Summary of US-JAERI and US-Japan Jupiter Experiments

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Background

- Longstanding JAERI and more recent MEXT collaborations
- Centered around irradiation effects on ferritic-martensitic steels (JAERI) and V alloys
- Product of long (>1 to 3 y) and sometimes difficult discussions and negotiations - different programmatic objectives and approaches with Japan emphasizing engineering and US science including deformation and fracture (e.g. Master Curve)
- Irradiations will begin in Fall 2002

US-Japan Jupiter (ALiVE)

- Instrumented lithium-bonded capsule in thermal neutron shielded in HFIR RB* positions: 8 dpa (peak) at 450, 600 and 700 C with limited (< 90 cm^3) of specimen volume - also some rabbits
- Focus on 2 heats of V-4Cr-4Ti (Japanese & US program heats) primarily differing mainly in interstitial impurity content - other alloys included as miniature tensile and TEM discs - mostly for impurity- alloying (e.g., Y) and higher strength alloy studies
- Microstructure (TEM, AP-wires, resistivity, SC, (special and multipurpose…..), subsized Charpy impact (Japan), mini-tensile, fracture toughness (0.18 DCT, HT-1/3PCC, DFMB (deformation smooth, notched, double notched and fracture pre-cracked), pressurized creep tubes, atom probe wires, and coatings on coupons….
- Shared space and US only/Japan only - US for fundamental studies and alloy development (?)

ALiVE Matrix Summary

Attachment 2: Specimen Volumes					450	600	700
Specimen Type	Code	Dimensions, mm	Volume, cc		Num	Num	Num
Fracture							
Disc Compact Tension	DCT	12f x 3.6	0.407	J/US	24	0	0
Pre-cracked Bend Bar	PBB	3.3 x 1.7 x 16.6	0.093	J/US	30	30	10
Deformation & Fracture Mini-beam	DFMB	1.5 x 1.5 x 7	0.016	J/US	60	30	10
Mini-Charpy	JCVN	1.5 x 1.5 x 20	0.045	J	50	0	0
Tensile							
Tensile SSJ-1	SSJ1	0.3 x 4 x 16	0.019	J	200	200	200
Tensile SSJ-2	SSJ2	0.5 x 4 x 16	0.032	J	20	20	20
Tensile - US	SSJ1	0.3 x 4 x 16	0.019	US	42	78	66
Creep							
Creep Tube	PCT	4.6f x 25.4	0.422	J/US	14	14	0
Microstructure							
Microscopy, Shear Punch Discs	TEM	3f x 0.3	0.002	US	140	140	120
Microscopy, Shear Punch Discs	TEM	3f x 0.3	0.002	J	275	275	275
General Purpose Coupons	GPC	20 x 10 x 0.25	0.050	US	54	46	42
Misc.	MISC		0.002	US	6	6	6
Sum of volume					30.5	18.2	9.7

ALiVE 'Fundamental' Studies

- Basic deformation & fracture process in V but believed to be somewhat (450 C) to substantially (600 and 700 C) outside region of severe hardening-embrittlement-flow localization (< 4?? C)
- Other opportunities limited by thermal neutron shielding (transmutation control) and alloy availability (time)
- Will (hopefully) have array of existing alloys and some new specimen configurations for new PIE (positrons, ASAXS, ….) in addition to TEM,...
- Possibility of B-doped alloys and/or B-based He implantation to produce high levels
- Room for fundamental studies specimens depend on temperature and other factors not fully decided (e.g., coatings)
- Will begin irradiation Fall 2002?

US-JAERI

- Common focus is on fracture toughness (MC-ΔT), hardening and ductility loss, irradiation creep and microstructural studies
- Instrumented lithium-bonded capsules in thermal neutron shielded and unshieded in HFIR RB* position: 8 dpa (peak) at 300, 400 and 500 C with limited (< 90 cm^3) of specimen volume - also some rabbits
- Uninstrumented gas gap capsule in target neutron position: 10 dpa (peak) and 40 dpa *□(peak - 2 capsules) at 300, 400 and 500 C with very limited (< 15 cm^3) of specimen volume - also some rabbits
- First capsule 10 dpa will initiate irradiation Fall 2002?

