ANALYSIS OF THE DHCE EXPERIMENT IN THE POSITION A10 OF THE ATR REACTOR*

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OBJECTIVE

The objective of this work was to assess the suitability of the neutron flux spectrum of the A-10 irradiation position of the ATR reactor for a DHCE (Dynamic Helium Charging Experiment) experiment using Eu_2O_3 thermal neutron filter. The amount of tritium leaking from the capsule and the initial tritium charge to a reference capsule was calculated as well as the helium to dpa ratio during irradiation.

SUMMARY

Calculations were performed to assess the possibility of performing DHCE experiments in mixed spectrum fission reactors. Calculated values of key parameters were compared with limit values for each quantity. The values calculated were: He-4 production from the $^6Li(n,t)^4He$ reaction, tritium leakage, required tritium concentration in lithium, initial tritium charge per capsule, and helium to dpa ratio after 10 dpa of irradiation.

INTRODUCTION

In DHCE experiment the helium production induced by high energy neutrons from a fusion environment is simulated by the use of the decay of tritium to ^3He. Tritium is charged to a mother alloy at a level that after the diffusion during the irradiation due the temperature increase, the amount of tritium inside the vanadium samples are such that the correct amount of ^3He is produced at the same time that atomic displacements take place.

One aspect of having ^3He instead of ^4He is the high $^3He(n,p)^3H$ cross section. Figure 1 shows the cross section of that reaction. As can be seen the cross section has a 1/E behavior and it is as high as 5,000 barns in the thermal region. This fact implies that in a thermal neutron rich environment the produced ^3He would be burned and the helium production could not be simulated by the DHCE experiment. Then, the requirement of eliminating the thermal and as much as possible of the epithermal neutron flux is an imperative for the success of a DHCE experiment in a mixed spectrum fission reactor.

Another aspect that can be a limiting factor for the success of a DHCE experiment is the solubility limit of tritium in lithium or other thermal bonding material. This limitation comes from the fact that the distribution of tritium atoms between the thermal bonding material and the vanadium samples only applies for free atoms and when the tritium concentration is below the saturation limit.

In terms of helium production in the lithium due to the $^6Li(n,t)^4He$ reaction, there is the pressure limitation inside the capsule. The pressure inside for a typical irradiation capsule has to stay below roughly 20 atm. Then, the lithium enrichment has to stay below some limiting number to avoid excessive gas production inside the capsule and the excessive build-up of pressure.

The analysis of the tritium leakage becomes important because of reductions in available tritium for decay and possible restrictions associated with tritium contamination in the reactor.

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Relative to the transport of the DHCE capsules, a large tritium inventory inside the capsule creates problems for transporting the capsule and it may result in significative cost impact for the experiment. Then, the assessment of the required tritium inventory per capsule is an important issue.

Finally, a DHCE experiment must be designed to simulate the helium production in a fusion environment, which is roughly constant with the irradiation time. Then, the helium to dpa rate profile must be roughly constant during the irradiation.

