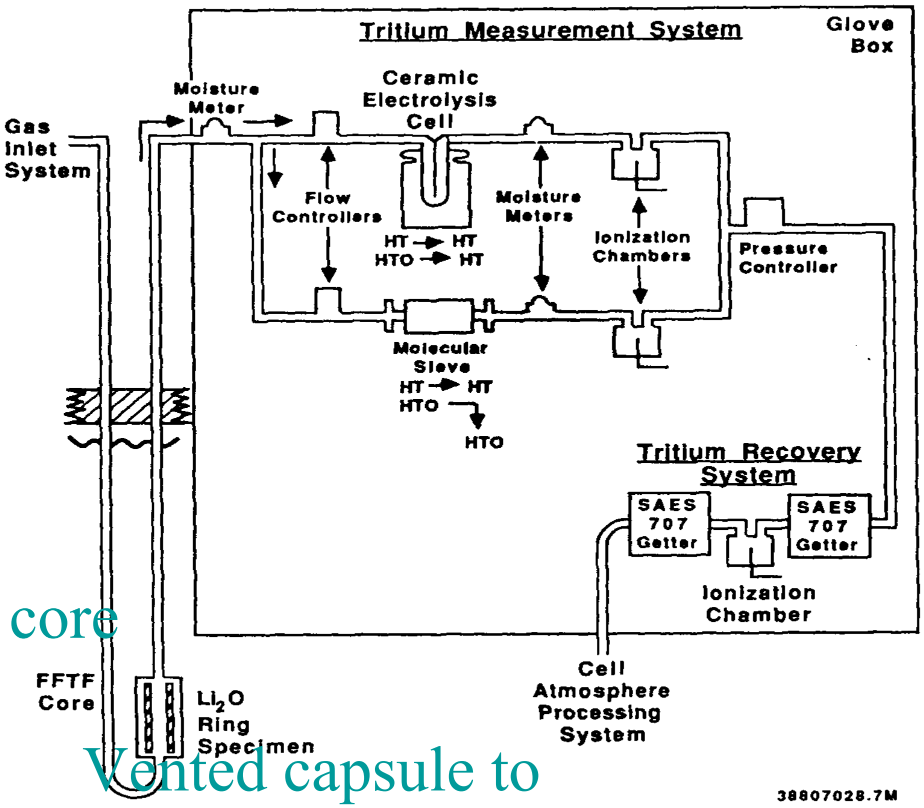


Figure 10-2. Schematic diagram of STARFIRE blanket concept showing solid breeder microstructure with bimodal pore distribution and

It is generally accepted that $\tau < 1$ day states the minimum operative temperature T_{min}

TRITIUM RELEASE RATE (R) MEASUREMENTS



Reactor core

Vented capsule to irradiate Li-ceramic rings

- Tritium generation and recovery is performed by inserting Li-ceramic specimens in instrumented vented capsules.

  Their rates G and R are measured in line.

  Irradiations are performed in high flux material testing fission reactors.

  Neutron flux, temperature, purge gas flow-composition are the main controlling parameters.

  The sketch shows the loop used in U.S. at the Fast Flux Test Facility (FFTF) reactor for the BEATRIX-II program (1990)

Li-CERAMICS TEMPERATURE WINDOWS

Journal of Nuclear Materials 155–157 (1988) 188–201
North-Holland, Amsterdam

C.E. Johnson et al. / Ceramic breeder materials

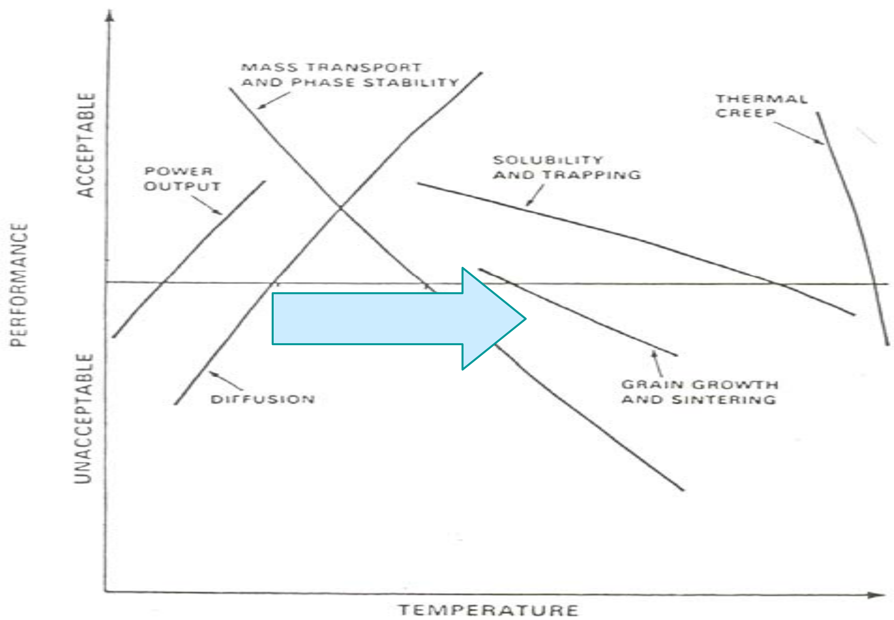


Fig. 1. Breeder material properties as a function of temperature.

Oxide (**gLi/cc**)	**T_{min}**	**T_{1max}**	**T_{2max}**	**m.p.(°C)**
Li_2O **(0.93)**	320	750	1100	1430
Li_4SiO_4 **(0.54)**	350	640	930	1250
Li_2ZrO_3 (**0.33**)	300	850	1000	1615
Li_2TiO_3 **(0.33)**	350	820	1000	1550
$LiAlO_2$ (**0.27**)	420	850	1100	1610

- The increase of temperature helps in power and tritium recovery at expense of the stability of ceramics.
- A compromise was stated.
- T_{min} is stated by τ = *1 day*
- T_{max} results from dimensional (T_{1max}), chemical, thermal and mechanical stability remaining *acceptable* as the durability *(*T_{2max}) under irradiation at extended burn-up
- A large data-base exist for pellets (density 70-80% of TD) tested by several tens of irradiation experiments performed in fission reactors.
- Microstructure (grain size) play an important role on T_{1max} –T_{min} windows

A Li-ceramic breeder ranking list based on main properties

Items \ Materials	Li_2O	Li_2TiO_3	Li_2ZrO_3	Li_4SiO_4	γ-$LiAlO_2$	Points
Li Density (g/cm^3)	⑤ 0.94	③ 0.43	② 0.38	④ 0.51	① 0.27	×3
Thermal Conductivity (500°C)•(W/m/°C)	⑤ 4.7	② 2.4	① 0.75	④ 2.4	④ 2.4	×2
Thermal Expansion (500°C)•(DL/L_0%)	① 1.25	③ 0.8	⑤ 0.50	② 1.15	⑤ 0.54	×1
Reaction of Water	① very	⑤ less	⑤ less	③ little	③ little	×3
Residence Time (440°C)•(h)	⑤ 0.03	(⑤) (-)	⑤ 0.01	② 3.0	① 50	×4
Swelling* (DV/V_0%)	① 7.0	(⑤) (-)	⑤ <0.7	③ 1.7	⑤ <0.5	×1
Transmutation Nuclides	⑤ $^{16}O(n,p)$:7s	② $^{46}Ti(n,p)$:84d $^{47}Ti(n,p)$:3.4d $^{48}Ti(n,p)$:1.8d	① $^{90}Zr(n,p)$:64h $^{91}Zr(n,p)$:57d $^{94}Zr(n,2n)$:10^6y $^{96}Zr(n,2n)$:64d	④ $^{28}Si(n,2n)$:4s $^{29}Si(n,p)$:6m $^{30}Si(n,\alpha)$:9m	③ $^{27}Al(n,2n)$:6s $^{27}Al(n,p)$:9.5m $^{27}Al(n,\alpha)$:15h	×3
Evaluation	65	(62)	56	54	43	

＊: [^6Li Burn up]= 3atm% (500°C)

[Evaluation]=[point of item]•[Points]

Pebbles vs. pellets

- Large brittle ceramics are weaker than small ones.
- Single small pebbles (size below ~ 1 mm) get small thermal gradients as shared by a “pebble-bed” undergoing a large heat generation, their mechanical degradation should be reduced as compared to an equivalent geometric pile of pellets (dimensions ~ cm and above).
- Small spheres are easy movable and handled in (remote) plants.