US-JAERI

- Focus on F82H (IEA and mods 1-3) and helium effects on fast fracture by B and Ni element/isotope tailoring and composite ^{54}Fe specimen
- Other alloys included as tensile, TEM discs
- Microstructure (TEM, AP-wires, resistivity, SC, (special and multipurpose…..), subsized Charpy impact (??? Japan), mini-tensile, fracture toughness (0.18 DCT, HT-1/3PCC, DFMB (deformations smooth, notched, double notched and fracture pre-cracked), pressurized creep tubes, atom probe wires - specimen mix varies from RB* to target
- Shared space and US only/Japan only - US for fundamental studies and alloy development (e.g., NFA)

US-JAERI Matrix Summary

10 dpa capsule

	dpa	Helium appm	He/dpa	Temp C	Tensile SS-new 48.0			Toughness 0.5-1/3PCCVN 98.0			Toughness DFMB 24.5			TEM 2.0			MPC 50.0			APFIM 3.0		
					Share	JP	US	Share	JP	US	Share	JP	US	Share	JP	US	Share	JP	US	Share	JP	US
Number of specimens					36	39	0	14	0	0	120	60	0	75	55	0	18	0	0	75	0	0
F82H IEA	10			300	4			8			24			5			3			5		
F82H TIG WJ	10													5								
F82H TIG WB	10													5								
Fe-54 F82H	10			300																5		
F82H+1.4%Ni	10			300	4			6			20			5			2			5		
F82H+1.4%Ni60	10			300	4									5			2			5		
F82H mod1	10			300		3						20			5					5		
F82H mod2	10			300		3						20			5							
F82H mod3	10			300		3						20			5							
JNC-ODS	10			300		3									5							
JAERI ODS1	10			300		3									5							
JAERI ODS2	10			300		3									5							
JAERI ODS3	10			300		3									5							
US Advanced ODS	10			300																		
US fundamental studies	10			300																		
sum					12	21	0	14	0	0	44	60	0	25	35	0	7	0	0	25	0	0
F82H IEA	10		0.0	400	4						24			5			3			5		
F82H TIG WJ	10													5								
F82H TIG WB	10													5								
Fe-54 F82H	10			400																5		
F82H+1.4%Ni	10		0.0	400	4						20			5			2			5		
F82H+1.4%Ni60	10			400	4									5			2			5		
F82H mod1	10		0.0	400		3									5					5		
F82H mod2	10			400		3									5					5		
F82H mod3	10			400		3									5							
US Advanced ODS	10			400																		
US fundamental studies	10			400																		
sum					12	9	0	0	0	0	44	0	0	25	15	0	4	0	0	25	0	0
F82H IEA	10		0.0	500	4						16			5			3			5		
F82H TIG WJ	10													5								
F82H TIG WB	10													5								
Fe-54 F82H	10			500																5		
F82H+1.4%Ni	10		0.0	500	4						16			5			2			5		
F82H+1.4%Ni60	10			500	4									5			2			5		
F82H mod1	10		0.0	500		3									5					5		
F82H mod2	10			500		3																
F82H mod3	10			500		3																
US Advanced ODS	10			500																		
US fundamental studies	10			500																		
sum					12	9	0	0	0	0	32	0	0	25	5	0	7	0	0	25	0	0

Four additional more capsules.

US-JAERI D&F Matrix

capsule	10dpa (Target3)			40dpa(Target 1&2)			unshielded 6dpa		Shielded 6dpa		Rabbit
TEMP (oC)	300	400	500	300	400	500	300	400	300	400	300
DFMB											
F82H IEA	24	0	0	24	24	24	26	26	26	26	20
Fe-54 F82H					20						
F82H+1.4%Ni58				20	20	20					
F82H+1.4%Ni	20	0	0				20	20	20	20	
F82H+1.4%Ni60 *				20	20	20					
F82H+60ppmB2(Old)							20	20	20	20	
F82H+60ppm10B(Old)							20	20	20	20	
F82H+60ppm11B							20	20	20	20	15
F82H+60ppm10B							20	20	20	20	15
F82H+30ppm nB							20	20	20	20	
F82H+10ppm nB							20	20	20	20	
.5T-1/3PCC											
F82H IEA	8	8	8	10	10	10	12	12	12	12	
F82H+1.4%Ni58				6	6	6					
F82H+1.4%Ni	8	8	8								
F82H+60ppm11B									6	6	8
F82H+60ppmB2											8
F82H+60ppm10B									6	6	8
F82H+60ppmB											8
.18DCT (12.5t)											
F82H IEA							10	10	10	10	
SS-NEW(&3) (0.76t)											
F82H IEA	4	4	4	8	8	8	18	18	18	18	4
F82H+1.4%Ni58				8	8	8					
F82H+1.4%Ni	4	4	4				6	9	6	6	
F82H+1.4%Ni60	4	4	4	8	8	8					
F82H+60ppmB2(Old)							6		6	6	
F82H+60ppm10B(Old)							6		6	6	
F82H+60ppm11B							6	6	6	6	4
F82H+60ppm10B							6	6	6	6	4
F82H+30ppm nB							6	6	6	6	
F82H+10ppm nB							6	6	6	6	

