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CNNC

The microstructure of post-irradiated A508-3 steel and its effects on Charpy impact energy

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Introduction



Reactor Pressure Vessel

- ✓ One of the most important safety shield of the reactor
- ✓ Cannot change, determined the lifetime of the reactor

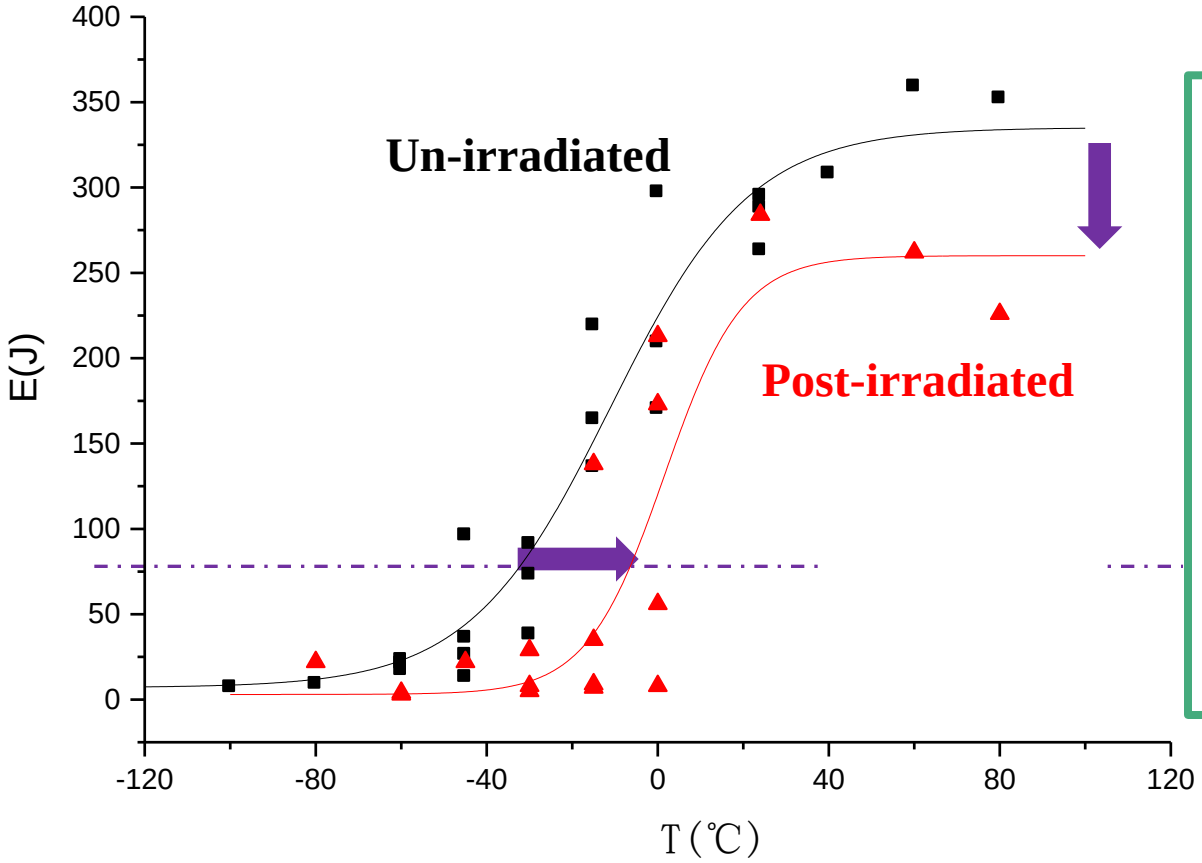
Key issues：

- ➢ Irradiation embrettlement

Severe conditions:

- ➢ Neutron irradiation
- ➢ Multi-stress situation
- ➢ High temperature and thermal shock
- ➢ Water/steam corrosion
- ➢ ……

Introduction



Irradiation effects:

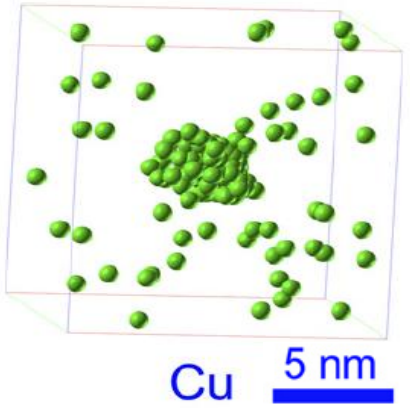
- Ductile-to-brittle transition temperature (DBTT) increase
- Maximum absorb energy decrease
- ……

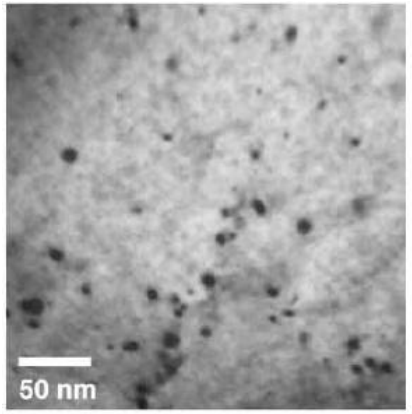
The Charpy V-notch impact energies of the A508-3 steel from the HFETR as a function of temperature for the un-irradiated and irradiated conditions at neutron fluence of 2.97×10^{19} n/cm^2

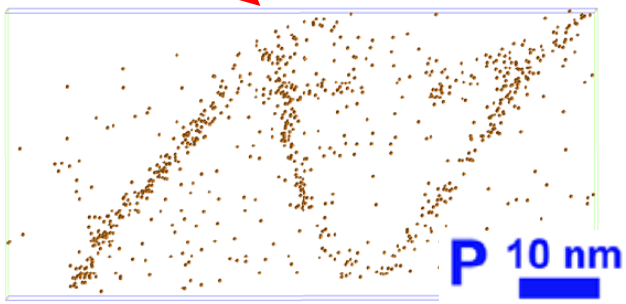
Introduction

The main reasons of the irradiation embrittlement of the RPV steel are：

- **The precipitation of nanoscale atomic clusters (Copper, Nickel, Manganese, etc.)**
- **The formation of dislocation loops inside matrix**
- **The segregation of Phosphorus atoms beyond boundary**