Li-ceramics fabrications

- Classical routes for powders: (for all the Li oxides)
  - Calcining, a solid state reaction induced by carbonates decomposition under annealing to get the needed compounds as fine powder;
  - examples:
    - $Li_2CO_3 + TiO_2 \rightarrow Li_2TiO_3 + CO_2$
    - $Li_2CO_3 \rightarrow Li_2O + CO_2$
  - Forming: powders are cold pressed in dyes of the needed shape (pellets); pebbles are obtained by extruding-cutting-spheronizing or by powders agglomeration in a rotating device.
  - Sintering: high temperature annealing-sintering at the needed density (% of TD)
- Melt-spraying: A molten compounds mixture is sprayed in drops solidifying during their flight;
- example: molten Li_2CO_3 and SiO_2 to fabricate Li_4SiO_4 pebbles
- Wet or Sol-Gel routes: “drops” of a solution of Li and Metal salts are “gelled”, then dried and sintered in nice spheres

Fabrication of Li-Orthosilicate at Schott Glas

R. Knitter, G. Piazza, J. Reimann, P. Risthaus, L. V. Boccaccini (FZK)

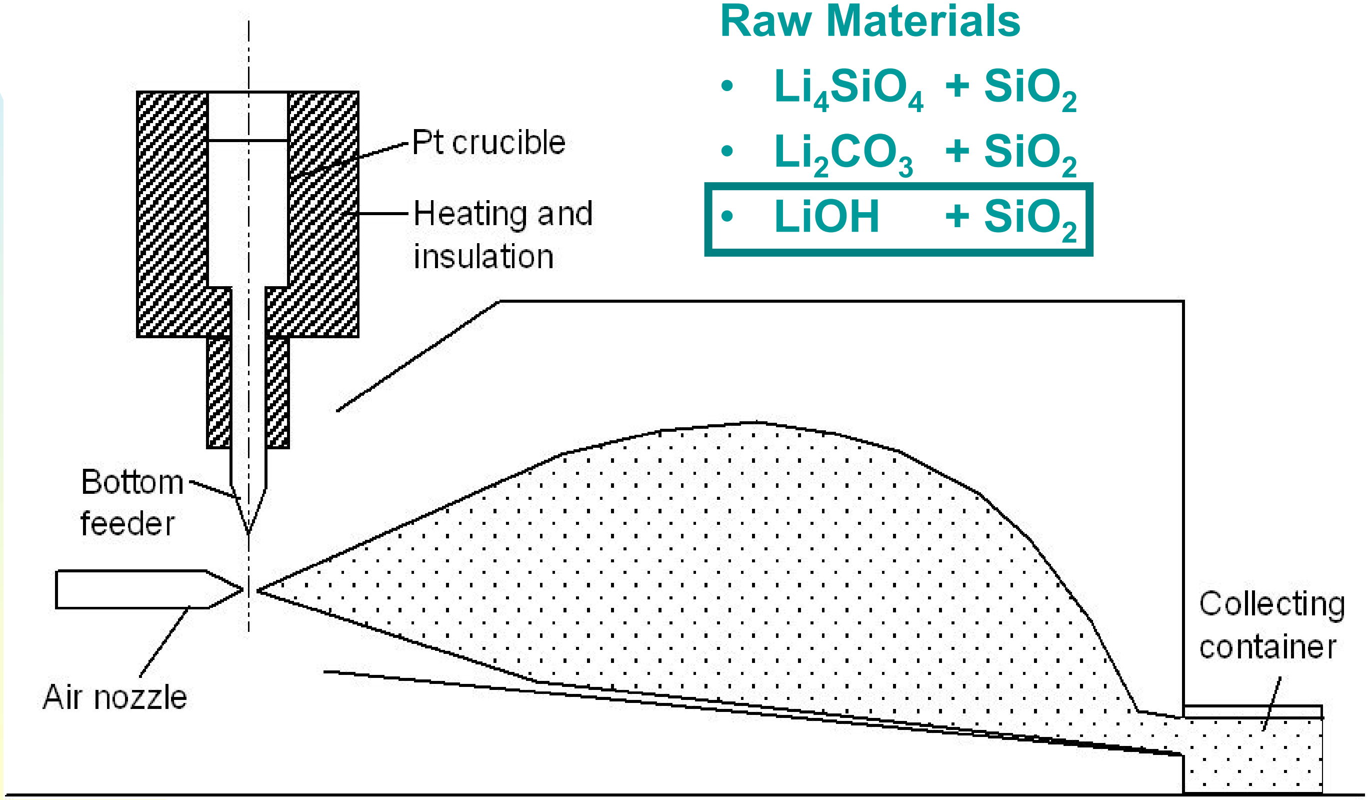
➔Aim Li_4SiO_4 + 2.5 wt% SiO_2

Raw Materials

- Li_4SiO_4 + SiO_2
- Li_2CO_3 + SiO_2
- LiOH + SiO_2

1450°C

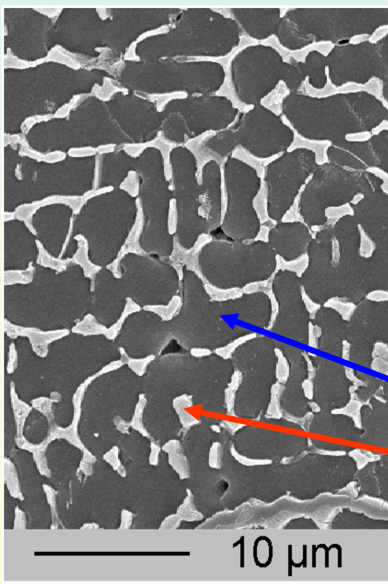
~ 1350°C



Melt-Spraying Facility at Schott Glas, Mainz

Production	2 x 1.5 kg per day
Yield of screened pebbles	50 % (250 – 630 µm)
	200 – 300 kg per year
Drawbacks	Batch processing
	Limited control of fabrication parameters
➔	Variation of batch properties
Advantage	Recycling of material

