

EVALUATION OF THE DHCE EXPERIMENT - L. R. Greenwood, D. L. Baldwin, G. W. Hollenberg and R. J. Kurtz (Pacific Northwest National Laboratory)***OBJECTIVE**

To evaluate the results of the DHCE experiment to enhance helium production in vanadium alloys in order to assess the readiness to conduct a future DHCE experiment.

SUMMARY

The Dynamic Helium Charging Experiment (DHCE) experiment was conducted in the Fast Flux Test Facility (FFTF) during cycle 12, which was completed in 1992. The purpose of the experiment was to enhance helium generation in vanadium alloys to simulate fusion reactor helium-to-dpa ratios with a target goal of 4-5 appm He/dpa. The Fusion Materials Science Program is considering mounting another experiment in hopes of gathering additional data on the effect of helium on the mechanical and physical properties of vanadium structural materials. Pacific Northwest National Laboratory was assigned the task of evaluating the feasibility of conducting another DHCE experiment by carefully evaluating the results obtained of the first DHCE experiment. This report summarizes the results of our evaluation and presents recommendations for consideration by the Materials Science Coordinators Organization.

Background

A very brief description of the experiment is that vanadium alloys are encapsulated in TZM capsules along with lithium and a "mother" alloy that is pre-charged with tritium. When the reactor comes up to power and the capsule temperature rises, the tritium diffuses out of the mother alloy and reaches an equilibrium distribution between the liquid lithium and vanadium alloys. As the tritium decays, ^3He is produced in the vanadium alloys. When the irradiation is stopped and the temperature falls, the tritium returns mostly to the lithium. The ^6Li content was varied along with the tritium charging in an attempt to provide a nearly constant generation of ^3He from the decay of tritium and replacement from the $^6\text{Li}(n,\alpha)t$ reaction. Tritium leakage from the capsules and the distribution of tritium between the lithium and the vanadium alloys are the most important temperature-dependent parameters. Ideally, if all the parameters are well understood and chosen appropriately, then the DHCE concept is capable of producing nearly constant helium to dpa ratios in the vanadium alloys during the irradiation.

At the time the experiment was designed, there was considerable uncertainty concerning the distribution of tritium between the liquid and the vanadium alloy specimens. It should further be noted that the limited data available at the time on the tritium distribution for vanadium alloys predicted about a factor of 10 increase over pure vanadium.[1] In view of these uncertainties, the experiment was designed assuming a range of possible distribution ratios ($K_A = 0.073$ to 0.73) for the capsules at temperatures between 430 and 600°C, where K_A is the atomic ratio of tritium in V to that in liquid Li. This design uncertainty is important to remember in any evaluation of the DHCE results in that the plan was to hopefully span the range of tritium distribution values so that at least some of the vanadium specimens would have fusion relevant helium-to-dpa values.

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Post-Test Prediction of Helium Levels

In view of the DHCE results, it is now clear that the tritium distribution coefficients for vanadium alloys and Li are generally similar to those for pure vanadium (except in a few cases, as noted above) rather than about a factor of 10 higher than vanadium, as was assumed when the DHCE experiment was designed [1,2]. Improved models of tritium leakage from the TZM capsules are also now available [2]. Hence, the obvious question is to determine how well the DHCE data can be described and explained using these new tritium distribution coefficients and tritium leakage parameters.

The DHCE calculations are somewhat complicated in that they depend on the FFTF power history, nuclear reaction rates, tritium decay, tritium distributions, and tritium diffusion. Calculations are performed separately for each capsule condition considering the initial tritium in the mother alloy, ^6Li enrichment, irradiation position in the reactor, and capsule temperature. Revised calculations were performed using the new tritium distribution coefficients and tritium leakage parameters. The new calculations show ^3He values at the end of irradiation time, March 19, 1992. The assumption was made that the tritium all went into the lithium rather than remaining in the alloys at the end of irradiation. The capsules remained in FFTF for about 9 months at 220°C and then were at room temperature for 6-9 months before opening at ANL. Hence, it is possible that some of the ^3He generated during this 15-18 month interval wound up in the vanadium alloys; however, tritium distribution calculations at these lower temperatures predict that virtually all of the tritium will reside in the lithium. Tritium measurements were conducted for one sample of V-4Cr-4Ti at each level of the DHCE experiment. [3] These measurements were performed by measuring the ^3He increase in the samples over a period of about 50 days. Two of the samples in positions 4D1 and 4D2 showed tritium values that were statistically above the background, although with significant uncertainties. If these data are extrapolated back to the end of irradiation and the decay of tritium is calculated, then it is possible that up to about 35% of the ^3He in the samples at these positions may have been generated from tritium decay after the irradiation. However, most of the samples were degassed sometime in 1994 prior to the ^3He measurements in 1995, so the exact tritium decay period is not precisely known. In any case, it is possible that some of the ^3He values from the 430°C capsules are biased due to the retention of tritium in these samples. Tritium trapping is also a possibility, as is discussed below.

Comparison of Data and Calculations

All of the ^3He data and the new calculations are shown in Table 1. This table was taken from Reference 2, except that we have added the ^6Li enrichments, the calculated post-test tritium levels given the initial tritium charge, the measured post-test tritium levels, the desired concentration of tritium in Li, the solubility limit of tritium in Li, the new K_A and tritium leakage values. The calculated post-test tritium levels attempted to account for the tritium inventory at about the time the capsules were opened, taking into account the reactor history, decay, generation from ^6Li and ^3He reactions, and tritium leakage from the capsules. The measured post-test tritium levels may not include all of the tritium, as discussed in reference [15].