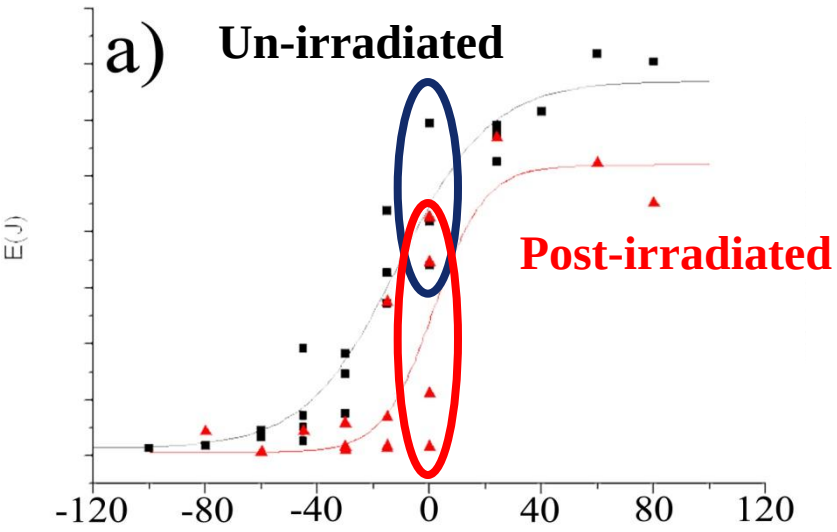






[1] V. Slugena, A. Kryukov. Nuclear Engineering and Design 263 (2013) 308– 312
[2]M.K. Miller, K.F. Russell, M.A. Sokolov, R.K. Nanstad. Journal of Nuclear Materials 361 (2007) 248–261
[3] M. Hernández-Mayoral , D. Gómez-Brice. Journal of Nuclear Materials 399 (2010) 146–153

Introduction



Charpy V-notch impact energy curve of A508-3 steel

The impact energies of un-irradiated and post-irradiated A508-3 steel under the same testing environment are unstable.

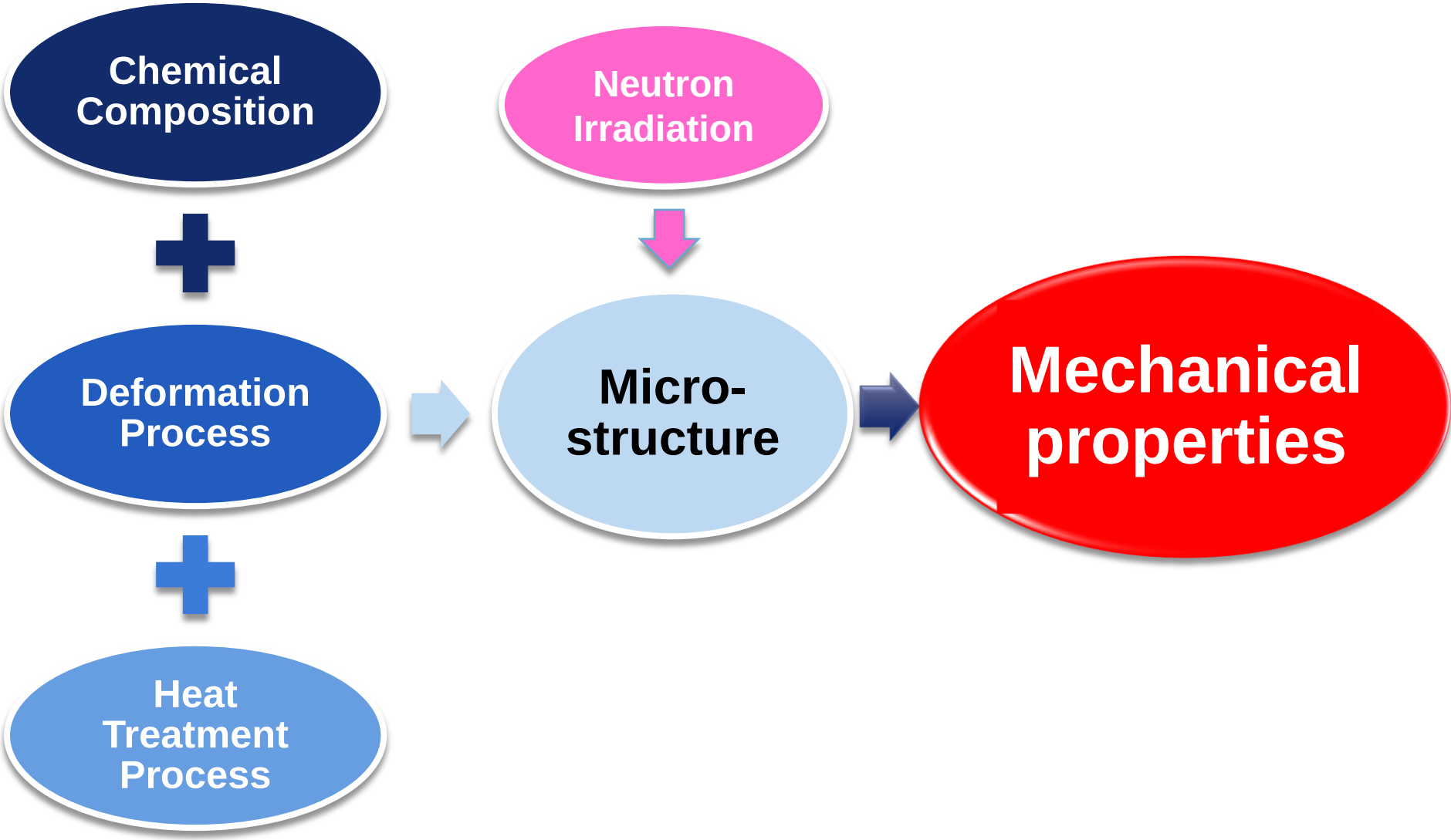
WHY?