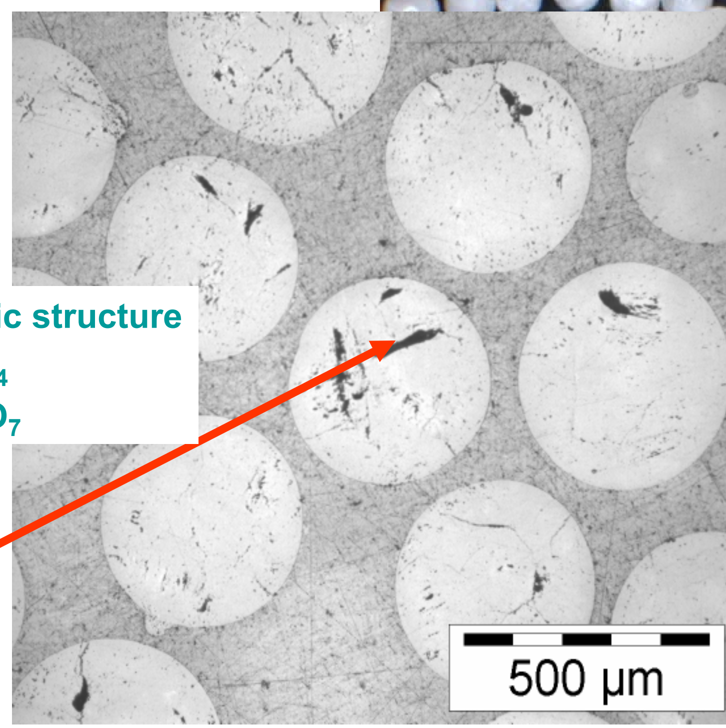
pebbles cross section

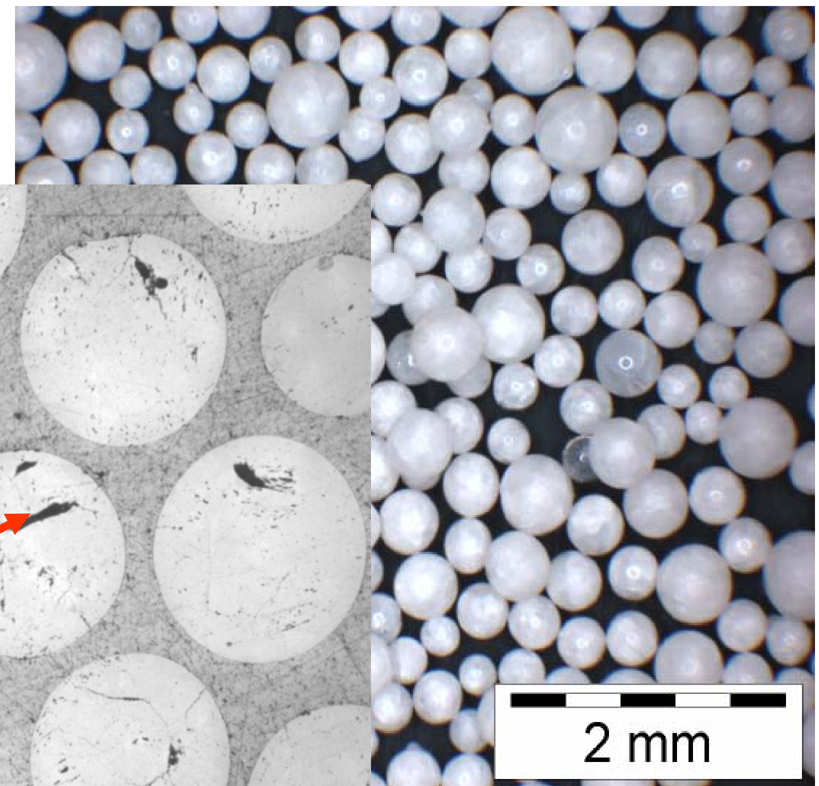


Dendritic structure

Li_4SiO_4

$Li_6Si_2O_7$





micropores

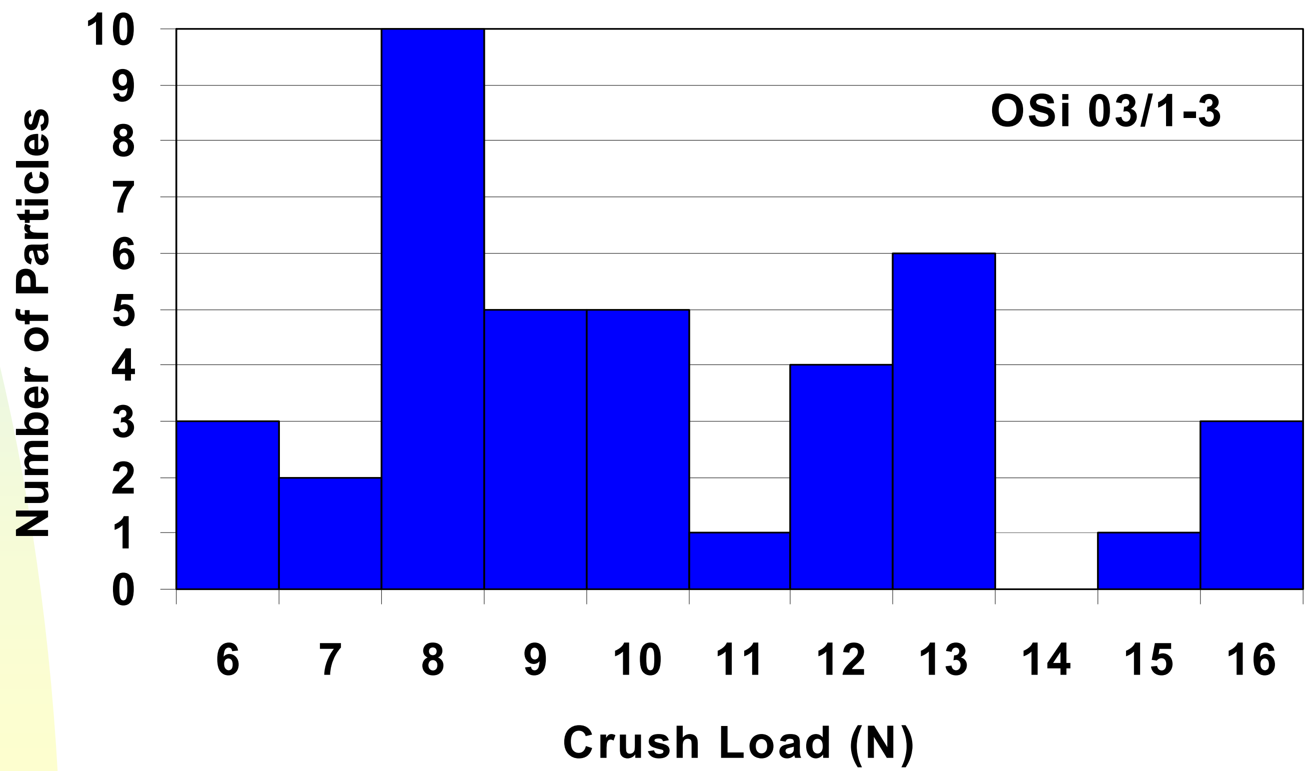
R. Knitter, G. Piazza, J. Reimann, P. Risthaus, L. V. Boccaccini
(FZK- Karlsruhe)

Crush Load OSi 03 ex hydroxide

Pebble diameter 500 µm (dried at 300°C)

Batch 1- 3

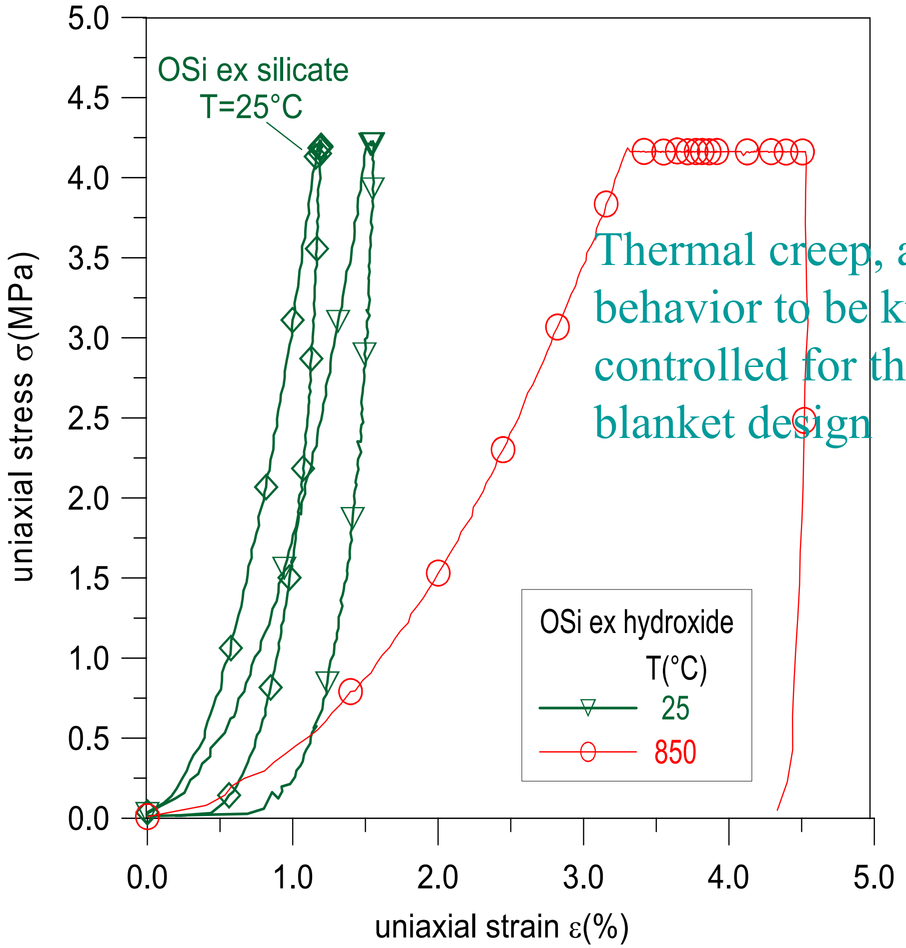
10.1 ± 2.8 N



Thermomechanical Tests on Pebble Beds

R. Knitter, G. Piazza, J. Reimann, P. Risthaus, L. V. Boccaccini (FZK- Karlsruhe)

Stress-strain dependence for T = 25°C and T = 850°C



Thermal creep, an irreversible behavior to be known and controlled for the HCPB blanket design

Li_4SiO_4 pebbles fabrication Conclusions

R. Knitter, G. Piazza, J. Reimann, P. Risthaus, L. V. Boccaccini (FZK)

Fabrication of lithium orthosilicate pebbles using LiOH and SiO_2 as raw materials in a melt-sprying process

- material meets the specification of HCPB
- single process for all required ^{6}Li enrichments
- low impurities by high-purity raw material
- rejections and irradiated material can be recycled
- variation in batch properties are due to batch processing and will be reduced by a continuous process

EXTRUSION-SPHERONISATION-SINTERING PROCESS

The process can be adapted to a range of pebbles specifications (pebble size, pebble density, grain size).

The purity level of the pebbles is very good.

The current facility at CTI (Caramiques Techniques et Industrielles) allows to produce 150 kg/year of Li_2TiO_3 pebbles.

Pebble size from 0.6 to 1.2 mm with density ranging about 90% of TD and an average crash load of about 30 N

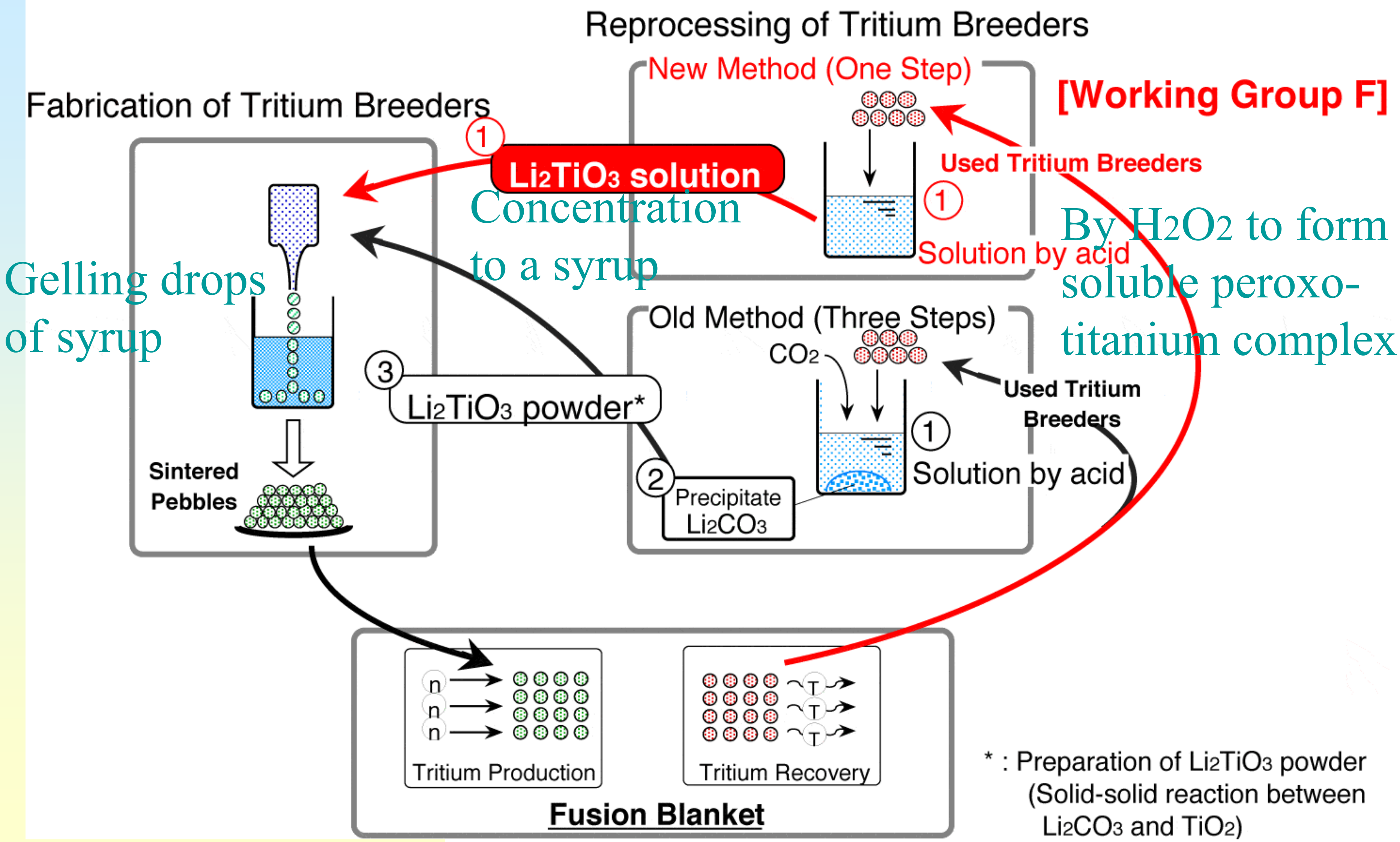
INVESTIGATION OF 0.6-0.8 mm Li_2TiO_3 PEBBLES

