



ARIES-DB Design Issues

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- TBR-related issues – what's new?
- ITER reweldability limits for 316-SS – an update.
- OB DCLL blanket segmentation – a suggestion.
- Degradation of physical properties with neutron irradiation – few examples.



TBR-Related Issues

What's new?

- T cost to supply 1% deficiency in breeding.
- New experimental results measuring LiPb tritium production rate (TPR).
- Impact of “plasma burn-up fraction” on TBR requirements.
- Net TBR comparison: ARIES vs UCLA.
- Li content in LiPb eutectic. **17 at%** or **15.7 at%**



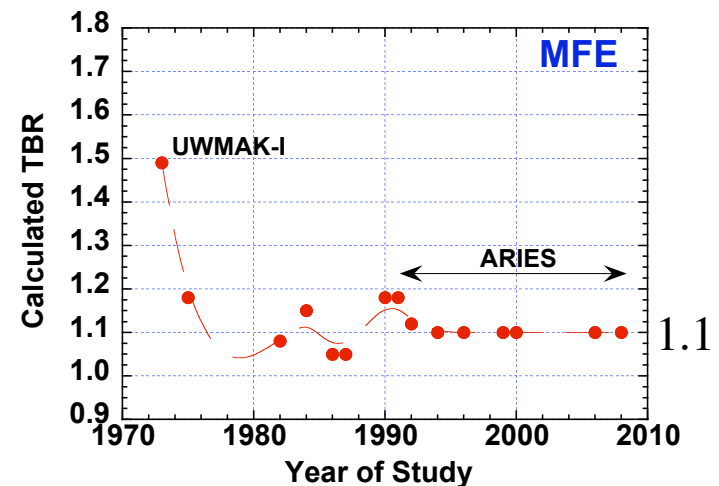
T cost to Supply 1% Deficiency in Breeding

- **T cost is excessive:**
 - \$30,000 / g of T - Canada
 - > \$30,000 / g of T - US (including shipping/handling)
- 1% less breeding $\Rightarrow$ Shortage of ~ 1 kg of T/y* for 2 GW P_f
- Cost of purchasing T exceeds \$100,000/day.

Calculated TBR should be accurately estimated
to avoid purchasing T during operation

* Based on 55.6 kg/y per GW P_f .

TBR Requirements



- **Background info:**

- **ARIES** designs considered Calculated TBR of 1.1 for liquid breeders
- Breeding margin (TBR -1) divided into 4 categories:
 - Margin for known deficiencies in nuclear data (6*-10%)
 - Margin for known deficiencies in modeling (3*-7%)
 - Margin for unknown uncertainties in design elements (0*-3%)
 - Margin for T bred in excess of T consumed in plasma (1*-2%).

- **New evaluation/assessment:**

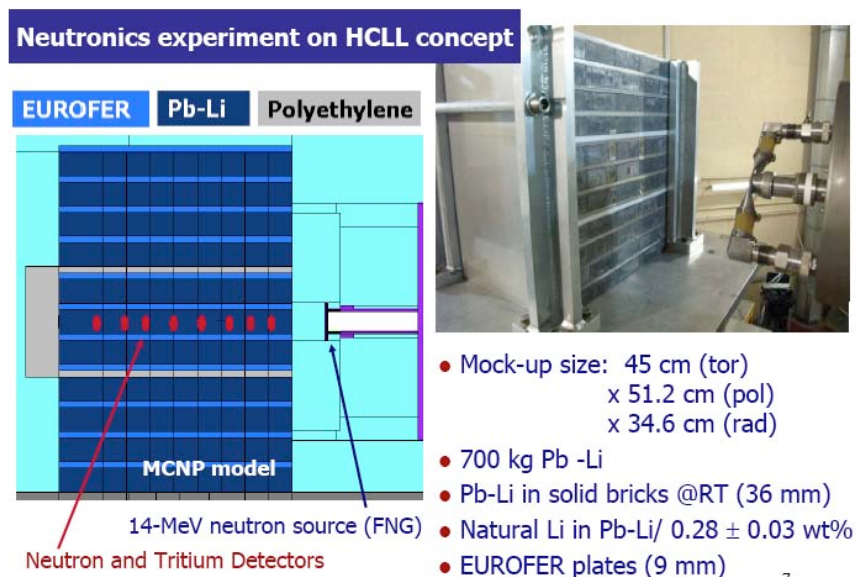
- FNG experimental measurement of LiPb tritium production rate (Margin # 1)
- Sensitivity of “excess T bred” to “plasma burn-up fraction” (Margin # 4).