It is obvious comparing the calculated ^3He values with the experimentally measured levels that three of the alloys (V-1Si, V-5Fe, and V-5Cr-5Ti (Si, Al, Y)) exhibited much higher ^3He than the other specimens, as discussed below. If one ignores the results for these three alloys, then the rest of the data is in acceptable agreement with the new calculations (within a factor of two), as shown in Figures 1 – 4. Figure 1 shows the dependence of the ^3He

produced on initial tritium charge for specimens irradiated at all three temperatures. Figures 1 – 3 show separate plots for each of the three irradiation temperatures. There are three significant deviations from this trend (agreement within a factor of two). One measured value of 34.7 appm for V-3Ti-1Si at 430°C, one value of 26.3 appm for V-5Cr at 600°C, and one value of 74 appm for V-4Cr-4Ti (ANL) irradiated at 600°C.

The fact that three of the alloys (V-1Si, V-5Fe, and V-5Cr-5Ti (Si, Al, Y)) consistently show much higher ^3He levels than the other seven alloys would seem to imply that the composition or microstructure of these materials results in much higher tritium solubility and/or trapping. Information cited in Reference 1 suggests that alloys with Y have much higher solubilities for tritium, which could explain the very high values for the V-5Cr-5Ti (Si, Al, Y). Calculations carried out by Natesan [4] show that Y is a very strong H getter; V, Ti and Nb are intermediate H getters, and Cr, Mo are non-getters. For example, Natesan's

Table 1. ^3He Concentration in V-Alloys from DHCE Experiment Compared to Revised Calculations

Parameter	Capsule						
	4D1	4D2	5E2	5D1	5E1	5C1	5C2
DPA	25	27	13	14	18	18	14
Temperature, °C	430	430	430	500	500	600	600
^6Li fraction	0.05	0.045	0.01	0.065	0.01	0.08	0.08
Initial Tritium, Ci	99	70	26	74	57	16	18
Final Tritium, Ci	90	66	22	55	37	8.7	10.4
Post-test Tritium, Ci*	46.3	38.4	3.4	ND	~24.1	4.5	12.3
^3H / Li, appm (desired)	31,000	22,000	9,300	19,000	14,300	4,900	4,500
^3H / Li, appm (limit)**	17,400	17,400	17,400	34,450	34,450	75,700	75,700
K_A^{***}	0.0136	0.0136	0.0136	0.0197	0.0197	0.0294	0.0294
^3H , leakage	4.9×10^{-9}	4.9×10^{-9}	4.9×10^{-9}	2.0×10^{-8}	2.0×10^{-8}	8.9×10^{-8}	8.9×10^{-8}
Calculated ^3He	10.1	10.1	5.38	14.2	10.0	4.55	4.34
V	8.83	15.2	2.54	31.6	12.3		10.4
V-5Ti	18.0	12.2	3.05	19.2	7.19		8.10
V-5Ti (BL46)		15.5					8.59
V-5Cr	6.45				3.35		26.3
V-5Nb	7.65				6.78		5.70
V-5Mo	9.81				3.56		8.22
V-5Mo							5.02
V-3Ti-1Si	34.7				5.02		6.25
V-4Cr-4Ti (BL47)	11.6	9.04	2.46	14.0	5.51	8.02	6.80
V-4Cr-4Ti (ANL)	9.86	20.9	2.48	14.1	5.58	7.90	74.0
High ^3He Alloys							
V-1Si	105				59.9		48.8
V-5Fe	80.6				34.9		93.4
V-5Cr-5Ti(Si,Al,Y)	177				108		260

*Data may not include all of the tritium, as discussed in reference 13.

**Solubility limit of H in Li.

*** K_A is the tritium distribution coefficient between the liquid lithium and the vanadium alloys.

calculations show that at a H pressure of 10^{-6} torr the concentration of H in Y at 600°C is roughly two to four orders of magnitude larger than in V, Ti and Nb. Further, at the same temperature and H pressure the H concentration in Cr and Mo is between three and four orders of magnitude below that in V. We were not able to estimate the getter strength of these elements when alloyed with V or, perhaps more importantly, when these elements form second phases, but work performed by Matsui, et al. [5] provides some insight into the relative tritium trapping efficiency for some of the binary alloys. Matsui, et al. charged pure V and five binaries with tritium at 400°C to study the effect of He on tensile properties. All specimens were charged in the same container at the same temperature and tritium gas pressure. The specimens were held under these conditions for a predetermined time for tritium to decay to ^3He . The measured ^3He levels following this exposure were V-5Fe (154 ppm), V-5Mo (267 ppm), V-5Cr (269 ppm), V (363 ppm), V-5Nb (405 ppm), and V-5Ti (688 ppm). The trend of the measured ^3He levels generally follows the trend of H solubility in the various alloying elements. This same trend is not observed in the DHCE binary alloys. Based on solubility data alone one would predict that the V-5Fe should have one of the lowest ^3He levels rather than one of the highest.