Characteristics of Li_2TiO_3 pebbles

Reference of batch	Pebble size (mm)	Open porosity (%)	Closed porosity (%)	Bed density (g/cm^3)	Grain size (µm)	Cr. load (N)
CTI 1532 Ti 1100 CEA	0.8 - 1.2	6.0	5.3	1.82	1.5 - 5	30 ±15
		88.7% of T.D.				
CTI 942 Ti 1100 CEA	0.6 - 0.8	2.0	4.9	1.91	1 - 4	30 ±15
		93.1% of T.D				

SOL GEL fabrication routes

Comparison between Old and New Methods on Pebble Fabrication



Objectives and Implementation Sharing of Working Group F

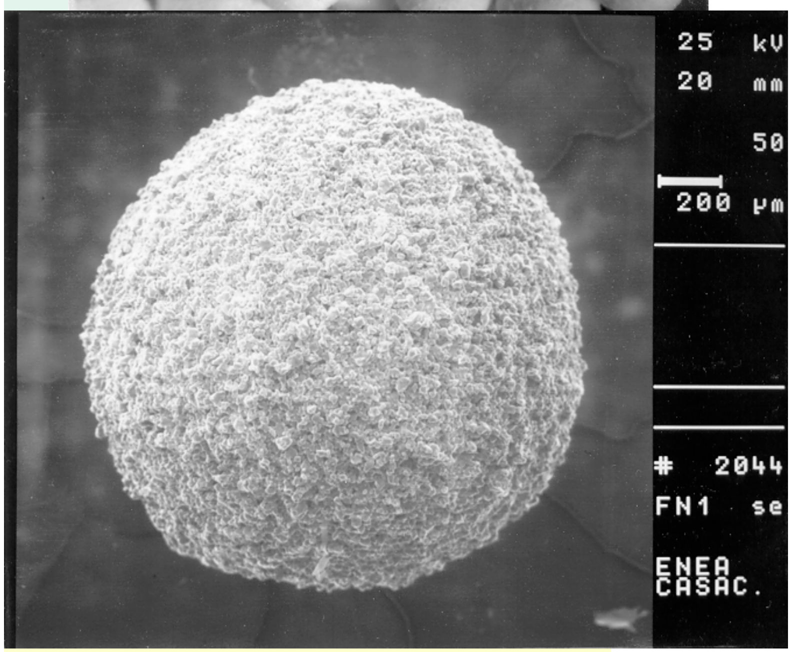
Objectives

The objectives of new task are as follows:

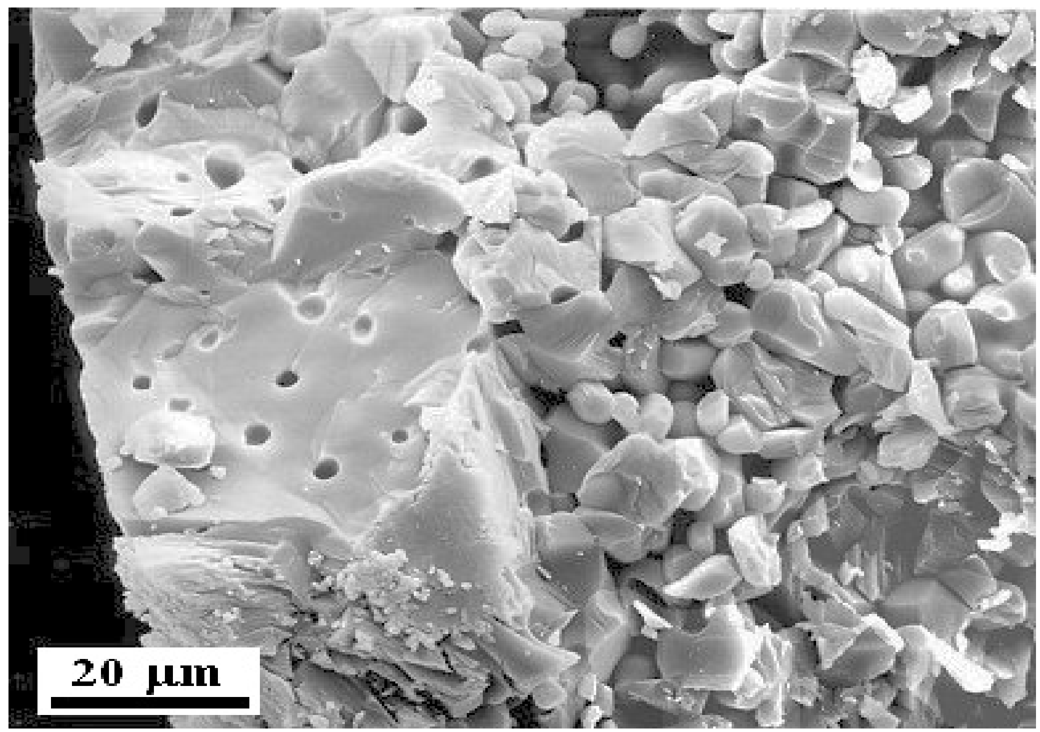
1) Development of small-scale fabrication confirmation by direct wet process (including recycling confirmation of ^{6}Li in Li_2TiO_3 solution)
2) Characterization of Li_2TiO_3 pebbles.

	JAERI	ENEA
Fabrication of Tritium Breeder Pebbles	Fabrication of Li_2TiO_3 pebbles by direct wet process - Fabrication of Li_2TiO_3 pebbles (kg scale fabrication)	Study on recycling confirmation of ^{6}Li in the solution
Characterization of Tritium Breeder Pebbles	Fabrication and delivery of Li_2TiO_3 or oxide-doped Li_2TiO_3 pebbles (or disks) - Selection of oxide for dopping Tritium release property of Li_2TiO_3 or oxide-doped Li_2TiO_3 pebbles (or disks) - Post-irradiation tritium release by TPD tests	Solid-gas chemical interaction of Li_2TiO_3 or oxide-doped Li_2TiO_3 pebbles (or disks) - H_2 consumed by the reaction of the specimen with $Ar+H_2$ purge Kinetics on reduction and tritium release of Li_2TiO_3 or oxide-doped Li_2TiO_3 by calculation code developed in ENEA

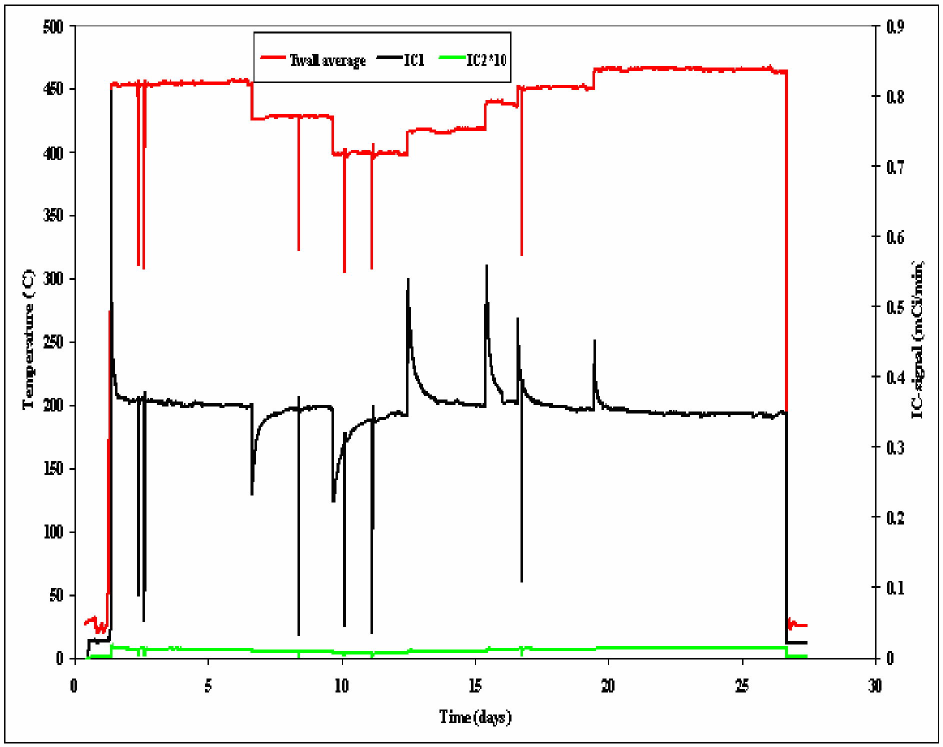
Wet chemical fabrication route of Li_2TiO_3 pebbles