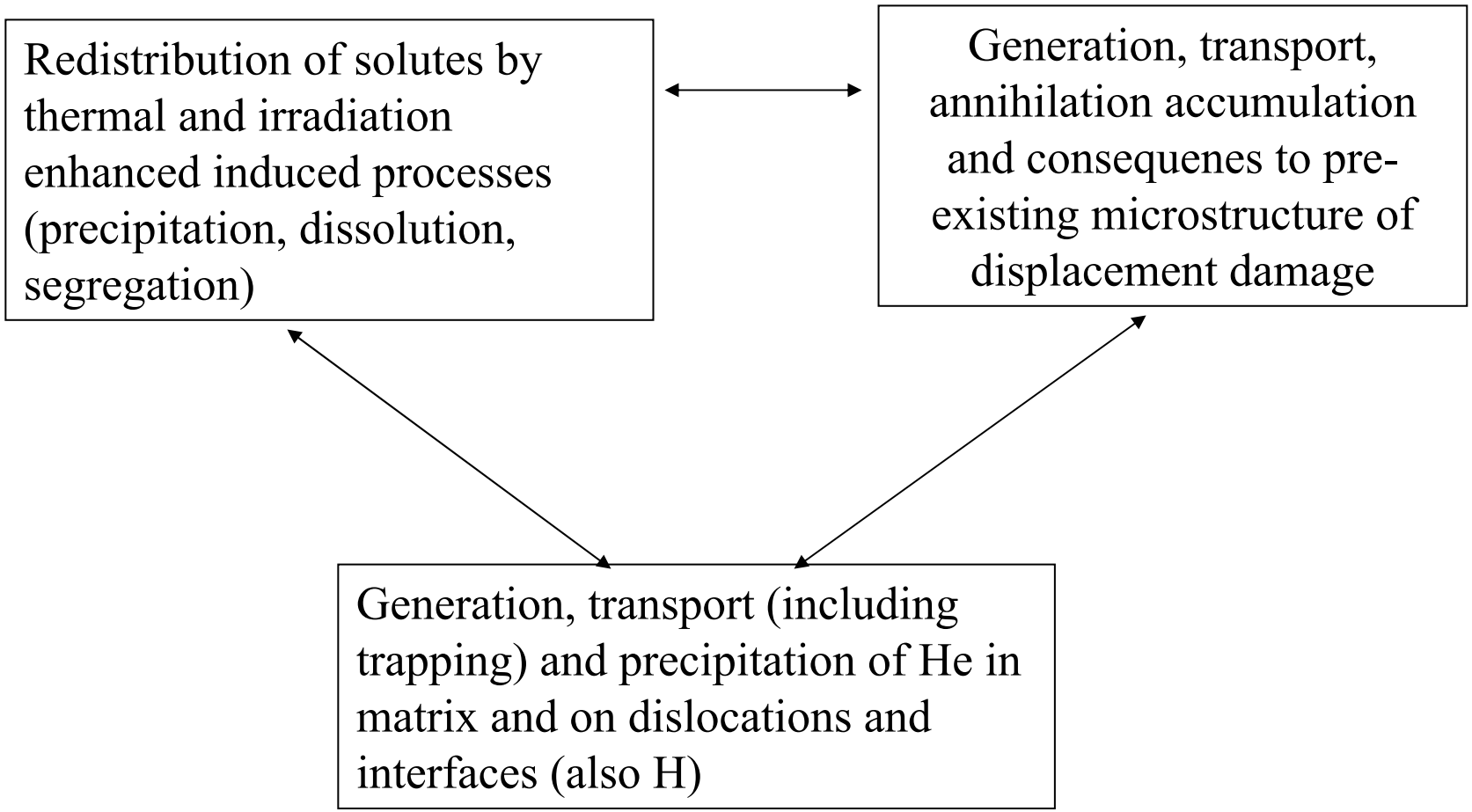
US-JAERI 'Fundamental' Studies

- Basic deformation & fracture process in (300 C), near (400C) and outside (500 C) region of severe hardening-embrittlement-flow localization (< 4?? C)
- Will systematically examine $\Delta T/\Delta\sigma_y$ - f(He???) in semi-controlled fashion
- Opportunities limited by volume (specially target) and alloy availability (time)
- Will (hopefully) have array of existing and some new (NFA) alloys and some new specimen configurations for new PIE (positrons, ASAXS, ….)