The other two high ^3He alloys, V-1Si and V-5Fe, are known to have high swelling with the formation of a large number of voids following irradiation in FFTF [6-10]. Recent experiments with irradiated stainless steel have shown that H can be trapped in these voids along with He [11-14]. Hence, it is possible that the high ^3He content of these alloys is due to tritium trapping which could significantly increase the total tritium in these materials above the solubility limit. If tritium were trapped, it would stay trapped after the irradiation, causing some additional ^3He generation after the samples were removed from the reactor, as

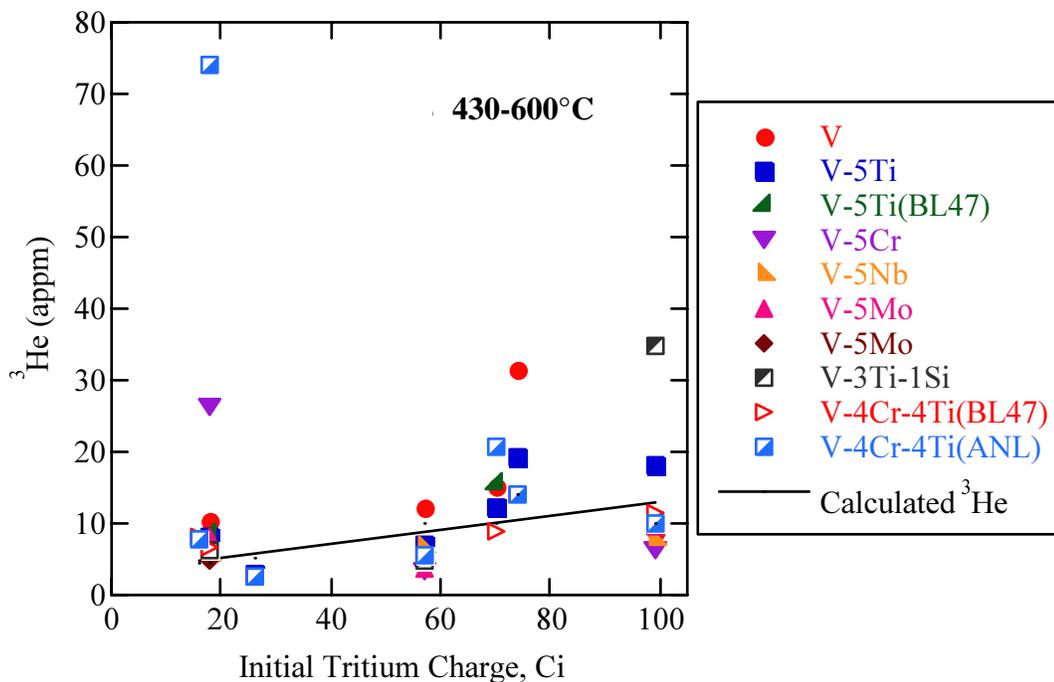


Figure 1. Dependence of measured and predicted ^3He levels for several vanadium alloys irradiated in FFTF between 430 and 600°C as a function of the initial tritium charge.

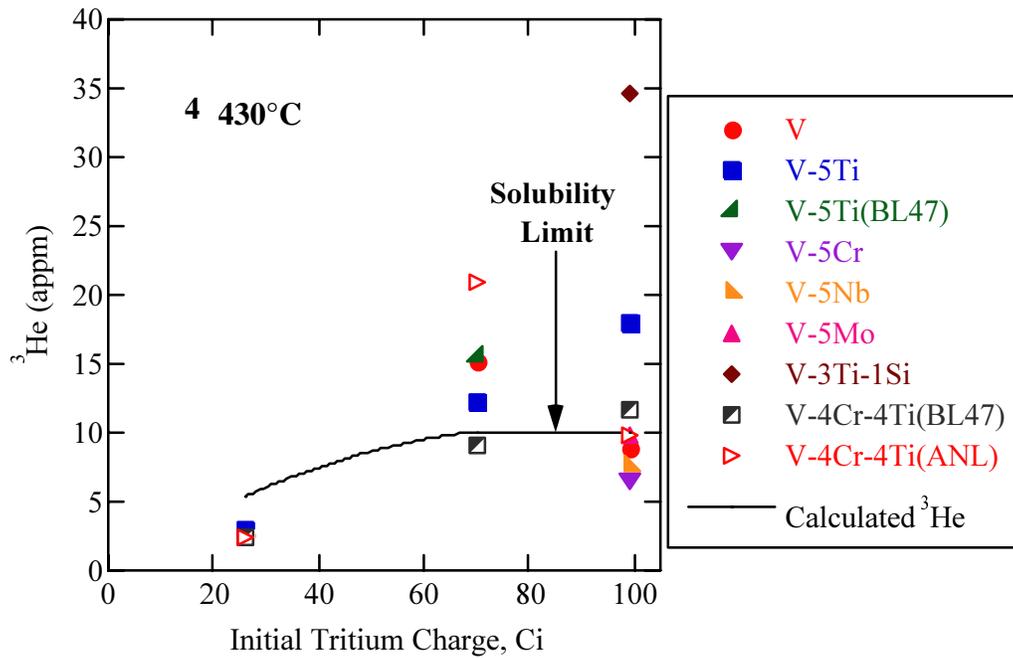


Figure 2. Dependence of measured and predicted ^3He levels for several vanadium alloys irradiated in FFTF at 430 °C as a function of the initial tritium charge.

