ARIES-DB Design Issues

L. El-Guebaly
University of Wisconsin-Madison

Contributors:
P. Batistoni (ENEA, Italy) and C. Kessel (PPPL)

ARIES-Pathways Project Meeting
December 15 - 16, 2009
GA, San Diego

Contents

- 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)

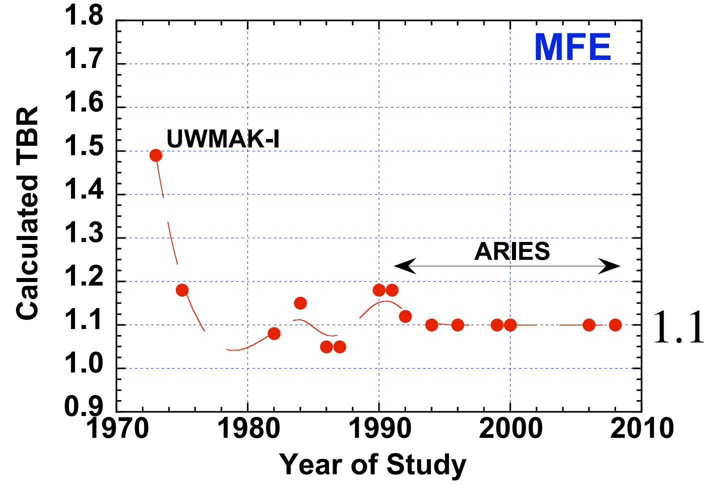
- 1% less breeding ⇒ Shortage of ~1 kg of T/y* for 2 GW P_f

- 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



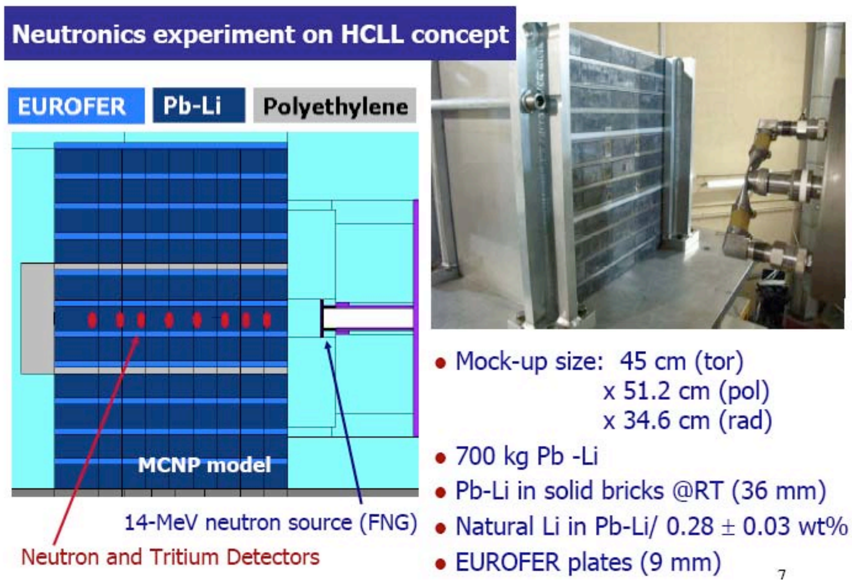
- **Background info**:
  - **ARIES** designs considered Calculated TBR of 1.1 for liquid breeders
  - Breeding margin (TBR -1) divided into 4 categories:
    - **Margin for known deficiencies in nuclear data** (6*-10%)
    - Margin for known deficiencies in modeling (3*-7%)
    - Margin for unknown uncertainties 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.

LiPb obtained from Fusion for Energy had much lower lithium content (0.28 wt%) than expected for $Li_{17}Pb_{83}$ (0.68 wt%).

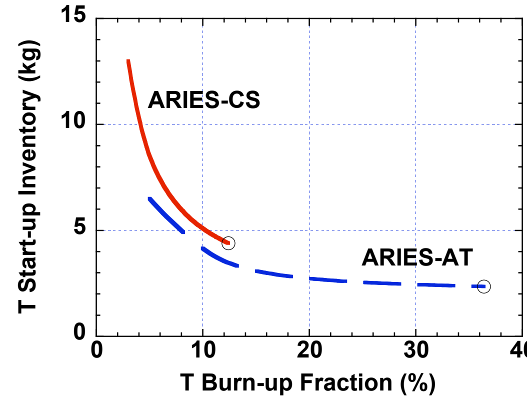
These results suggest reducing TBR margin for nuclear data deficiencies from 6% to 3% until FNG conducts new LiPb experiments with more accurate measurements.