Microstructure?

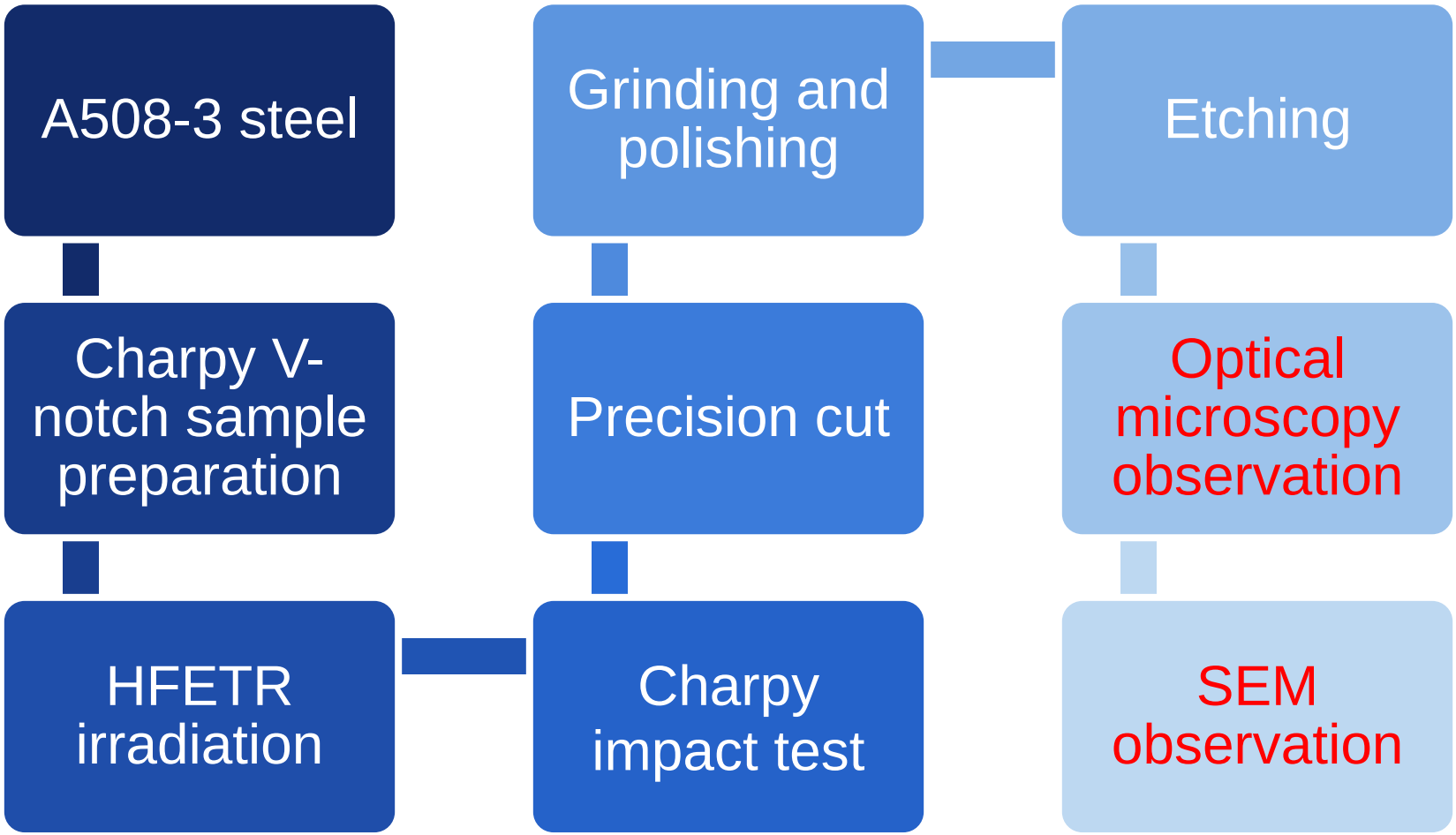
Grain Size?

Defects?