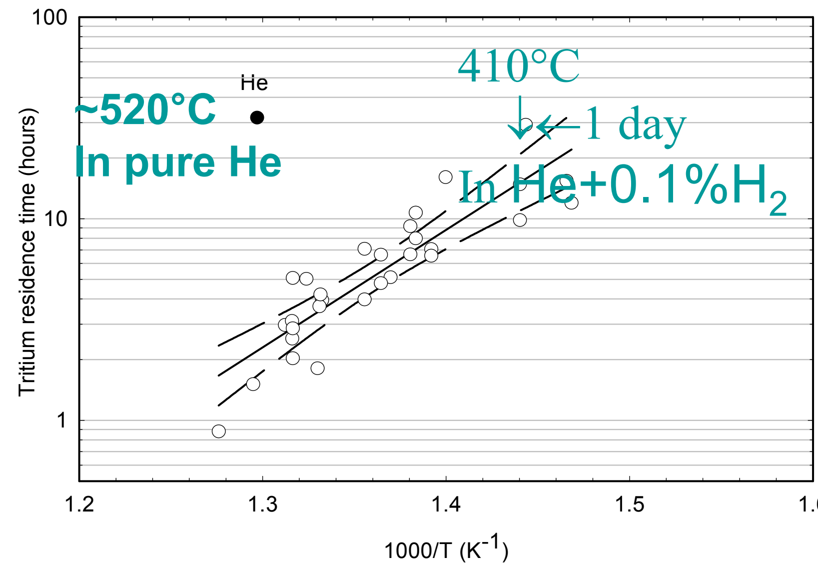
- **In ENEA-Casaccia a density varying from 60% (code FN-1) to 92% of TD (code FN-5) were obtained.**
- **Grain size was 20 ± 10 µm**
- **FN-5 meets the HCPB specifications and was tested in EXOTIC-8.9 experiment**



TRITIUM RELEASE from Li_2TiO_3 pebble bed (FN-5). Effect of the average temperature

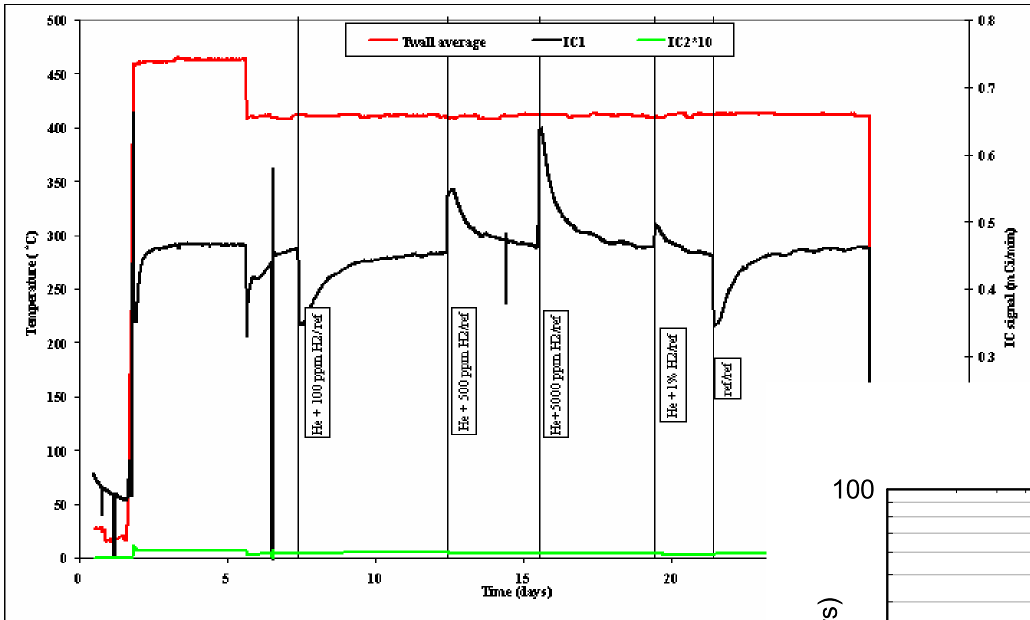


- EXOTIC-8.9 irradiation in HFR-Petten (440 FPD). Cycle 00-02.
- **R**, **I =∫(G-R)dt** and **τ = I/G**, are evaluated by step-changing the temperature, purge gas He+0.1%H_2
- Arrhenius type **τ** activation heat=111 kJ/mol

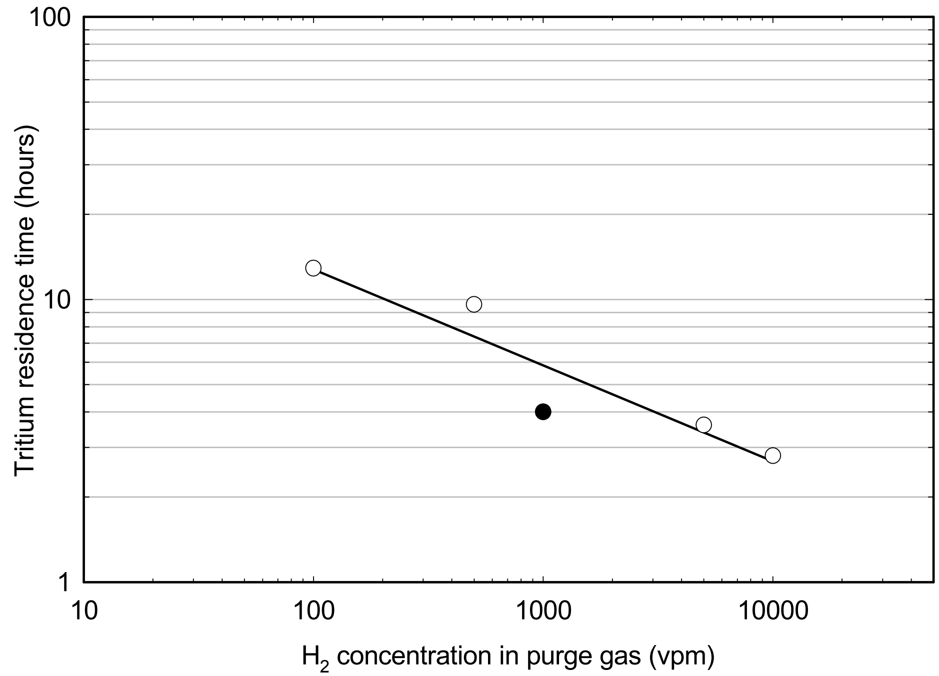


- **T_{min}** = 410°C for **τ** = 1 day
- Note the increase of **τ** in pure He

TRITIUM RELEASE from Li_2TiO_3. Effect of the H_2 in the He purge gas



- EXOTIC-8.9, Cycle 00-07.
- R, hence τ changing with H_2 concentrations in He at 471°C.
- Plot of τ vs. H_2 concentration