⇒ Reduce required calculated TBR from 1.1 to 1.07

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

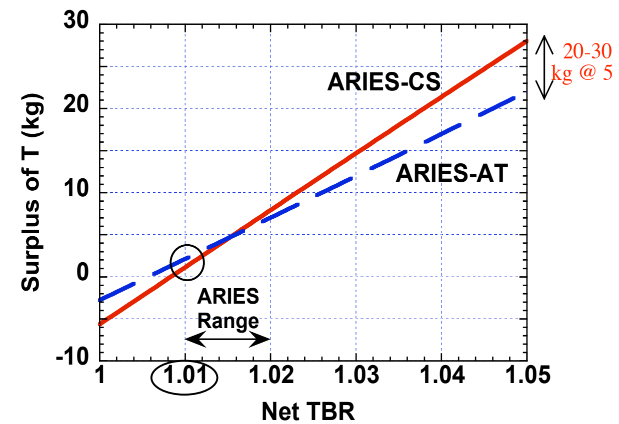
- Startup inventory of T for new power plant depends on burn-up fraction (f_b).

- 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, <u>ARIES prefers using t_d as knob to meet breeding requirements.</u>

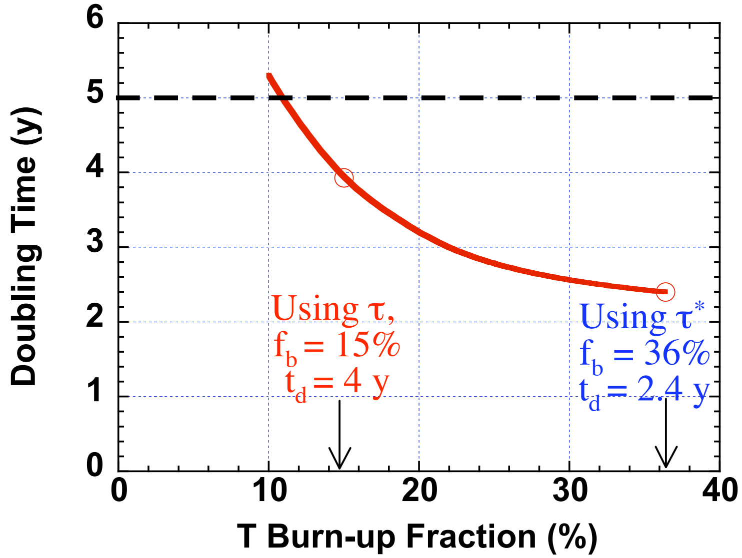
- Generating <u>excessive T</u> causes serious <u>storage problem and raises licensing concerns.</u>



- 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).