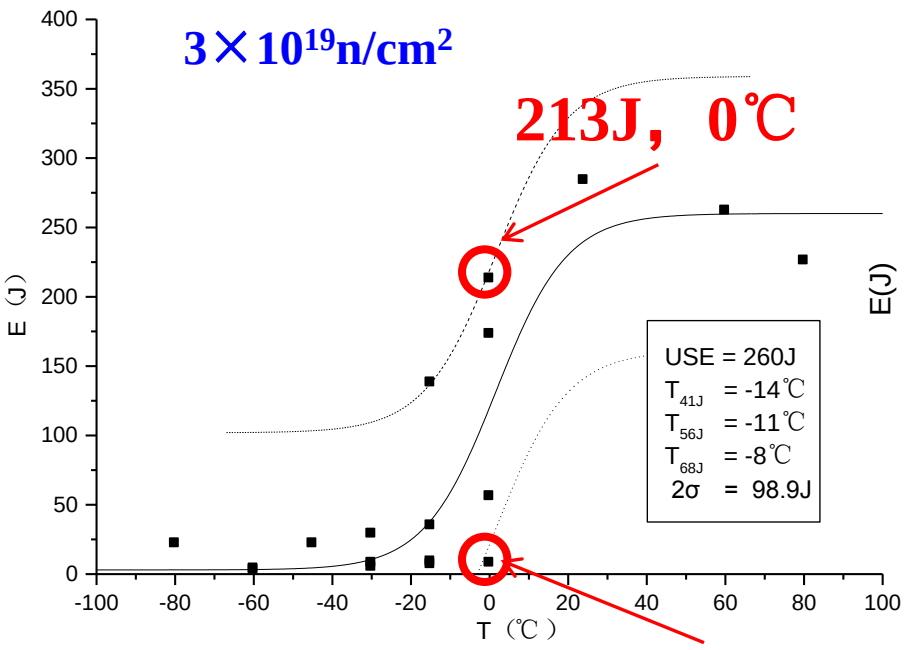
Introduction

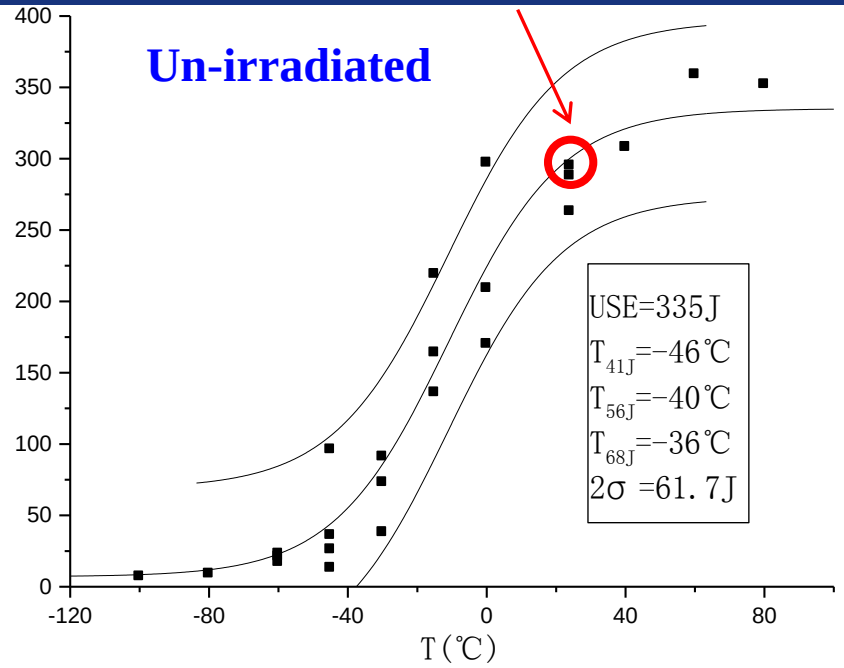


Experimental



Experimental

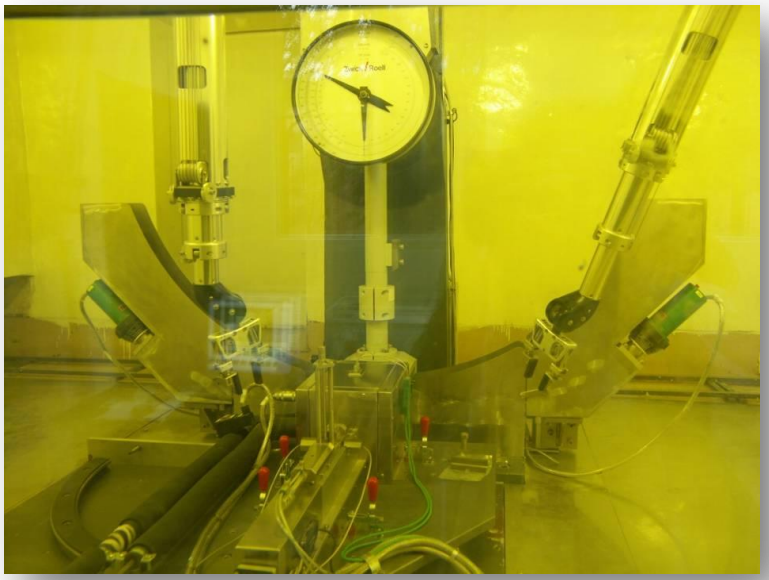




Charpy V-notch impact energy curves of A508-3 steel

Samples	Irradiation Temperature	Neutron fluence	Test temperature	Charpy V-notch impact energy
	T（℃）	（n/cm²）	T（℃）	E（J）
1#	290±15	0	24	263
2#	290±15	2.97×10^{19}	0	213
3#	290±15	2.97×10^{19}	0	8