- Unshielded targets present enormous opportunity to explore new approach to studying He effects using helium implanters

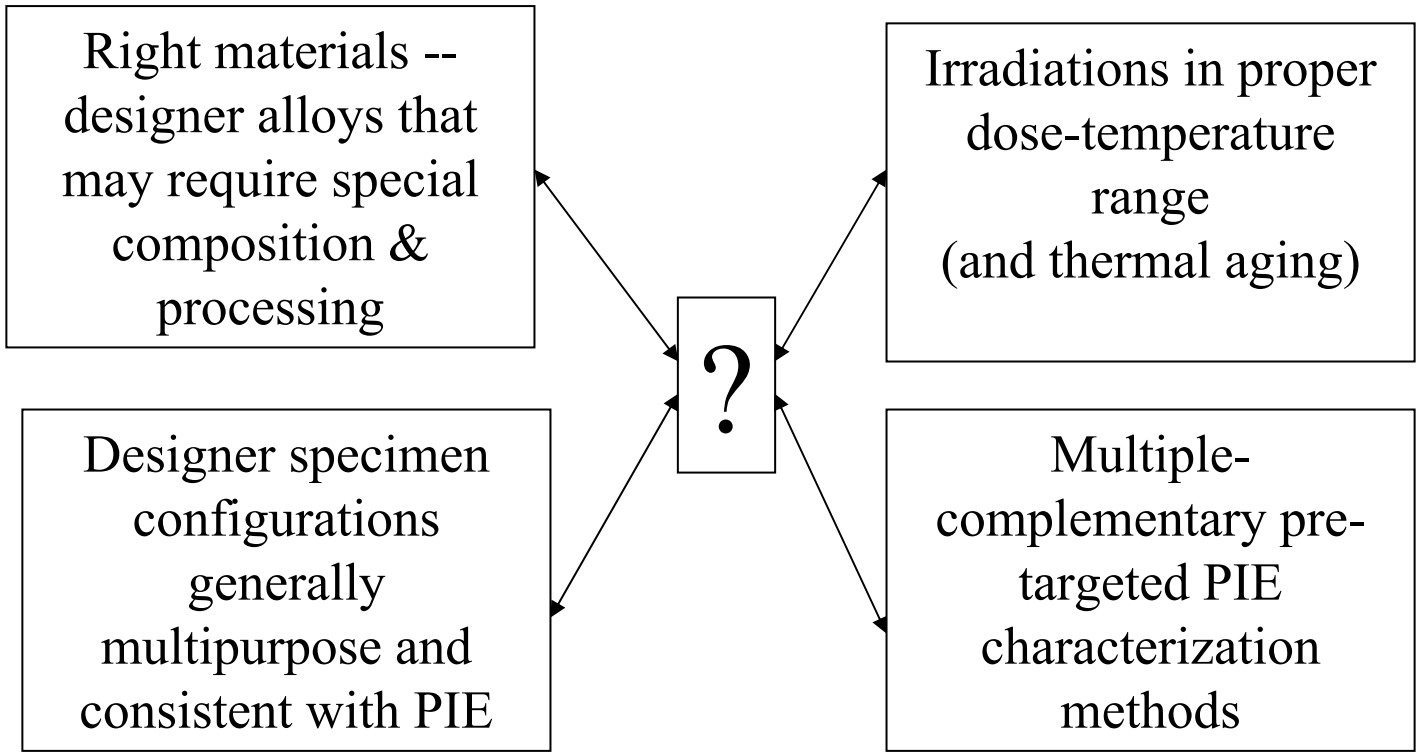
‘Fundamental’ Studies

- Carefully define questions to be addressed
- Generally focus on mechanisms (e.g. helium trapping) of radiation response and single variable $\Delta P = f(T, \phi t, \phi, He,$ alloy chemistry and SOL microstructure)
- Structured approach to the opportunities and limitations in combining the materials, the specimens, the irradiation conditions and PIE characterization methods needed to get the answers
- Time and resources a limiting factor