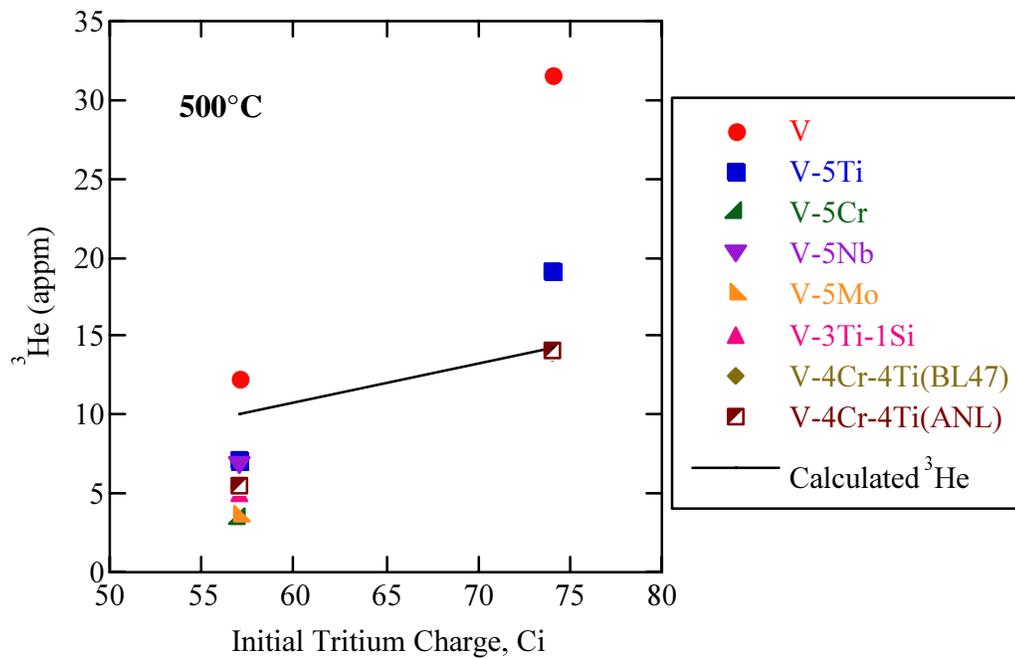


Figure 3. Dependence of measured and predicted ^3He levels for several vanadium alloys irradiated in FFTF at 500 °C as a function of the initial tritium charge.

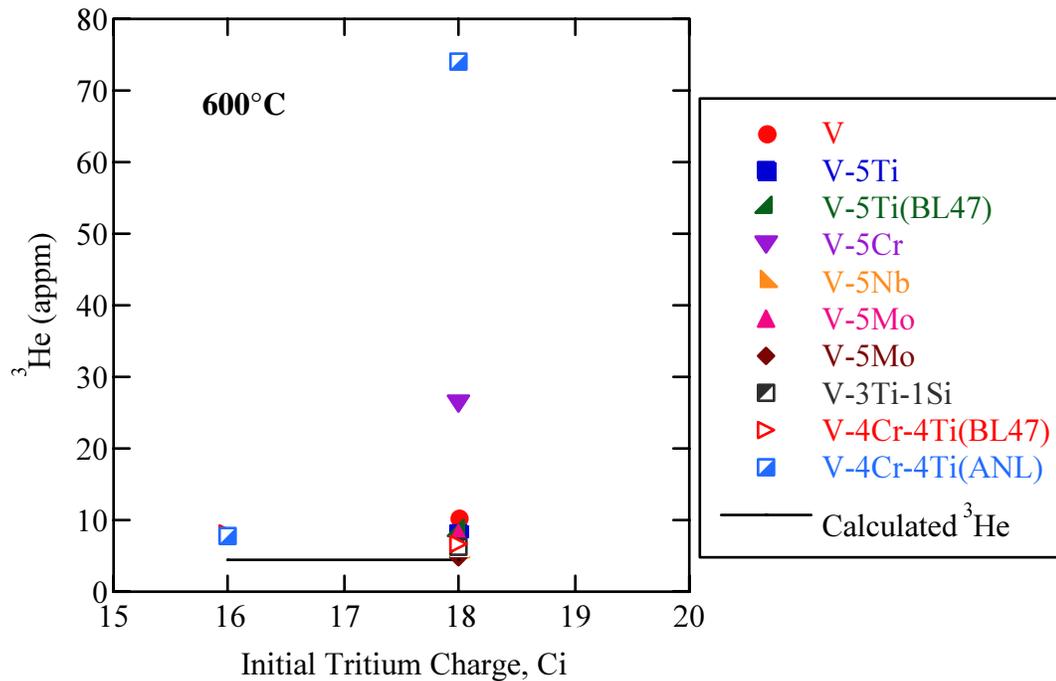


Figure 4. Dependence of measured and predicted ^3He levels for several vanadium alloys irradiated in FFTF at 600 °C as a function of the initial tritium charge.

discussed previously. In reference 1 it was noted that helium bubbles were observed in some of the alloys, although the three alloys with higher ^3He levels were not examined in this reference. Such helium bubbles might well allow the trapping of tritium. The data generated by Nakajima, et al. on V-5Cr also showed the formation of voids and high swelling at 600°C and relatively modest swelling at lower temperatures. This trend is in rough agreement with the DHCE results in that only the 600°C ^3He measurement was elevated for V-5Cr. Nakajima, et al, did not see any significant swelling for V-5Mo, V-5Ti and V-20Ti. It has been well documented that Ti effectively suppresses swelling in V alloys even when elements that promote high swelling, such as Fe, are present [8]. Thus, a swelling argument cannot be invoked to explain the high ^3He readings in the V-3Ti-1Si specimen at 430°C or the V-4Cr-4Ti (ANL) specimen at 600°C. It is apparent from the foregoing that understanding the cause of the systematically higher levels of ^3He in these materials is essential before another DHCE experiment can be conducted with these materials.