Experimental



Zwick RKP450 Charpy impact testing machine



Leica MEF4A Optical microscopy inside hot cell

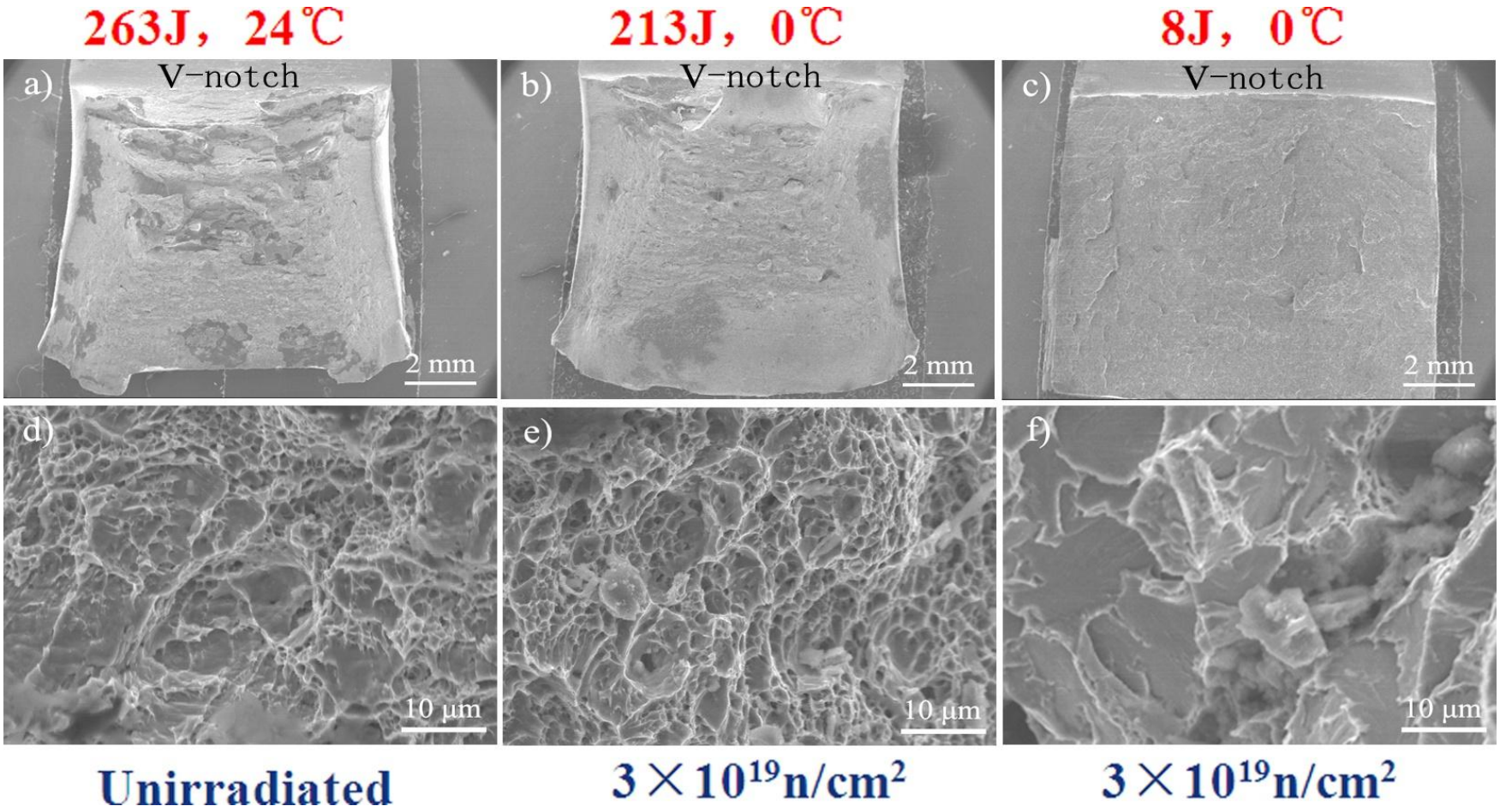
Experimental





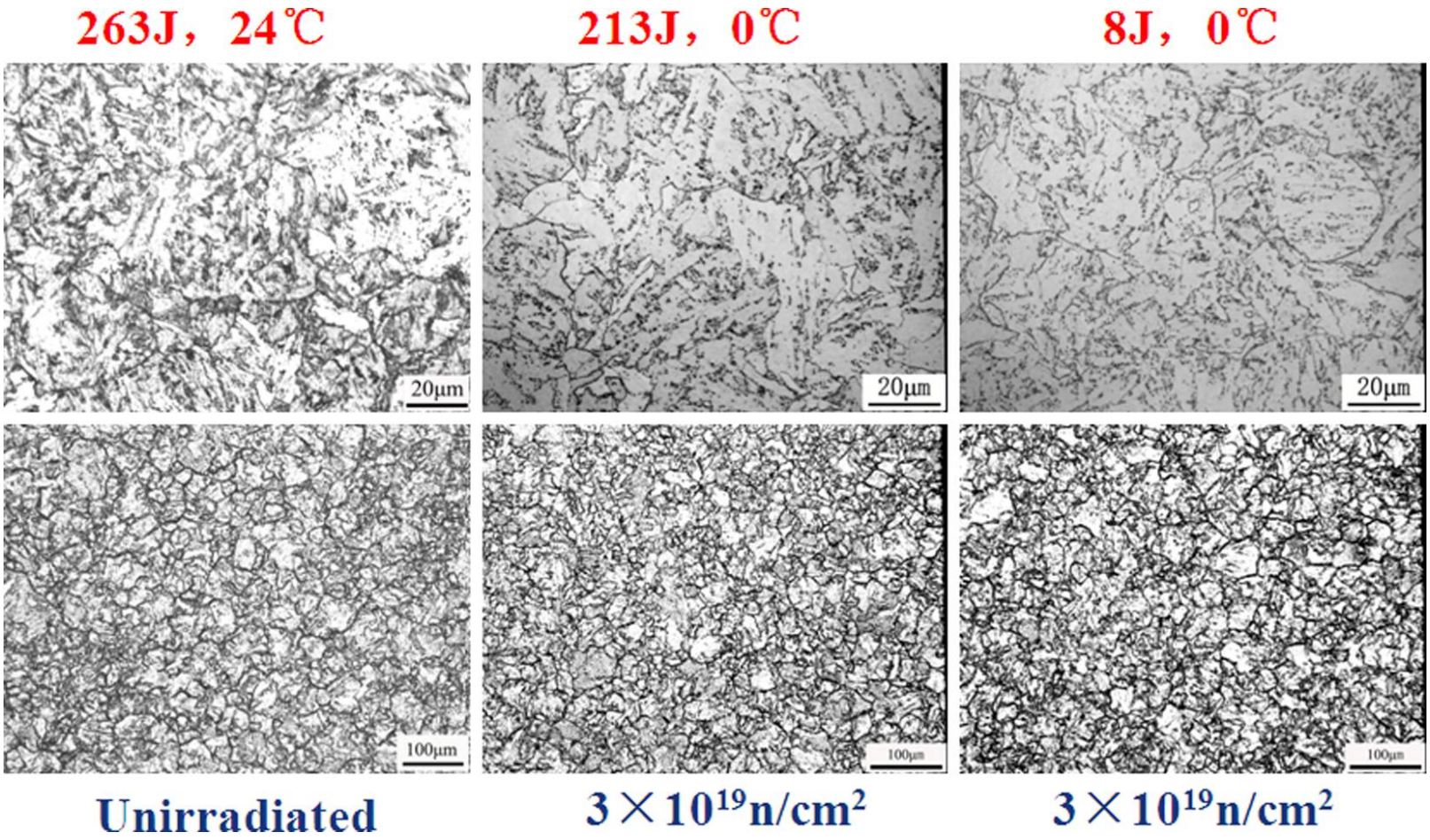
FEI Quanta 450 FEG field emission scanning electron microscope with EDS inside a cast iron cell