* Considered for ARIES LiPb designs.

FNG Experiment @ ENEA Italy

B. Batistoni et al., “Neutronics Experiments on HCPB and HCLL TBM Mock-ups in Preparation of Nuclear Measurements in ITER,”

Presented at ISFNT-9, Oct. 11-16, 2009, Dalian, China.



Calculations correctly estimate TPR within total experimental uncertainty (~7% - too large). Future experiments will reduce uncertainties in:

- Experimental results
- Measurement of Li content in LiPb.

These results suggest reducing TBR margin for nuclear data deficiencies from 6% to 3% until FNG conducts new LiPb experiments with more accurate measurements.

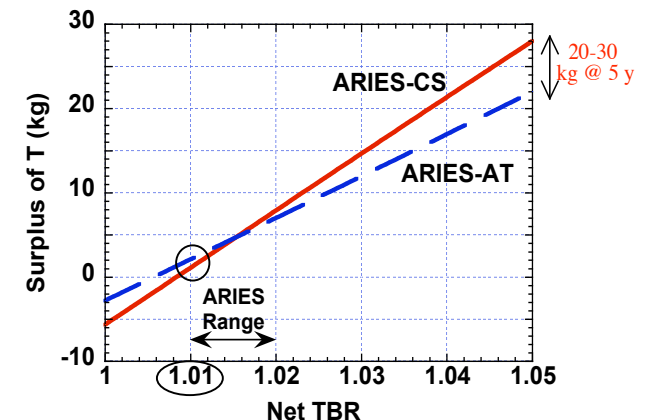
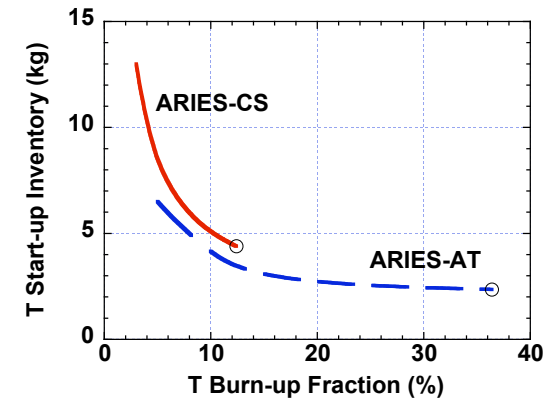
⇒ Reduce required calculated TBR from 1.1 to 1.07

LiPb obtained from Fusion for Energy had much lower lithium content (0.28 wt%) than expected for $\text{Li}_{17}\text{Pb}_{83}$ (0.68 wt%).



Plasma Burn-up Fraction Has **NO** Major Impact on “Excess T” Bred for Start-up of New ARIES-AT-type Plant

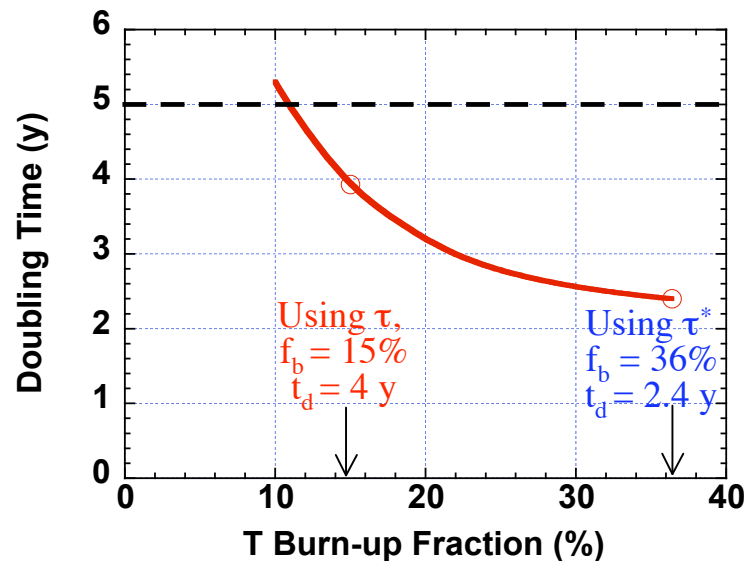
- Startup inventory of T for new power plant depends on burn-up fraction (f_b).
- Low f_b means:
 - High startup inventory, or
 - Long doubling time ($t_d = 1-5y$) (defined as time needed to supply new power plant with start-up T).
- If new design calls for lower f_b , ARIES prefers using t_d as knob to meet breeding requirements.
- Generating excessive T causes serious storage problem and raises licensing concerns.
- Note that:
 - CANDUE will produce 25 kg of T by 2025
 - Currently, PPPL is licensed for only 5 g of T
 - 4 kg of T in ITER, per N. Taylor.