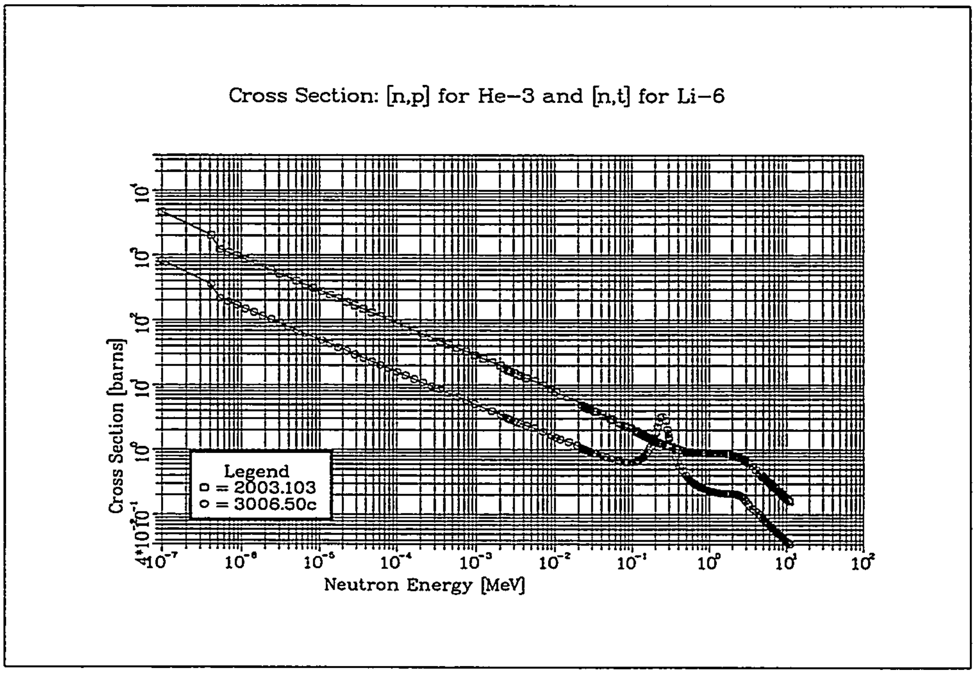

Figure 1. $^3He(n,p)^3H$ and $^6Li(n,t)^4He$ cross sections as a function of the incident neutron.

RESULTS AND DISCUSSION

Following are the aspects analyzed and the conclusion obtained from the calculations performed to assess a few parameters of a DHCE experiment in the position A-10 of the Advanced Test Reactor (ATR).

A- Total Helium production in Lithium below the equivalent maximum pressure inside the capsule.

The first part of the calculation was to define the maximum lithium enrichment that would produce a pressure inside the capsule below the 20 atm limit. The assumption assumed was conservative by nature, since it is considered that all ^4He produced would be in gas phase and as such contributing for the pressure build-up inside the capsule.

Assuming a gas plenum volume inside the capsule of 6 cm^3 (if this volume is reduced to 3 cm^3 the maximum number of helium atoms is reduced by a half) the maximum number of helium atoms that can be generated from the $^6Li(n, \alpha)\,^3H$ reaction is:

Temp = 400°C => $N_{he} = 1.31 \times 10^{21}$ ^4He atoms in the gas phase inside the capsule.

Temp = 425°C => $N_{he} = 1.26 \times 10^{21}$ ^4He atoms in the gas phase inside the capsule.

Temp = 500°C => $N_{he} = 1.14 \times 10^{21}$ ^4He atoms in the gas phase inside the capsule.

Temp = 600°C => $N_{he} = 1.01 \times 10^{21}$ ^4He atoms in the gas phase inside the capsule.

The ^4He production rate from ^6Li inside the capsule, for a fixed irradiation facility and position, is basically dependent only on the neutron flux spectrum and intensity. For a mixed-spectrum reactor such as ATR the use of thermal neutron absorber to filter the neutrons is an imperative. Then, the ^4He production rate will basically depend on the filter material and its thickness. Table 1 presents the maximum ^6Li enrichment for a 2.9cm^3 volume of lithium inside the capsule, to keep the pressure below 20 atm. after 10 dpa in the A-10 position of ATR, for a few filter materials and thicknesses analyzed. It can be noted that the Eu_2O_3 filter (50% density) has a superior performance compared to other filter materials analyzed. The fact that a higher enrichment can be allowed indicates that a lower ^3He burn-up is also achieved.

Table 1. Maximum allowable ^6Li enrichment to maintain the pressure inside the capsule below 20 atm for a gas plenum volume of 6 cm^3.

	Temp=400°C	Temp=425°C	Temp=500°C	Temp=600°C
3 mm thick Eu_2O_3	12.2 %	11.8%	10.6%	9.5%
1 mm thick Eu_2O_3	6.85%	6.6%	6.0%	5.3%
3 mm thick Gd-nat	4.75%	4.6%	4.1%	3.6%
0.8mm thick Eu_2O_3 + 0.2 mm thick Gd	7.2%	6.9%	6.25%	5.5%
2 mm thick Gd-nat + 1 mm thick Hf-nat	5.9%	5.7%	5.2%	4.6%
2 mm thick Eu_2O_3 + 1 mm thick Hf-nat	7.6%	7.4%	6.7%	5.9%

B- Acceptable helium to dpa ratio.