Results and Discussion



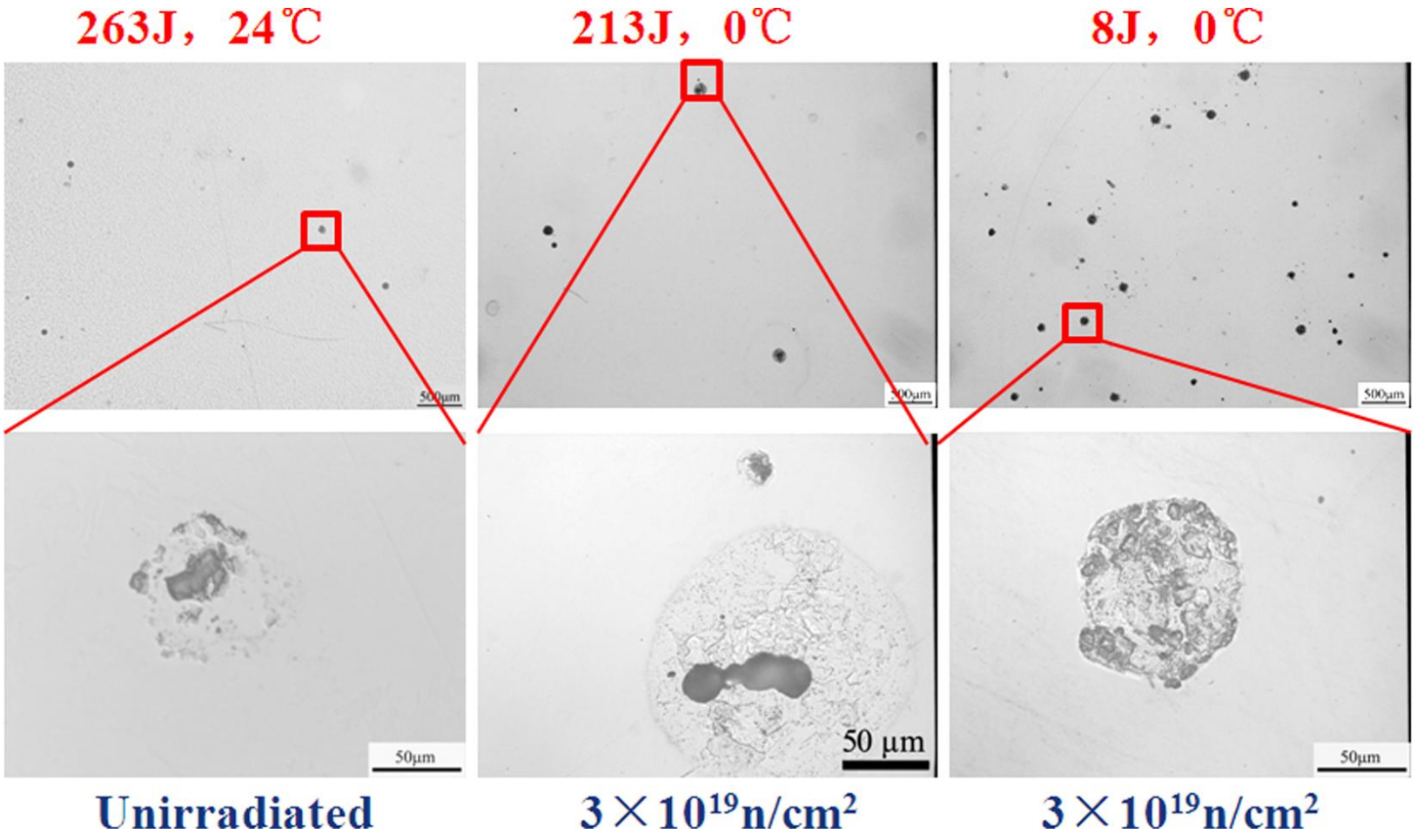
SEM image of the fracture

Results and Discussion



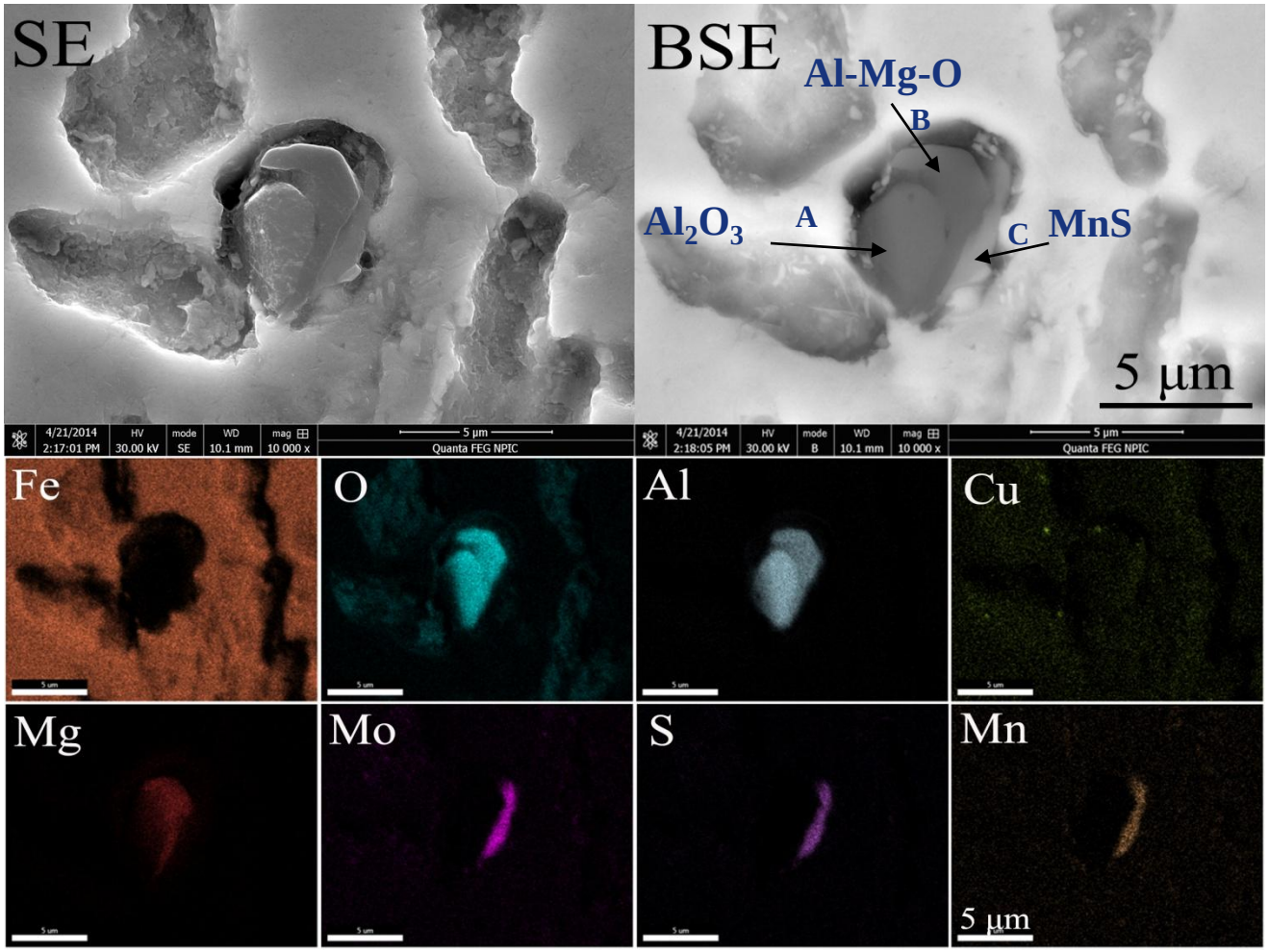
Optical metallography(upper) and grain size(lower) images – No big differences between un-irradiated and post-irradiated specimens

Results and Discussion



Optical images of morphology and distribution of defects(holes) – The lower the absorb energy is, the higher the number densities of defects!!!