Plasma Burn-up Fraction Has **NO** Major Impact on “Excess T” Bred for Start-up of New ARIES-AT-type Plant (Cont.)

- Per C. Kessel:
 - f_b is proportional to “particle confinement time” (τ) [difference between time of T injected into plasma and time of T lost out of plasma].
 - τ^* accounts for recycling of T from walls back into plasma.
 - $\tau^* > \tau$.
- Which confinement time should we use to estimate t_d ? τ or τ^* ?
- In ARIES-AT, we used τ^* : $f_b = 36\%$ and $t_d = 2.4$ y.
- Using τ , $f_b = 15\%$ and $t_d = 4$ y (still < 5 y).



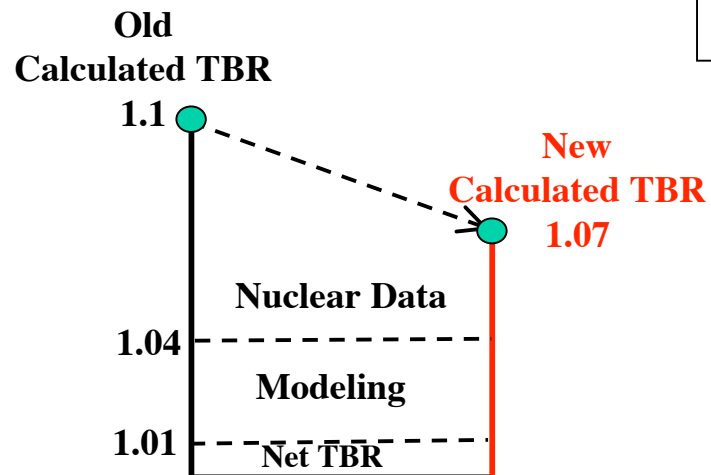
ARIES-AT
Net TBR= 1.01

Net TBR Comparison: ARIES vs UCLA

**No realistic blanket design
can breed that much T**

→ **Calculated TBR > 1.25**

T surplus ~ 50 kg !
**High Net TBR causes
serious T storage and
licensing problems**



ARIES
(LiPb System)

Nuclear Data (6-15%)

Modeling > 3%

Net TBR ~ 1.15

for: $f_b \sim 5\%$

$t_d = 5$ y

2 d T reserve

1.5 GW P_f

(~ 6 kg to fuel new plant)

UCLA



Remarks on TBR Requirements

- Serious effort should be made to **reduce breeding requirements** (i.e., Net TBR and all uncertainties).
- Unnecessary high breeding requirements already drew criticism for fusion.
- **M. Dittmar (Zurich) reported** in “The Oil Drum: Europe (11/10/09):
 - The list of fusion problems is already very long and shows that the belief in a self-sufficient tritium chain in completely unfounded
 - Experiments show that measured TBR results are consistently ~15% lower than the modeling predicts (Sawan and Abdou FED paper, 2006)
 - One might conclude that today’s experiments show consistently that no window for self-sufficient breeding currently exists and suggest that proposal that speak of future T breeding are based on nothing more than hopes, fantasies, misunderstandings, or even international misrepresentations.
- **Advanced physics and technology should reduce breeding margin below 7%,** (as ARIES suggests) through:
 - High burn-up fraction > 10%
 - More accurate measurement of LiPb TPR
 - Careful choice of design elements that degrade breeding (FW thickness, stabilizing shell materials and location, etc.)
 - State-of-the-art 3-D neutronics models using CAD-MCNP interface.



Li₁₇Pb₈₃ or Li_{15.7}Pb_{84.3} ?

Reference:

P. Hubberstey et al., “Is Pb-17Li really the eutectic alloy? A redetermination of the lead-rich section of the Pb-Li phase diagram ($0.0 < x_{\text{Li}}(\text{at}\%) < 22.1$),”
Journal of Nuclear Materials 191-194 (1992) 283-287.