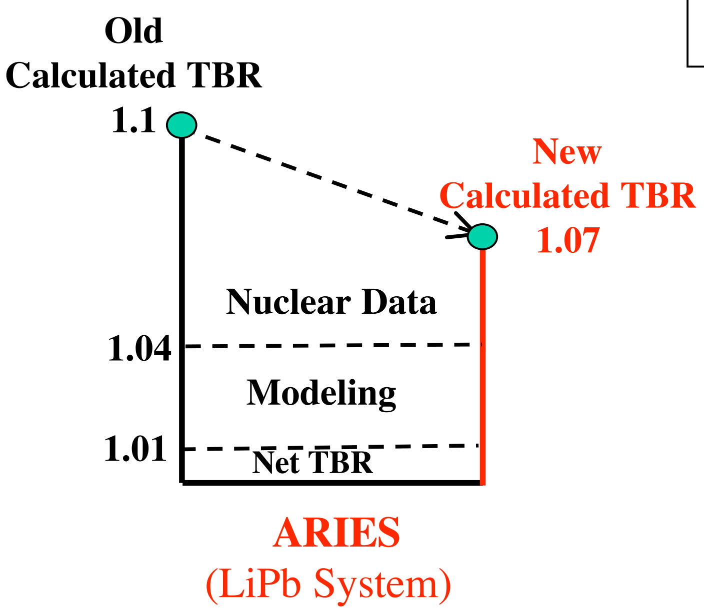


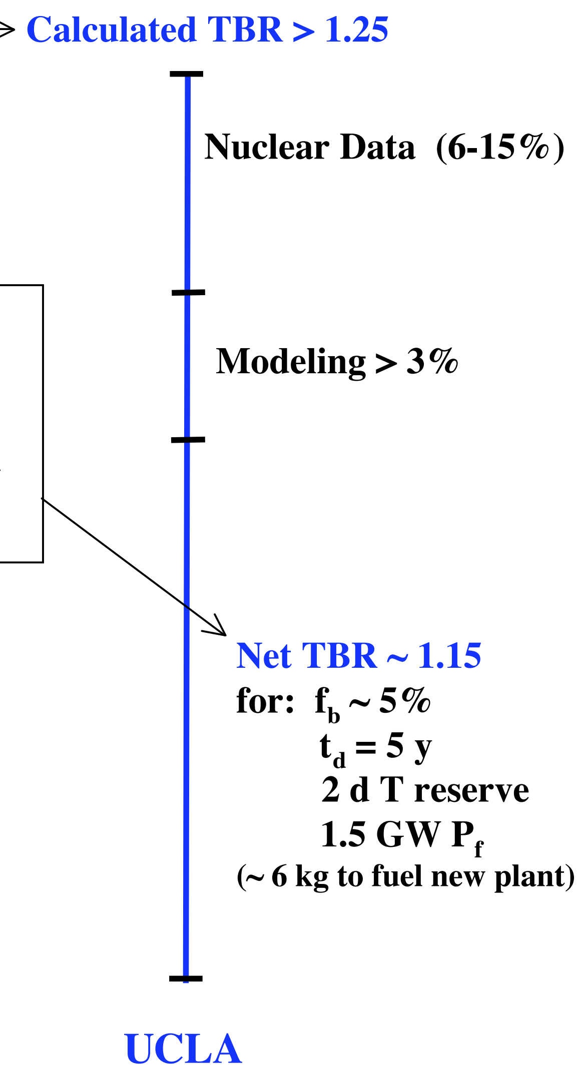
ARIES-AT
Net TBR= 1.01

Net TBR Comparison: ARIES vs UCLA

No realistic blanket design can breed that much T

<u>T surplus ~ 50 kg !</u>
High Net TBR causes serious T storage and licensing problems





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.

$Li_{17}Pb_{83}$ 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_{Li}(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 $Li_{17}Pb_{83}$?
- If so, its *minor* impact on TBR will be determined.

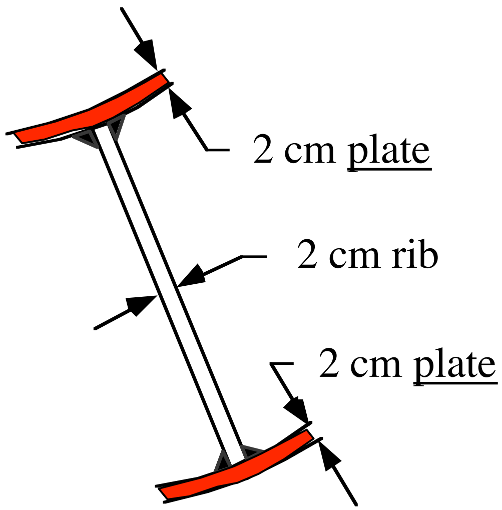
ITER Reweldability Limits for 316-SS

< 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.

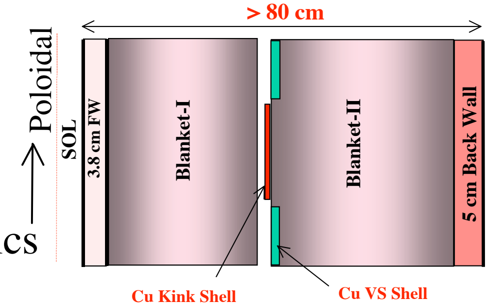
- Double-walled vacuum vessel with internal ribs:
  - ITER: **6 cm** plate of 316-SS and 1 appm limit
  - ARIES: **2 cm** plate of FS and 1 appm limit.
- Should ARIES:
  - Adopt ITER higher limit for thinner FS plate? or,
  - Revisit ARIES VV design?