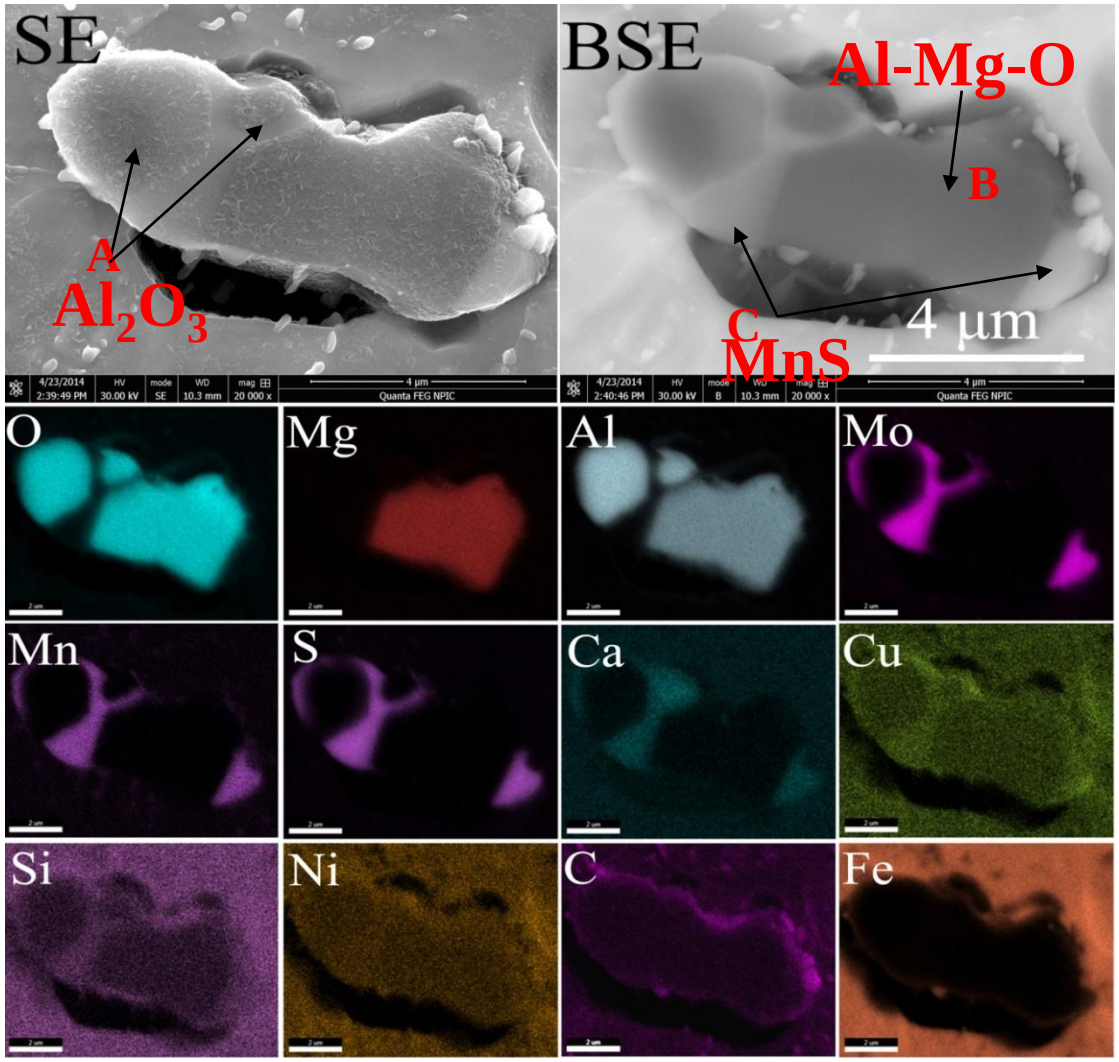
Results and Discussion



1#，un-irradiated

Positions		A	B	C
elements	Fe	0.08	-	3.00
	C	0.02	0.03	0.10
	O	55.42	56.56	-
	Al	44.34	29.89	0.27
	Mg	-	13.52	-
	Mo	-	-	1.38
	S	-	-	44.20
	Mn	-	-	42.74
	Ca	-	-	6.49
	Cr	-	-	0.25
	Ni	-	-	0.37
	Se	-	-	0.52
	Cu	-	-	0.68
	P	0.13	-	-