- Single LiPb liquid phase is maintained over wide range from 13.7 to 18 at% Li.
- *LiPb eutectic lies at 15.7 at% Li, not 17 at%.*
- T solubility in LiPb is sensitive to Li content.
- Should ARIES-DCLL design consider Li_{15.7}Pb_{84.3} instead of Li₁₇Pb₈₃ ?
- If so, its *minor* impact on TBR will be determined.

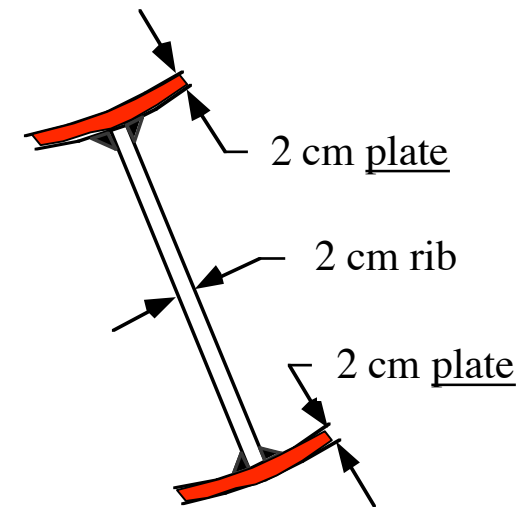
ITER Reweldability Limits for 316-SS

< 1 He appm for **thick plate** welding

< 3 He appm for **thin plate** or **tube** welding

Reference: ITER Nuclear Analysis Report G 73 DDD 2 01-06-06 W 0.1 - Section 2.5.1, page 15.

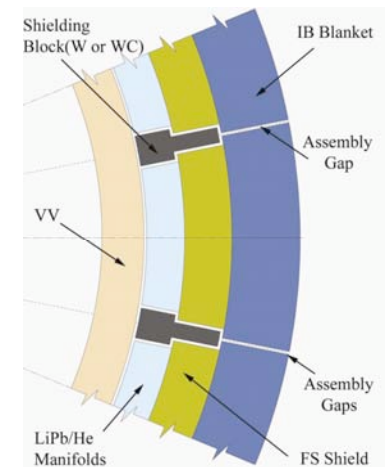
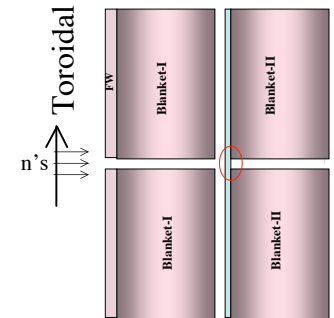
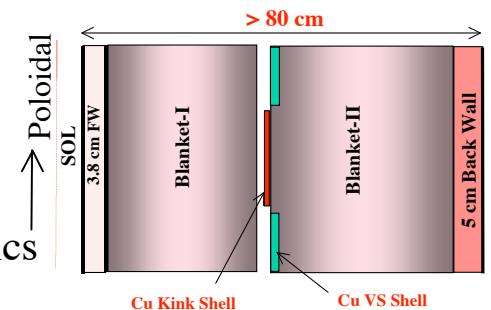
- Double-walled vacuum vessel with internal ribs:
 - ITER: **6 cm** plate of 316-SS and 1 appm limit
 - ARIES: **2 cm** plate of FS and 1 appm limit.
- Should ARIES:
 - Adopt ITER higher limit for thinner FS plate? or,
 - Revisit ARIES VV design?



ARIES-AT VV

Segmentation of OB DCLL Blanket

- T breeding calls for fairly thick OB blanket (80 cm).
- Possible location for OB stabilizing shell is behind OB blanket (undesirable for advanced physics).
- **Advantages of blanket segmentation:**
 - Place stabilizing shells between blanket segments to enhance physics
 - Replace outer segment less frequently:
 - Reduce replacement cost
 - Minimize radwaste stream.
- **Concerns:**
 - Neutron streaming through assembly gap shortens lifetime of outer segment
 - Sensitivity of stabilizing shells to n streaming (swelling, electric resistivity, etc.)
- **Suggestion:**
 - Provide right-angle bend gaps with WC shield insert (as proposed for IB).
- **Question:**
 - How to protect toroidally continuous IB & OB shells against streaming neutrons?
- Several **iterations between physics and engineering** will determine:
 - Optimum IB & OB shell locations
 - Size of OB blanket segments
 - Impact of shells on TBR.