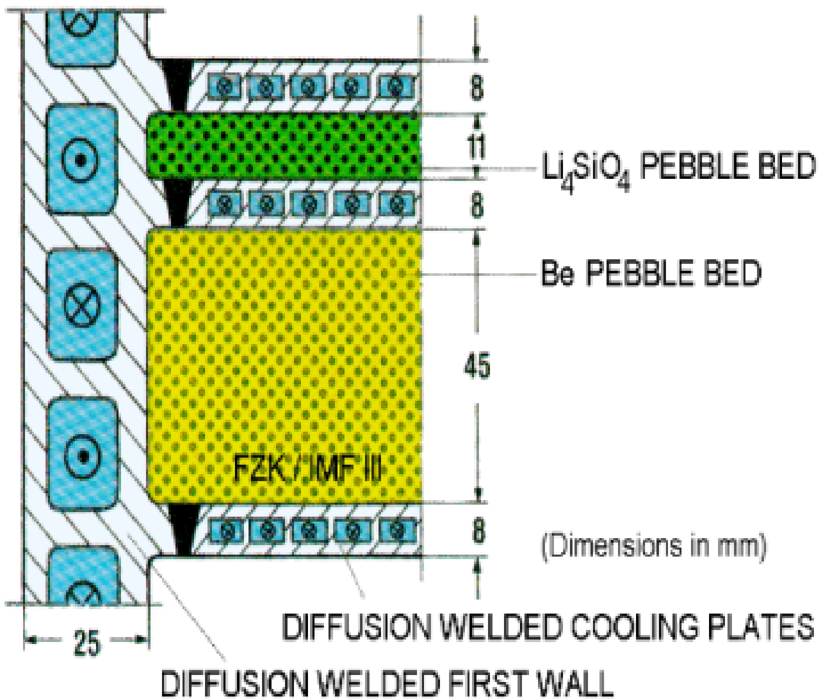


AN ECN KEMA COMPANY

22/02/2005

FZK - BOT blanket concept evolved in European HCPB Blanket for DEMO and ITER-BM

Equatorial He coolant flow



Dalle Donne et al. CERAMIC BREEDER BLANKET FOR NET

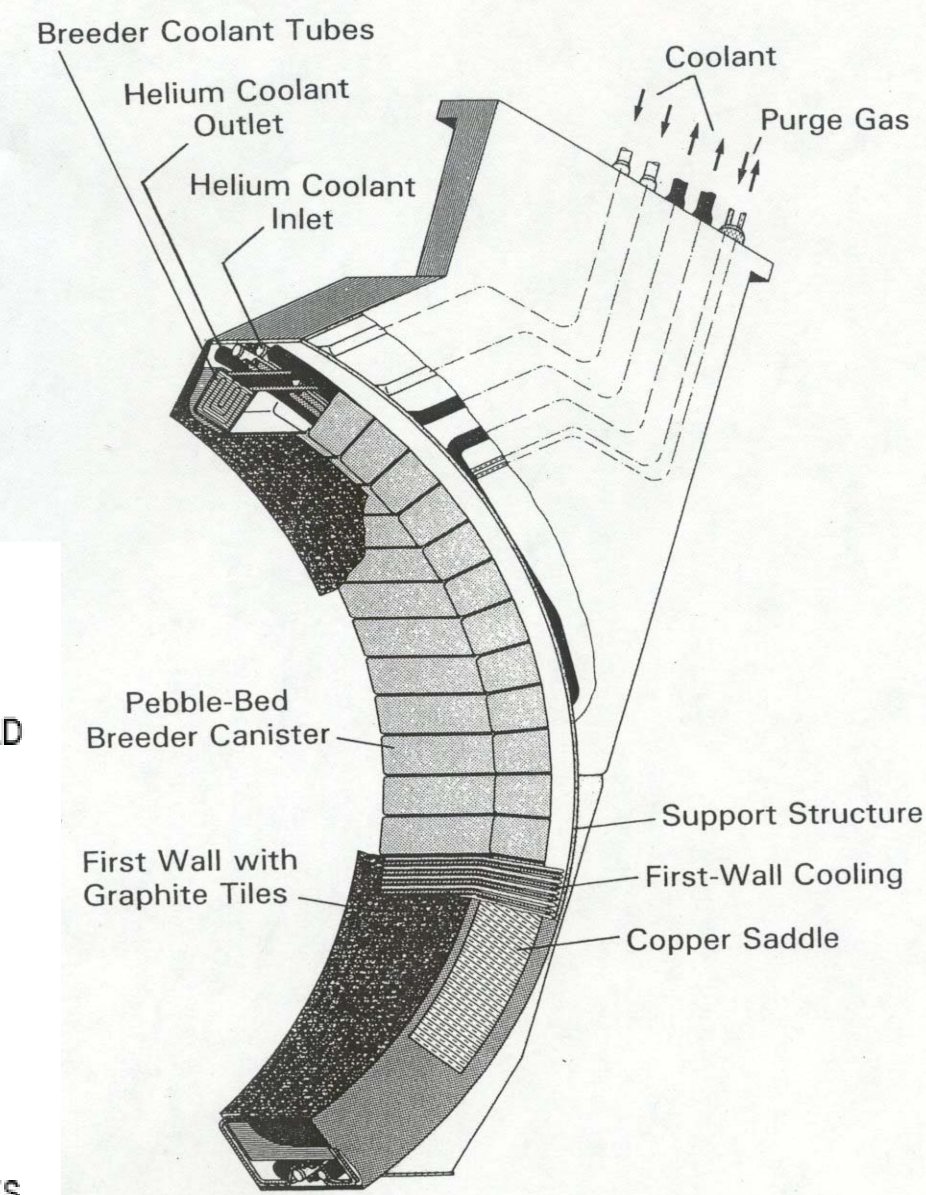
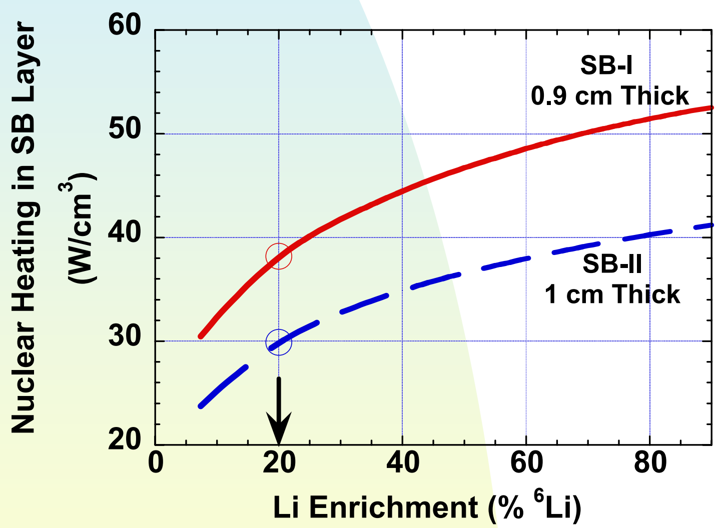


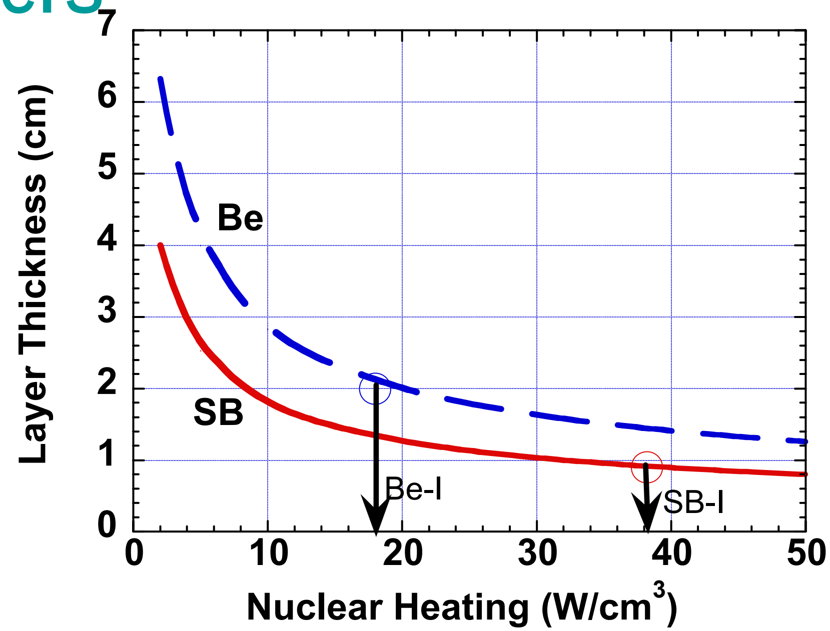
Fig. 3. Isometric view of a lateral segment of the outboard blanket.

Important role of the design

^{6}Li increase gives higher heat deposited in layers

layer thickness is limited by T_{max}





Enrichment of individual layers adjusted to keep heating and upper temperature within limits

High nuclear heating at front implies thin Be and SB layers

NGK Beryllium Pebbles Realize Power Generation in Fusion Reactor

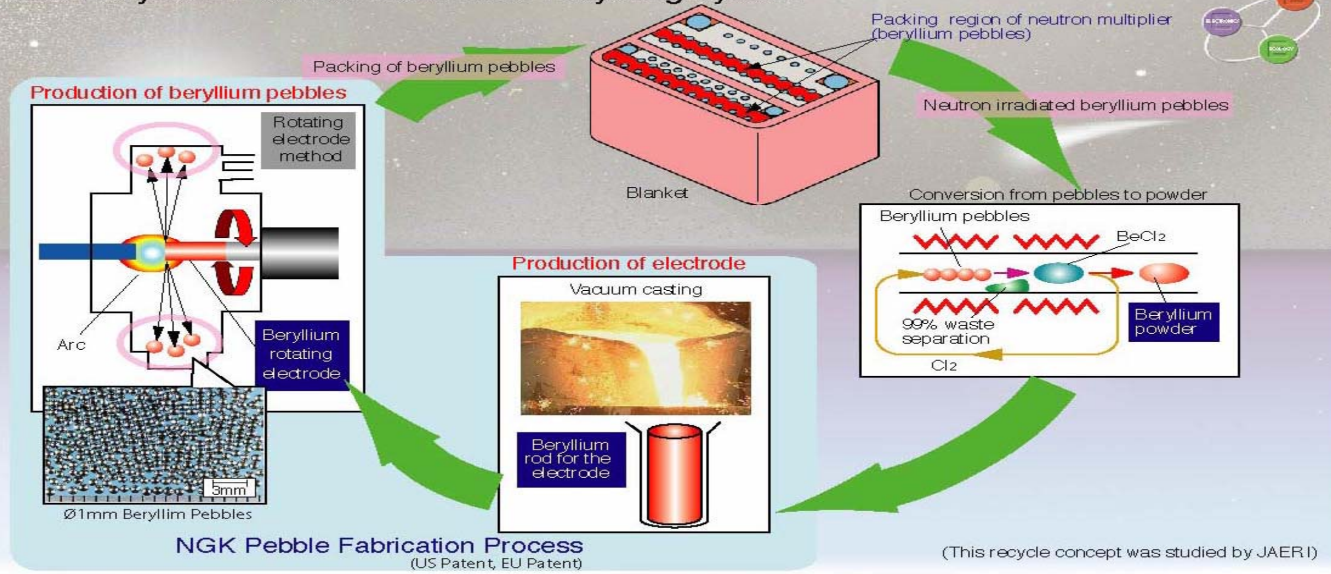
Advantege of NGK Beryllium Pebbles as Neutron Multiplier

- Small swelling under neutron irradiation
- Good spericity and smooth surface
- Easy recycling
- Good productivity

← Rotating Electrode Method

(Developed with JAERI)

NGK Beryllium Pebbles leads total recycling system



(This recycle concept was studied by JAERI)

NGK Beryllium Pebbles (BP-1 : Standard grade) have been selected as International Standard Material for Neutron Multiplier

- Reference Material for EU HCPB
- Reference Material for JA Solid Blanket

NGK INSULATORS, LTD.

http://www.ngk.co.jp/english/

Out-of-pile testing of small-scale and medium-scale HCPB blanket mock-ups

are carried-out at :

1) FZK Karlsruhe – HEBLO facility
2) ENEA Brasimone – HE-FUS3 facilty

OBJECTIVE:

thermal-mechanical behaviour of the pebble beds.