Comparison of the data and calculations at 430 and 500°C show reasonable agreement (with the two exceptions noted). However, at 600°C, the data appear to generally exceed the calculations. This would suggest that either the tritium leakage rate at 600°C is lower than the new recommended value and/or the tritium distribution coefficient is higher than the new recommended value. Changing either of these parameters could easily improve the fit to the data except for the one very high value of 74 appm for V-4Cr-4Ti.

Solubility of H in Lithium

When the original DHCE calculations were performed, the solubility limits for H in lithium were not considered. Figure 5 shows the H solubility in Li from C. C. Addison [16], as

described by the equation $\ln(H)=8.112 - 5314/T$, at%. However, there is some scatter on solubility data in the literature, as shown later in Figure 7. In the original DHCE experiment, two of the capsules contained tritium levels that exceed this limit. The impact of this is that the LiH that formed in the capsule was limited by the LiH solubility limit, such that the soluble tritium did not exceed the limit shown in Figure 5. Consequently, the tritium levels were correspondingly reduced in the vanadium, thereby reducing the production of ^3He . These revised calculations are shown in Table 1 as well as the curved line on the plot at 430°C in Figure 2.

The presence of precipitated LiH in contact with the V samples should not increase the level of ^3He production. If the system is in the two-phase region, then the partial pressure of precipitated LiH is exactly what is shown on the dissociation pressure diagram at the selected temperature (see Figure 6). If excess LiH or H is added and the system is in equilibrium, then the excess LiH drops out of solution and the partial pressure does not change. In the two-phase region, at equilibrium, the pressure depends only on temperature and not on concentration. This pressure is the same at the surface of the LiH as it is above the Li since they are expected to be in equilibrium. Therefore, neither the solubility nor dissociation pressure are dependent upon the excess quantity of H or LiH added to the lithium. To drive more H into V (in the two-phase region), the addition of excess LiH will NOT do it, only higher temperatures will accomplish that. Although it does not seem reasonable that non-equilibrium conditions could exist for these temperatures and lengths of exposure, such non-equilibrium conditions might increase the tritium in the samples temporarily. It should also be noted that the scatter in the data shown in Figure 6 (or the solubility data shown later in Figure 7) results in about a factor of 2 uncertainty in our ability to predict or explain data from the DHCE experiment or to design a future experiment.

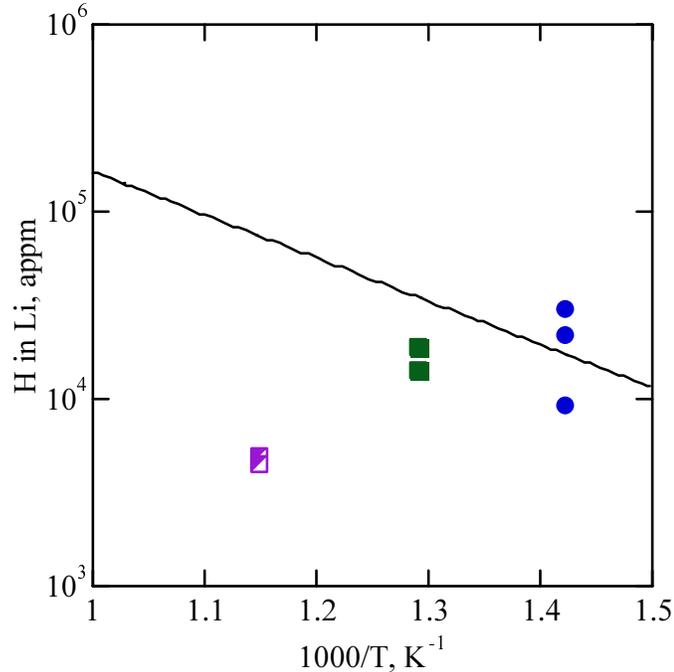


Figure 5. Solubility of H in Li (line) compared to the desired levels of tritium (points) for the DHCE capsules listed in Table 1.

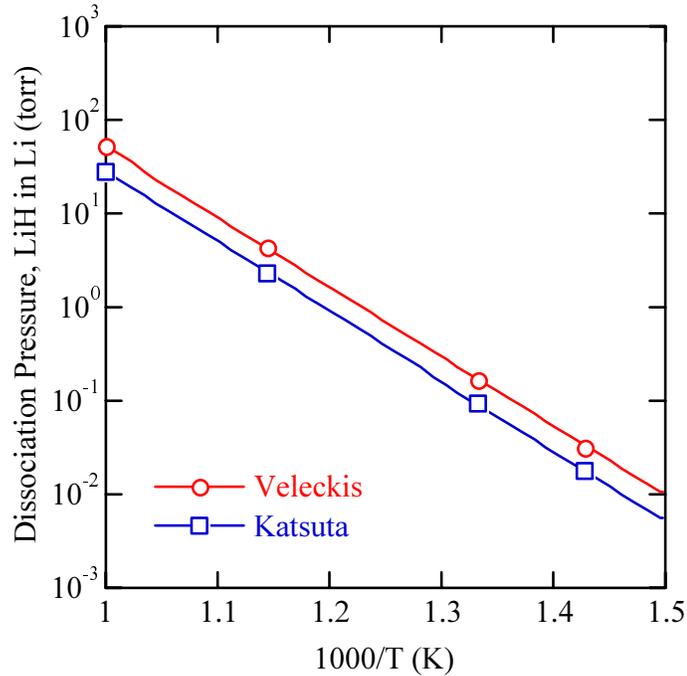


Figure 6. Dissociation pressure of LiH in Li [15,16].