Basic Issues and Questions



Concurrent Ingredients



Single Variable - Mechanism Experiments

- Fine scale T-ϕt for candidate model alloys
- Solute redistribution and phase stability - precipitation, re-solutioning and segregation, effects on defect accumulation and consequences to pre-existing microstructure - α' (Cr), Laves (W), carbides (Cr, W, Ti, Ta), Y-clusters and oxides, Cu precipitates (model)
- General substructure dislocation, lath, subgrain stability
- Single variable study of hardening elements
- Radiation enhanced diffusion and induced segregation (diffusion couples)
- Dose rate (ϕ plus T-ϕt-…. interactions)
- Generation, transport (including temporary trapping) and ultimate fate of He - precipitation of He bubbles in matrix, on dislocations, particle interfaces and grain boundaries

Helium Implantation

- The isotope (68%) $^{58}Ni(n_{th},\gamma)^{59}Ni(n_{th},\alpha)$ reaction is a potent source of helium that was exploited in the 1980's (Simons, Odette, Mansur and others). The helium can be controlled by the amount of Ni, spectral and isotope (58/60) tailoring. However, Ni is a confounding factor in alloys that do not normal contain Ni. Other sources - ^{10}B, ^{6}Li, ^{64}Zn, ^{54}Fe and triple fission
- Early proposals for using nuclear n,α (4.8 MeV) reactions (Odette 1986, Mansur 1989) was never pursued for a number of reasons (Ni in stainless steels, coarser scale of microstructures, bad memory) but was resurrected in planning for the US-JAERI experiments (Odette 2001)