Degradation of Physical Properties with Neutron Irradiation – Few Examples

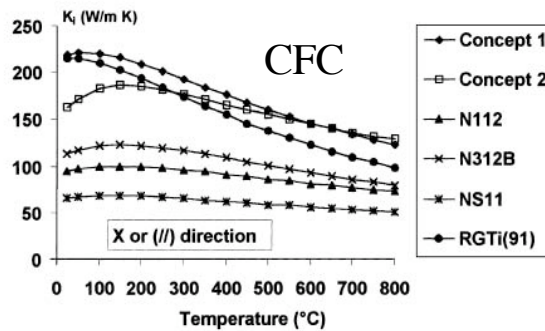


Fig. 3. Thermal conductivity of the materials as a function of the temperature after irradiation at 775°C/0.35 dpa g.

Ref.: Neutron Irradiation Effects on Carbon Based Materials at 350°C and 800°C, J.P. Bonal, C.H. Wu, Journal of Nuclear Materials, 277 (2000) 351-359.

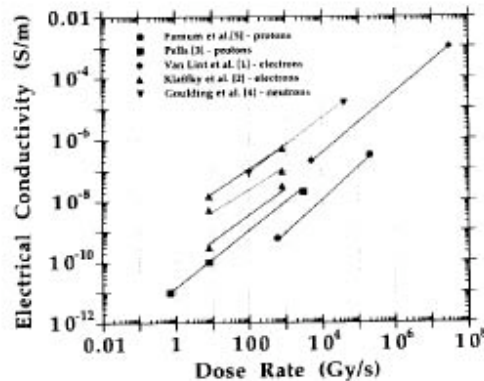


Fig. 1. Radiation induced conductivity measured in alumina during electron [1,2], proton [3,5] and fission neutron [4] irradiation.

Ref.: Investigation of Radiation Induced Electrical Degradation in Alumina Under ITER-Relevant Conditions
L.L. Snead et al., Journal of Nuclear Materials, 226 (1995) 58-66

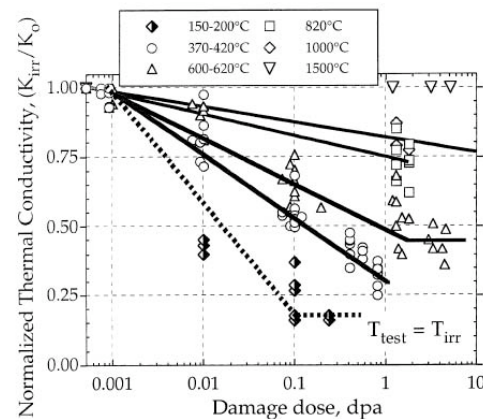


Fig. 4. Normalised thermal conductivity of different CFCs as a function of damage dose [45,53,59-63].

Ref.: Neutron Irradiation Effects on Plasma Facing Materials, V. Barabash et al., Journal of Nuclear Materials, 283-287 (2000) 138-146.

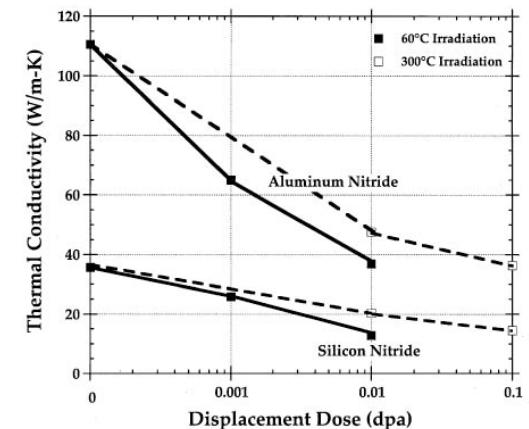


Fig. 3. Thermal conductivity vs. neutron dose for polycrystalline Si_3N_4 and AlN irradiated at either 60 °C or 300 °C.

Ref.: Thermal conductivity degradation of ceramic materials due to low temperature, low dose neutron irradiation, L.L. Snead, S.J. Zinkle, D.P. White, Journal of Nuclear Materials, Volume 340, Issues 2-3, 15 April 2005, Pages 187-202

- Available data show consistent degradation of thermal and electric properties with irradiation.
- Most published data are for ITER's materials irradiated at low fluences.
- No data available for ARIES materials at high fluences of power plants.
- ARIES analysis should consider some degradation of thermal and electric properties. How much?