Scoping Calculations for a New DHCE Experiment

The original Dynamic Helium Charging Experiment (DHCE) was conducted in the fast reactor FFTF. It is now proposed that a new DHCE experiment be conducted in some other suitable reactor and we have taken ATR as a base case, although the experiment might also be conducted in HFIR. Therefore, calculations were performed to determine whether a future DHCE experiment in ATR is feasible, given the results of the first DHCE experiment, as well as revised estimates of the tritium distribution coefficients between Li and V, the tritium solubility in lithium, and the tritium leakage rates from the capsules.

The main objective of a DHCE type experiment is to achieve fusion-like ratios of helium generation to displacement damage. A fusion reactor first wall spectrum has a He(appm)/dpa ratio of about 5 in vanadium. The original DHCE experiment generally reached He/dpa ratios of only 0.3 to 1.0 mainly due to overestimation of the tritium distribution coefficients for V and Li. The most obvious way to correct this problem is to simply add more tritium to the mother alloy at the start of the experiment. The ${}^6\text{Li}$ content is then similarly elevated to maintain a constant level of tritium. However, this solution may not work at lower temperatures due to tritium solubility limits in lithium. The addition of more tritium simply forms precipitated LiT and the soluble tritium will not exceed the solubility limit, correspondingly reducing the tritium (and ${}^3\text{He}$ formation) in the vanadium alloys. The solubility of hydrogen in lithium is shown in Figure 7. Note that there is some scatter in the experimental data, as will be discussed later.

Calculations for ATR

Table 2 summarizes the results of calculations performed for a proposed DHCE irradiation in

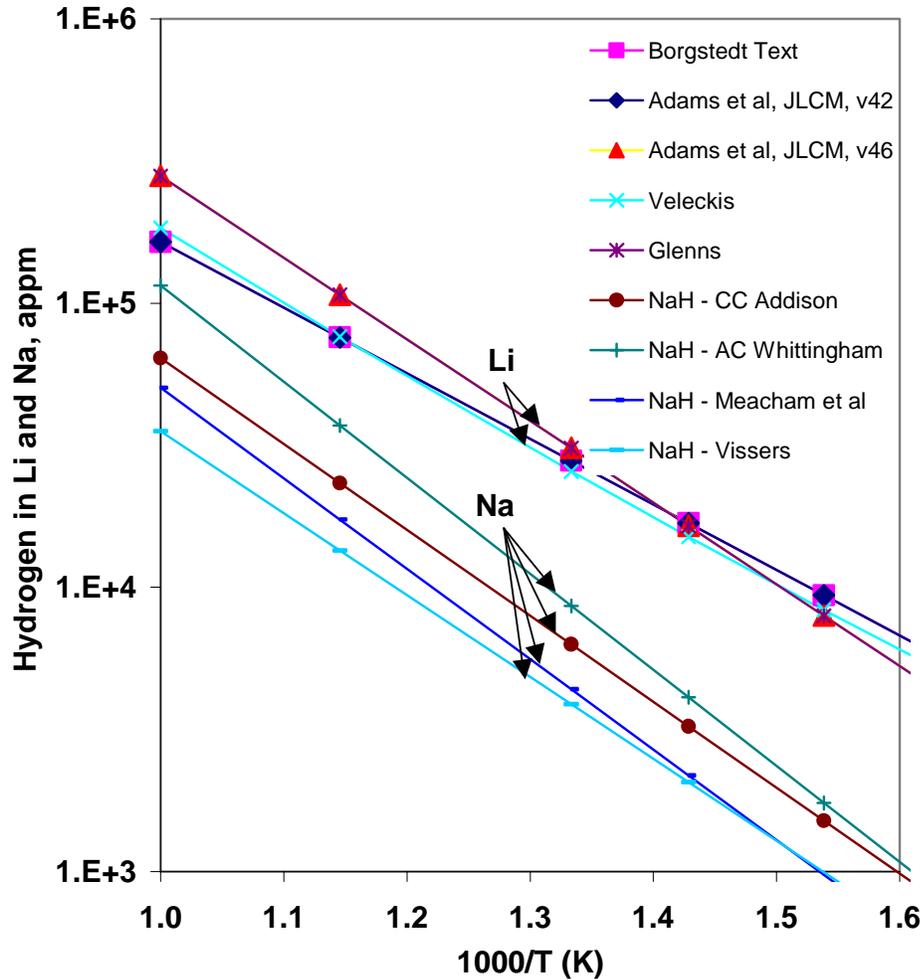


Figure 7. Solubility of H in Li, Na and NaK [14, 17-24].

ATR at temperatures between 430 and 700°C, using the same tritium distribution coefficients and leakage rates as were used to reevaluate the first DHCE experiment. The second and third columns show the Curies of tritium and corresponding tritium appm levels in lithium that would be required to achieve fusion-like He/dpa ratios at 1 and 2 FPY (full power year). The first row for each temperature ignores the tritium solubility in lithium whereas the second row (with the “Solubility Limit” label) gives both the solubility limits and reduced He/dpa ratios. As can be seen, the tritium solubilities limit the achievable He/dpa ratios at lower temperatures. At 430°C, the solubilities limit the achievable He/dpa ratio to just under 1. Adding more tritium doesn’t help since it forms LiT and is thereby prevented from diffusing into the vanadium alloys. At 500°C, the achievable He/dpa ratio increases to about 3, which is about half of the desired value.