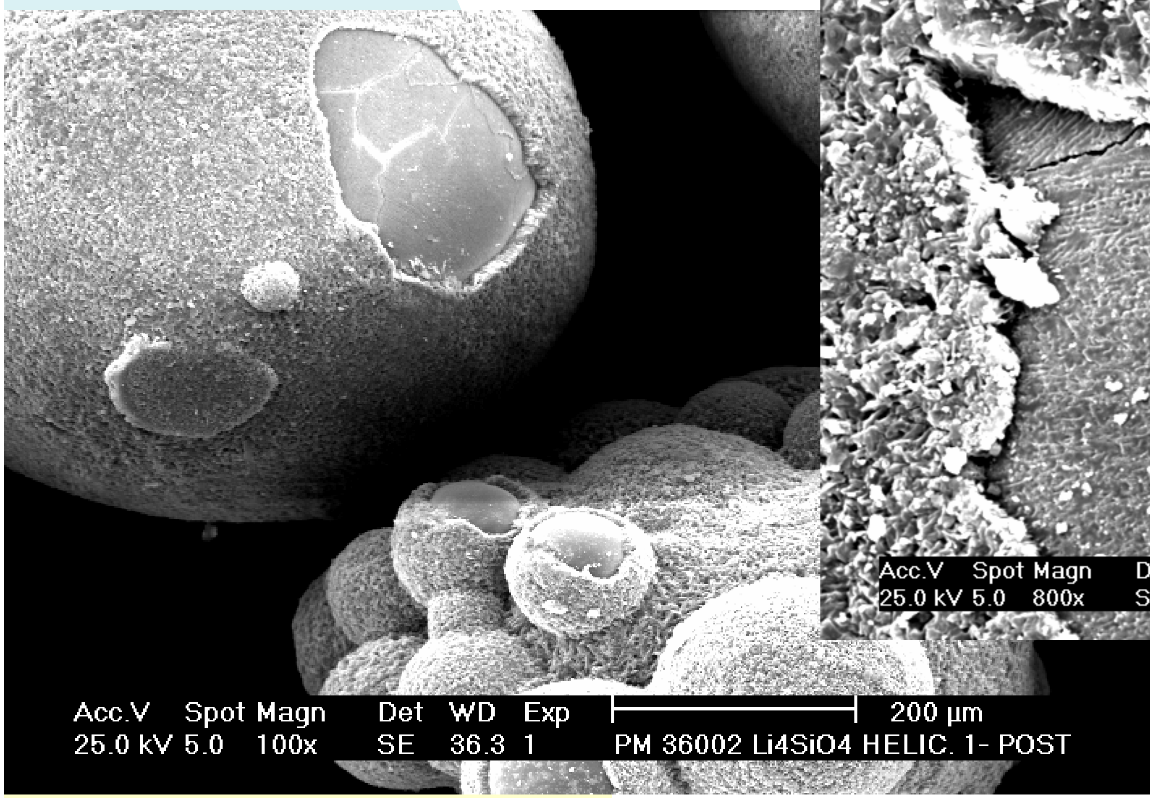
The mock-ups represent portions of blanket segment with adequate adjustment of temperatures, temperature gradients, coolant temperature and flow distribution.

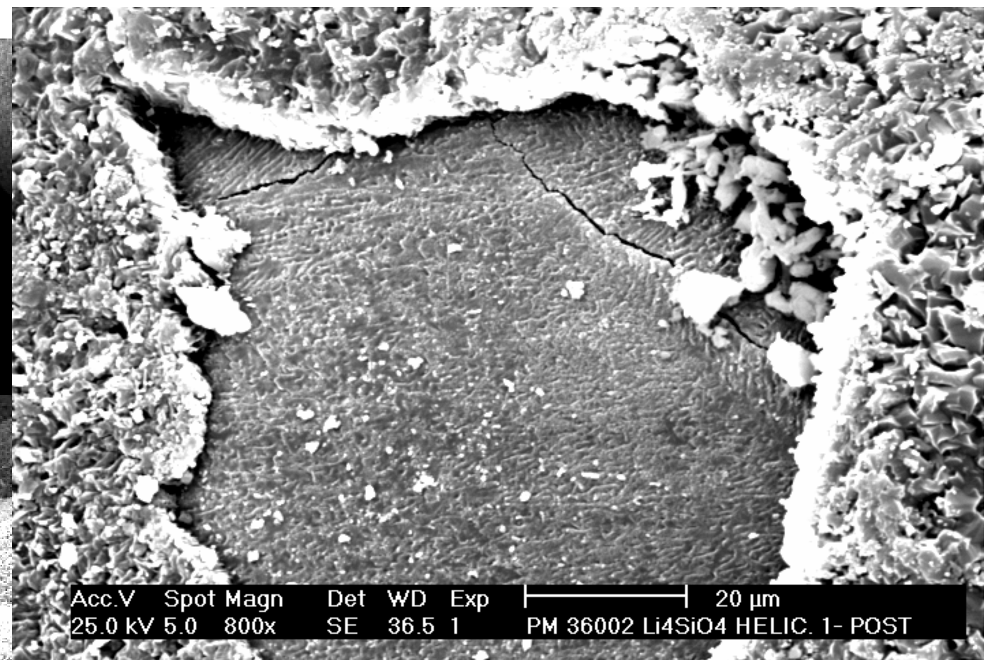
Steady state as well as cyclic power and accidental situations are investigated. Internal heat sources are simulated by flat electrical heaters.

HELICHETTA experiment (ENEA-Brasimone) simulated HCPB thermal cycling of Li_4SiO_4 pebble-beds (top temperature 600-650°C).

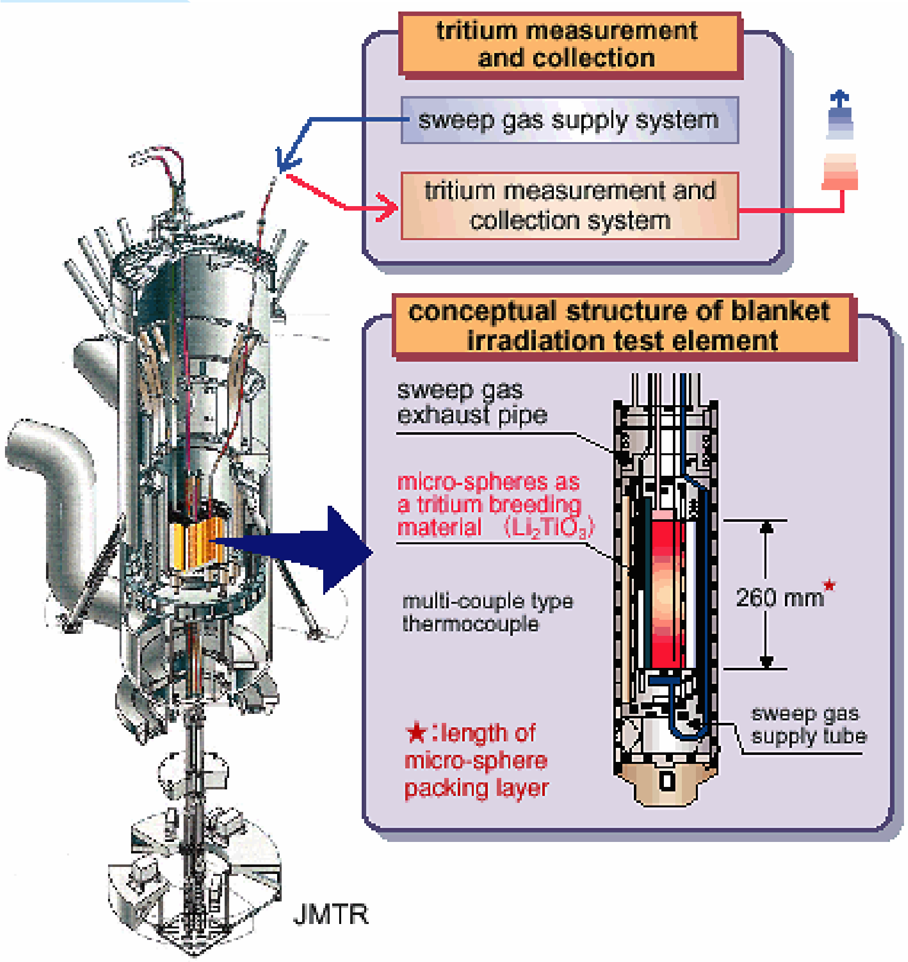
Powders were released from the cells during the pebble discharging (7%).

SEM examination of the pebbles confirmed the pebble necking and superficial fragmentation.