The helium to dpa ratio that can be obtained using Eu_2O_3 filter with 50% density (in powder form) and the maximum ^6Li enrichment shown in Table 1 is dependent on the distribution coefficient (weight per cent of tritium in vanadium divided by the weight per cent of tritium in lithium) and on the irradiation temperature. Table 1 presents, for the cases considered (Eu_2O_3 filter with 3 and 1 mm thickness and TZM capsule walls with 1 and 2.5 mm, respectively), the helium to dpa ratios after 10 dpa of irradiation. These values are calculated considering an initial tritium charge equivalent to a tritium concentration in the vanadium samples of 1500 appm. It can be noted that although the helium to dpa ratio is not exactly 5, values relatively close to the target values can be obtained. The cause for the decrease in the helium to dpa ratio for high temperature irradiation is the increase in the tritium leakage from the capsule. A way to reduce the leakage is to increase the thickness of the TZM capsule wall or using other means to reduce the hydrogen permeability of the capsule walls.

Table 2. Estimated helium to dpa ratio after 10 dpa's of irradiation in the position A-10 of the ATR reactor using Eu_2O_3 thermal neutron filter.

3 mm thick Eu_2O_3 filter with 1 mm TZM capsule wall.

Distribution Coeff.	Temp=400°C	Temp=500°C	Temp=600°C
0.0200	7.4	6.8	4.3
0.0100	6.4	5.9	3.7
0.0050	5.9	5.5	3.5
0.0033	5.7	5.4	3.4
0.0020	5.6	5.3	3.3

1 mm thick Eu_2O_3 filter with 2.5 mm TZM capsule wall.

Distribution Coeff.	Temp=400°C	Temp=500°C	Temp=600°C
0.0200	6.2	5.9	4.7
0.0100	5.3	5.1	4.1
0.0050	4.9	4.8	3.9
0.0033	4.8	4.6	3.8
0.0020	4.7	4.6	3.7

C- Total amount of tritium dissolved in Lithium below the solubility limit.

The maximum calculated amount of tritium (in atom percent) dissolved in lithium during irradiation for a 10 dpa's irradiation campaign is presented in Table 3. These values are calculated considering the maximum allowable enrichment and as such do not depend on the filter material used.

Table 3. Maximum amount of tritium (in atom percent) dissolved in lithium during irradiation.

Distribution Coeff.*	Temp=400°C	Temp=500°C	Temp=600°C
0.0200	2.4%	2.2%	*1.6%*
0.0100	4.0%	3.6%	*3.1%*
0.0050	7.0%	6.3%	*6.3%*
0.0033	10.%	*9.4%*	*9.4%*
0.0020	16.%	*15.7%*	*15.7%*

*Distribution coefficient is defined as the weight fraction of tritium in Vanadium divided by the weight fraction of tritium dissolved in Lithium.

The values in italic in the above table indicate that the initial concentration of tritium in lithium is larger in the beginning of the life and as such is tabulated as the constraint value. These values can be compared with the solubility limit of tritium in lithium.

D- Tritium leakage rate below the acceptable limits.

Finally, concerning the leakage term. The amount of tritium to be released from the capsules during a continuos 10 dpa irradiation campaign (considering the 1-week/40days shut-down periods) is shown in Table 4 in Curies for a Lithium volume inside the capsule of 2.9 cm^3.

Table 4. Tritium leakage from the DHCE capsule (in Curies) during the an irradiation campaign of 10 dpa's.

3 mm thick Eu_2O_3 filter with 1 mm TZM capsule wall.

Distribution Coeff.	Temp=400°C	Temp=500°C	Temp=600°C	Initial Charge
0.0200	0.9	16.	100.	117.
0.0100	1.5	26.	165.	218.
0.0050	2.7	48.	297.	422.
0.0033	3.8	69.	430.	625.
0.0020	6.2	111.	695.	1032.

1 mm thick Eu_2O_3 filter with 2.5 mm TZM capsule wall.

Distribution Coeff.	Temp=400°C	Temp=500°C	Temp=600°C	Initial Charge
0.0200	0.8	6.5	52.	117.
0.0100	1.3	10.8	86.	218.
0.0050	2.4	19.6	157.	422.
0.0033	3.5	28.4	227.	625.
0.0020	5.6	45.6	371.	1032.

CONCLUSION

The values calculated tend to indicate that is possible to perform a DHCE experiment in the ATR A-10 position and to expect reasonable helium to dpa ratios during the irradiation.

FUTURE WORK

To perform a more detailed analysis of the parameters of the experiment and to compare the values obtained with other limiting values.