At higher temperatures, tritium solubility in lithium is no longer an issue. However, at the highest temperature of 700°C, the helium generation in vanadium is limited by the high tritium leak rate. (The tritium leak rates are given in Table I except for the value at 700 °C, which was calculated to be 2.9E-7 atoms/s.) As discussed above, the new tritium leak rates appear to be too high at 600°C, suggesting that the tritium leakage may be overestimated at higher temperatures by the new equations presented in Reference 2. However, even allowing for this possibility, it may be difficult to achieve the desired He/dpa ratios, especially at longer irradiation times such as 2 FPY where the ratio may decrease to half the desired value.

The He/dpa calculations shown in Table 2 are for the midplane position of ATR. It should be pointed out that the ratio would of course be higher away from midplane since the dpa rate is lower while the helium production would stay the same. Consequently, the He/dpa ratio could be up to a factor of 2 higher at other locations, although this does come at the cost of a corresponding lower net dpa in the alloys at the end of the irradiation.

Additional Problems in Experimental Design

The results of the original DHCE experiment showed considerable variability in the He levels achieved for alloys irradiated under identical conditions. As discussed above, three of the alloys (V-1Si, V-5Fe, and V-5Cr-5Ti (Si, Al, Y)) appear to have consistently higher K_A values than do the rest of the alloys. The other two or three high results are very inconsistent and no satisfactory explanation for their behavior has been developed. If these assumptions are correct, then the design of a future DHCE experiment is more complicated since separate capsules would be required for the main grouping of alloys and the three higher alloys. Otherwise, all of the materials in a capsule cannot achieve the same He/dpa ratios given the identical irradiation conditions.

Conclusions

If we accept the assumption that the tritium solubilities are higher than anticipated in the three alloys V-1Si, V-5Fe, and V-5Cr-5Ti (Si, Al, Y) (data supports this for Y additions, at least), then the revised calculations using the new parameters in Reference 2 produce acceptable agreement with the measured ^3He data. "Acceptable" in this case would mean

Table 2. ^3He /dpa Ratios for a DHCE Experiment in ATR at Midplane

Temperature, °C	^3H , Ci	^3H , appm	^6Li , at%	He/dpa	
				1 FPY	2 FPY
430	320	96,000	5	5.0	4.1
^3H Solubility Limit		17,400		0.9	0.7
500	225	67,500	25	5.2	4.3
^3H Solubility Limit		34,450		2.7	2.2
600	160	48,000	80	5.5	4.4
^3H Solubility Limit		75,700			
700	320	96,000	100	4.1	2.6
^3H Solubility Limit		141,500			

within a factor of two in most cases. As noted above, the only exception to this conclusion would be that the new recommended values for tritium distribution and leakage appear to either underestimate the tritium solubility or overestimate the tritium leakage at 600°C. Of course, this could be viewed as a positive conclusion if we want to extend the DHCE concept to higher temperatures.

It should also be pointed out that there are several other important factors that could help to explain the differences between the ^3He data and the calculations, as has been mentioned in previous correspondence on this subject. For example, there are significant uncertainties in the initial tritium loading values as well as possible losses on welding. (Better measurements and controls during loading might reduce this uncertainty.) Note the discrepancies between the calculated final tritium levels listed in Table 1 and the measured values. We recognize the difficulties associated with experimental measurement of the post-test tritium levels, but the data in Table 1 suggest that the initial tritium charge may not have been what was planned or that tritium leakage was higher than calculated (using the newly revised parameters from Reference 2). The most notable capsule is 5E2 in which the measured post-test tritium level was only about 15% of the predicted value. The measured ^3He levels for specimens from 5E2 are also uniformly only about 50% of the predicted value. Reference 1 mentioned a number of problems associated with charging of the mother alloys and capsule fabrication that might have contributed to differences in the initial tritium charge. Another possibility is that imperfections in individual capsules might strongly influence the tritium leakage rates. An additional possibility is that individual samples might have had less exposure to the lithium, due to protrusion above the Li, which would tend to lower the ^3He due to the much lower concentration of tritium in the gas phase. Such specimen protrusion was observed by Tsai, et al. [15] during capsule disassembly. Due to the high packing density of the specimens some were observed to protrude above the level of the Li bond. A recommendation from that report, which we fully support, is to review capsule design and specimen packing density to ensure proper Li bonding of all specimens. Finally, as mentioned previously, tritium measurements performed on some of the specimens indicate that some of the ^3He in the 430 °C samples may have been produced by tritium remaining in the samples after the irradiation.

Since the new calculations produce reasonable agreement with most of the DHCE data, we would expect that we can confidently predict, within a factor of two or better, the performance of additional experiments, assuming that we take into account the solubility limits for H in Li and other possible effects such as H trapping by Y or at voids. One obvious conclusion from the data is that DHCE-1 did not achieve the desired fusion reactor helium to dpa ratios of 4-5 (except for the three alloys that had unusually high ^3He values). The reason for this is that the best data available at the time significantly over predicted the tritium solubility in most of the vanadium alloys. (The design assumed K_A values from 0.073 to 0.73 for the vanadium alloys whereas the true values appear to be in the range of 0.01 to 0.03, similar to pure vanadium). Of course, this means that if the same experiment were to be repeated today, one would have to increase the initial tritium loading (and increase the ^6Li enrichment) significantly in order to hit the desired helium to dpa ratio. Such increased loading is certainly possible, although the design would have to carefully consider safety questions involving potential increases in the pressure that might be reached in some capsules due to higher tritium and especially ^4He from ^6Li reactions. Of course, since FFTF is no longer operational, the entire experiment needs to be redesigned around another reactor such as ATR or HFIR, taking into account the increased thermal neutron flux and need for thermal shielding.