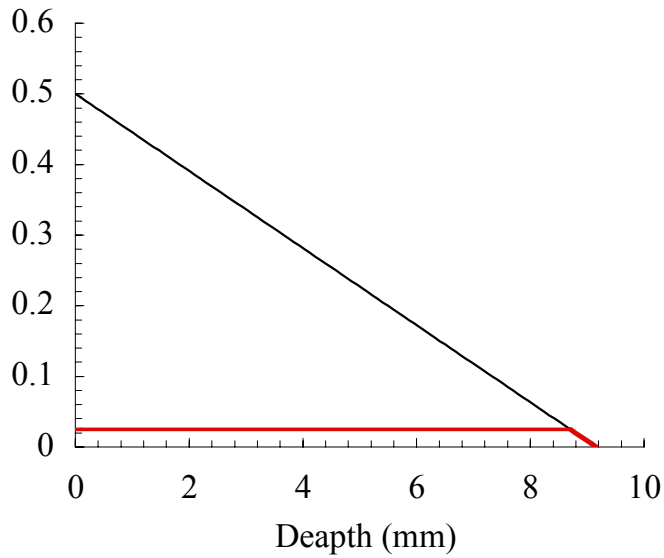
Ni Based Implantation

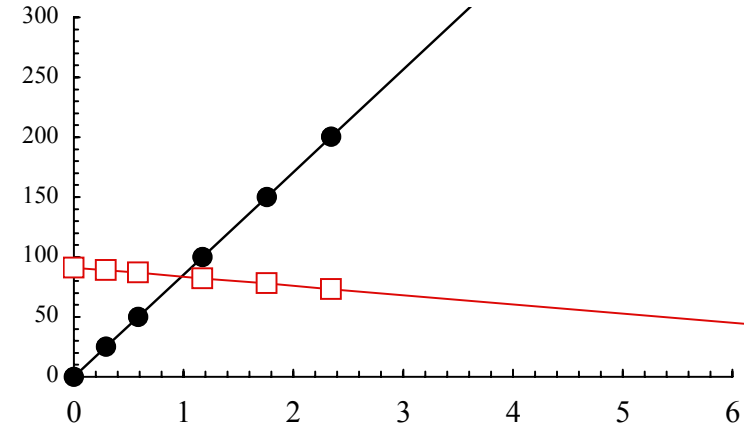
Greenwood

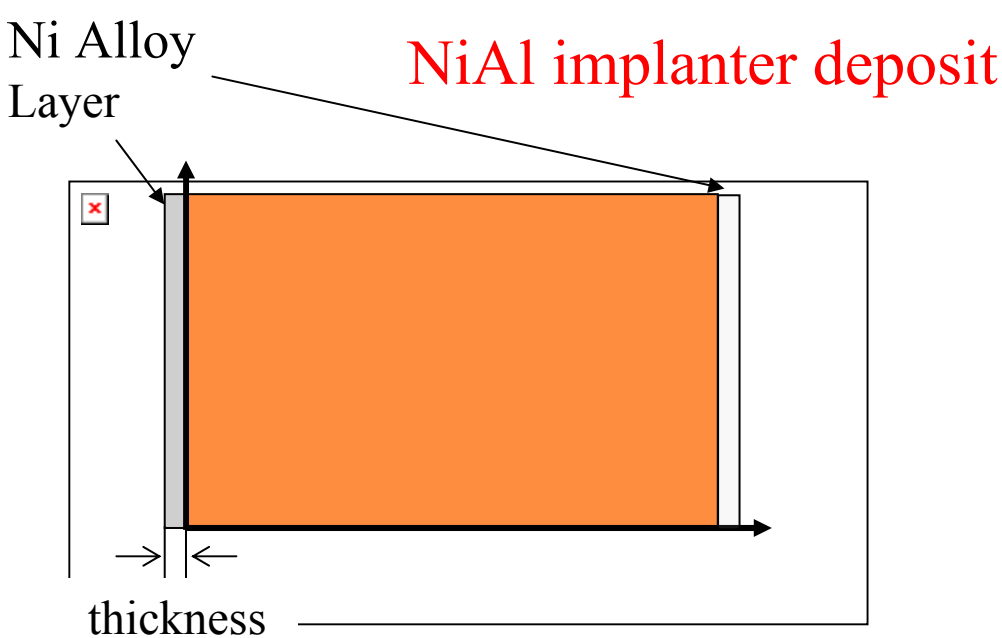
- Enormous range of He for any material!!

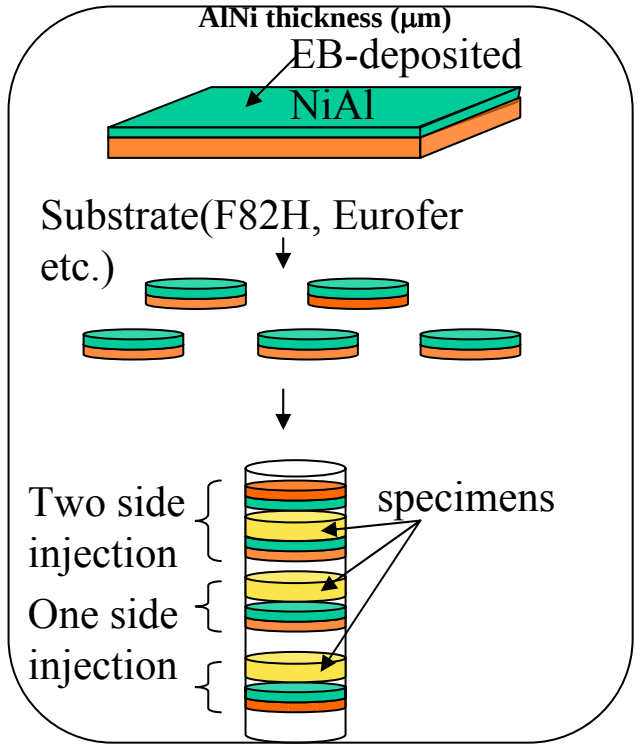
- Ni range in Fe ≈ 9 μm
- 350 appm He/dpa in Ni as SS 50% implanted from thick Ni implanters on both sides of a foil (≈ 18 μm)
- $X\% = 0.5t/r_e$ for thin implanters on both sides of a thin target foil or one side of a thick target
- Dimple-back-thin for micro-structure
- Low load hardness
- Pre-post irradiation hardness

Helium Injector Foil Experiment









Summary

- Opportunities to develop data in support of developing models
- Single variable experiments
- Targeted mechanism studies
- He implantation opens a new and exciting avenue for accelerating fusion materials development and creating a knowledge base
- Must be creative in approaches to experiments
- Will need cost-effective US irradiation experiments and integrated with PIE studies to take advantage of these opportunities