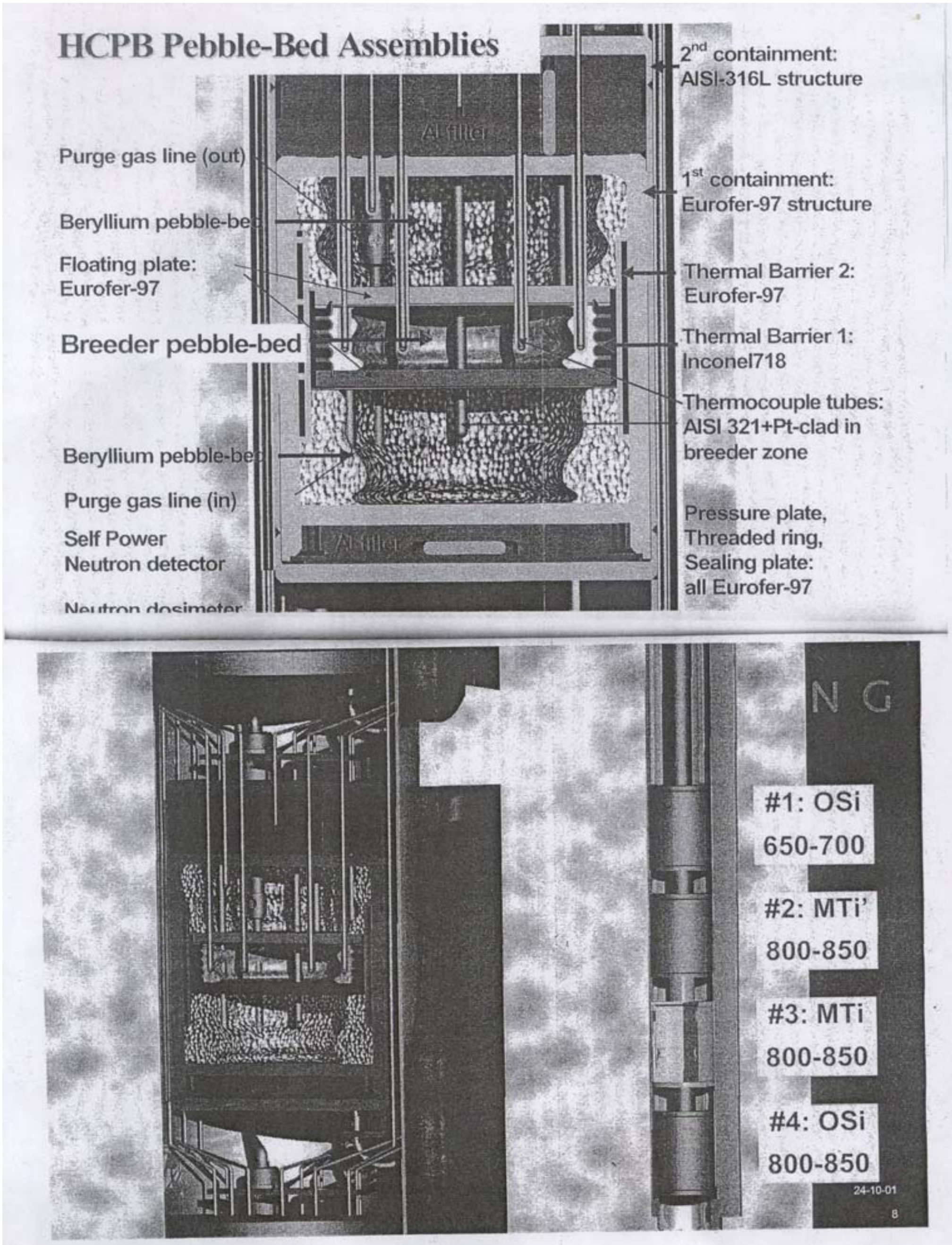


Tritium Breeding Modules (TBM) tests in High Flux Fission Reactors



- TBM with ^{6}Li-tailored ceramics are being irradiated in representaive environment (neutron flux, dose, BU and dpa)
- In EU (in HFR-Petten): and
- In JAERI (in JMRT-Oarai)

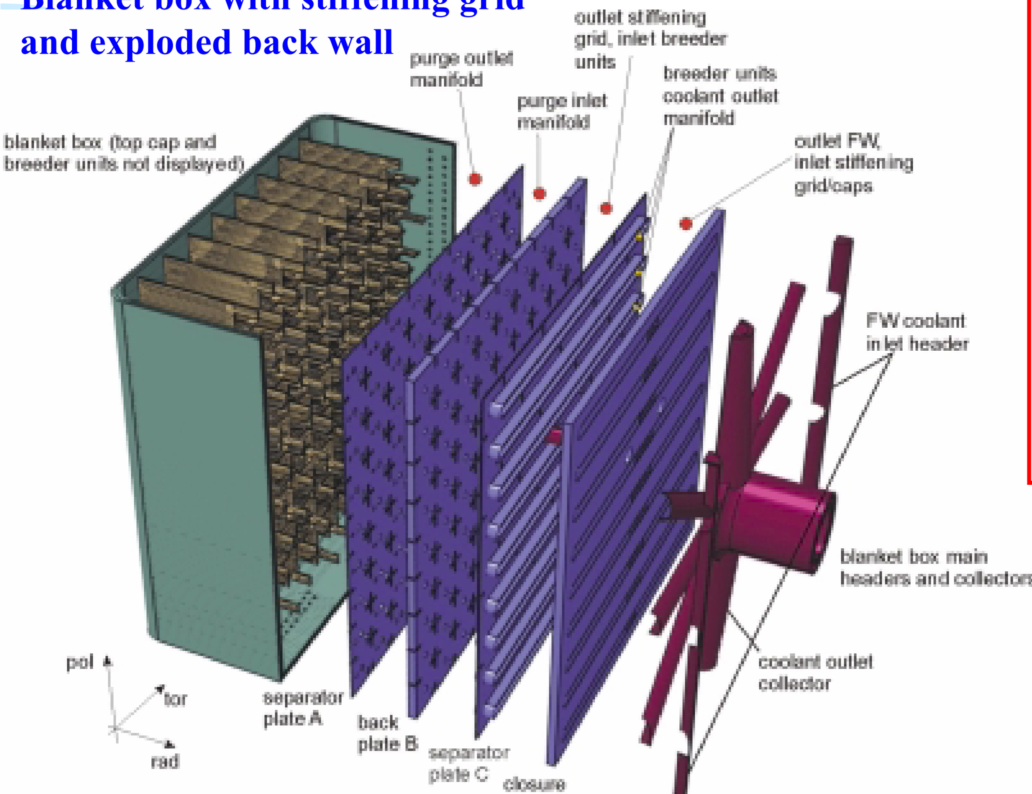
HICU (High neutron fluence Irradiation of pebble staCks for fUsion)

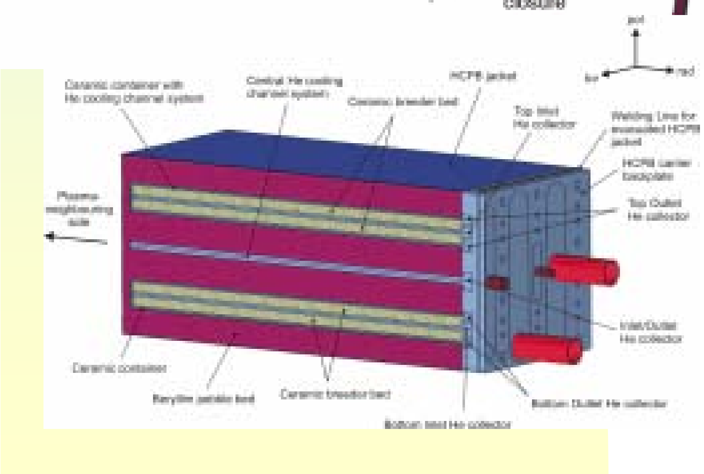


- Effect of neutron irradiation on the thermal-mechanical pebble bed at DEMO representative levels of temperatures and defined thermal-mechanical loads
- Li-isotope compostion in Li_2TiO_3 and Li_4SiO_4 pebbles and neutron spectrum tailored to have in the High Flux Reactor HFR-Petten a
- Fast neutron rate allowing DEMO relevant target dose of 20 dpa, dpa/BU ratio as well as 10-15% BU

Current He-Cooled Ceramic Breeder Blanket Module

Blanket box with stiffening grid and exploded back wall





Blanket breeder unit

- **Module design**
  - Dimension up to 4m x 2m x 0.8m
  - Box design with an array of stiffening grids (~20 cm spacing) to withstand coolant pressurization

  CB (Li_2TiO_3 or Li_4SiO_4) and Be in form of pebble beds, FS as structural material

Cool. T_{in}/T_{out} =300/500°C
Cool. P =8 MPa
Max FS Temp. <550°C
Max. Be Temp. < 750°C
Max CB Temp. <920°
Energy Multip. =1.25
TBR = 1.14
Cycle Eff. ~37% (Rankine)
Lifetime = 15MW-a/m^2

* S. Hermsmeyer, et al., "Revision of the EU Helium Cooled Pebble Bed Blanket for DEMO," SOFE 2003

CONCLUSION

- Li-ceramic breeder R&D started 20 years ago, when by the "TRIO" experiment resulted that
- *fusion fuel can be bred and recovered safely*
- (R.G. Clemmer, ANL-84-55 rep., J.Nuc. Mat. 133&134(1985)171).
- Data-bases of lab-scale fabricated pellets have been achieved by tens of materials-irradiations matrix tests for Li_2O, $LiAlO_2$, Li_2ZrO_3, Li_4SiO_4, Li_2SiO_3 performed by U.S., Canada, Japan and EU co-operation (BEATRIX programs) finished in 1995, accompanied by the EBR-II and FFTF fast breeder reactors final shut-down.
- Now pre-industrial-scale batch-production of ceramic pebbles is "optimized" and R&D for industrial continuous production may start.
- Li_4SiO_4 (FZK-Schott)
- Li_2TiO_3 (CEA-CTI, JAERI-NGK)
- Be and berillides (NGK)
- The pebble beds of these materials are being tested in mock-ups or modules in thermal fission reactors (HFR-Petten and JMRT) by Li-isotope and neutron spectrum tailoring allowing relevant simulation
- of DEMO fusion reactors and supply of data for the ITER BM designs