Possible Solutions and Recommended Work

As suggested in Reference 2, the tritium solubility limit problem with pure Li in ATR might be avoided by switching to Na, NaK, a mixture of Na and Li, or any similar mixture that has a lower solubility of tritium than does lithium. Preliminary calculations for ATR using pure Na confirm that we could achieve tritium distributions resulting in the desired He/dpa ratios. However, it is essential that the Sievert's constant for tritium solubility in this mixture of liquid metals exceed that of vanadium. Consequently, pure Na and NaK would not be good choices since they have lower tritium solubilities, as shown in Figure 8.

Mixtures with Li might give the desired characteristics, although Li and Na separate into two phases at lower temperatures. If the tritium solubility is not higher in the liquid metal, we cannot introduce the tritium into the capsule using a mother alloy at reactor startup, since most of the tritium will stay in the mother alloy, and the tritium will remain in the samples at the end of the irradiation. Both of these effects lead to helium production in the vanadium alloys before and after the irradiation rather than having helium and dpa produced at the same time. Furthermore, it is highly desirable that the mixture of liquid metals includes ^6Li so that we can replace the tritium lost to decay and diffusion. Calculations using pure Na show that the He/dpa ratio steadily declines during the course of the irradiation, thereby complicating our interpretation of the dependence of material property changes on the He/dpa ratio.

Figure 7 shows the available hydrogen solubility data in the literature for Li and Na (there is a similar scatter in the Sievert's constant data in figure 8). Looking at this scatter in the data, it is not clear that tritium solubility data is sufficiently accurate for these other possible mixtures of liquid metals to allow for the confident design of a DHCE experiment. Consequently, more work may be needed to determine these tritium solubilities, especially if we want to use a mixture of Na or NaK and Li in order to use the ^6Li reaction to replace tritium lost to decay and diffusion.

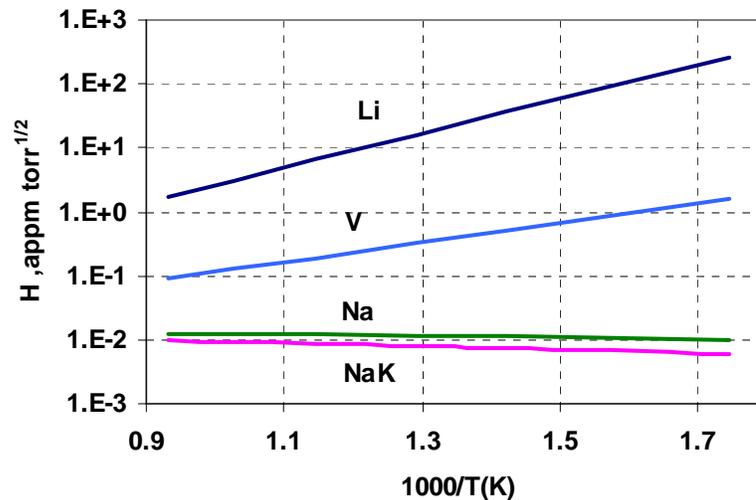


Figure 8. Temperature dependence of Sievert's constants are shown for H in Li, V, Na, and NaK [27].

Secondly, work is clearly needed to determine the distribution coefficients for tritium in the three alloys that showed much higher He levels than most of the other materials. These effects need to be better understood before an experiment can be designed to confidently predict He/dpa ratios in all of these materials. An experiment could be designed excluding these materials; however, these alloys may be of particular interest to fusion applications, especially V-5Cr-5Ti.

It is recommended that additional gas measurements be performed on the samples from the DHCE experiment, if these specimens are still available. Additional He measurements might help to resolve some of the discrepancies in the He data, especially the random high flyers for a few of the samples. Additional hydrogen or tritium measurements of the three alloys showing very high helium levels might resolve the question of whether these effects are due to tritium trapping. Examination of the samples by H. Chung et al noted the presence of bubbles in many of the samples. It has been suggested that such helium bubbles may also trap hydrogen or tritium. Tritium trapping would, of course, produce additional ^3He in the samples after the end of irradiation until the tritium was degassed.

As discussed previously, the tritium leakage rates appear to be over predicted at the higher temperatures. Understanding these differences would be critical to a future design at 700°C, where the current leak rates may prevent us from achieving the desired He/dpa ratio. It may be possible to use capsule materials with better leakage characteristics or a double encapsulation approach, but this remains to be demonstrated.

In summary, a future DHCE experiment in ATR can be performed with our current knowledge for a restricted range of parameters, namely for the main grouping of alloys in the previous DHCE experiment (excluding the three with higher He levels), and at medium temperatures between about 550 to 650°C. This in itself might be a very useful experiment to conduct. However, if we want to expand the range of alloys and temperatures, then more work is clearly needed prior to such an expanded DHCE experiment.

FUTURE WORK

Although this evaluation shows that a future DHCE experiment is feasible in ATR, HFIR, or some other reactor, obviously, a great deal more effort is required to design such an experiment. Thermal neutron shielding is required for any mixed spectrum reactor to reduce the transmutation of vanadium to chromium and to control the burnup of ^6Li and ^3He . It is especially important to evaluate the burnout of the thermal neutron shielding since the shields will most likely need to be replaced during the course of a DHCE experiment.

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