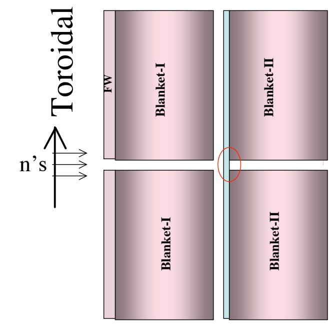


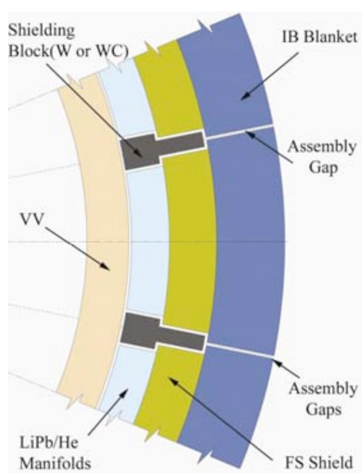
ARIES-AT VV

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

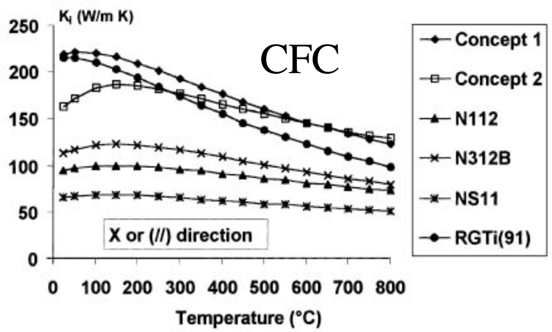


Fig. 3. Thermal conductivity of the materials as a function of the temperature after irradiation at 775°C/0.35 dpa g.

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.

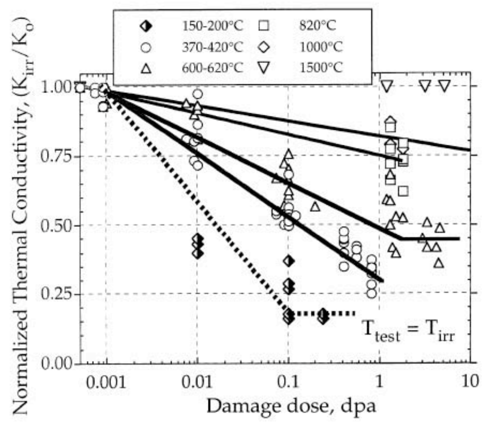


Fig. 4. Normalised thermal conductivity of different CFCs as a function of damage dose [45,53,59–63].

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

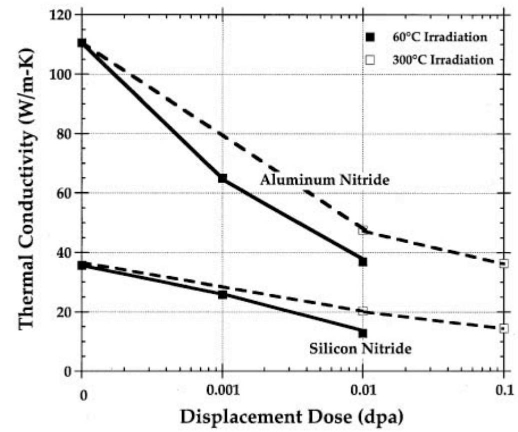


Fig. 3. Thermal conductivity vs. neutron dose for polycrystalline Si_3N_4 and AlN irradiated at either 60 °C or 300 °C.

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

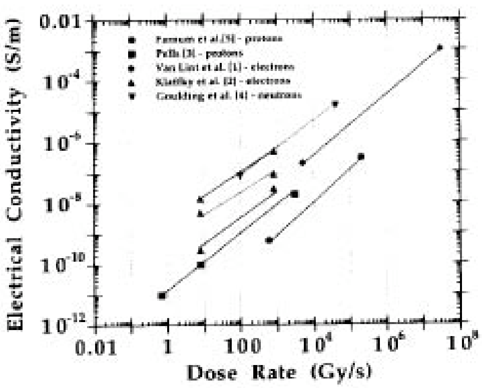


Fig. 1. Radiation induced conductivity measured in alumina during electron [1,2], proton [3,5] and fission neutron [4] irradiation.

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

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