	总计	100	100	100

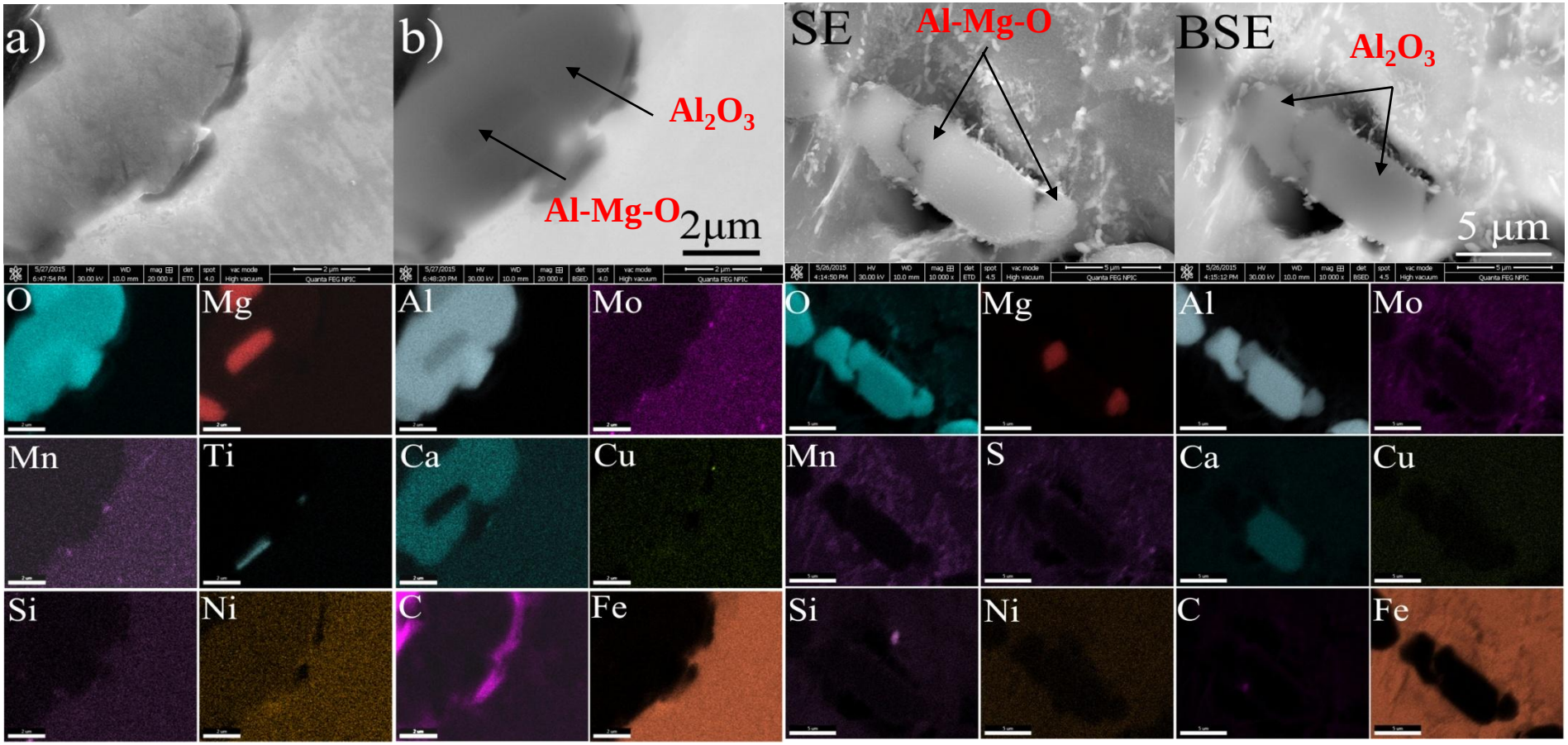
Results and Discussion



1#， un-irradiated

- ✓ 3 kinds of non-metallic inclusions inside un-irradiated specimen: Al_2O_3, MnS, and Al-Mg-O ternary phase ($MgAl_2O_4$)
- ✓ The boundary between non-metallic inclusions and the matrix is quite loose

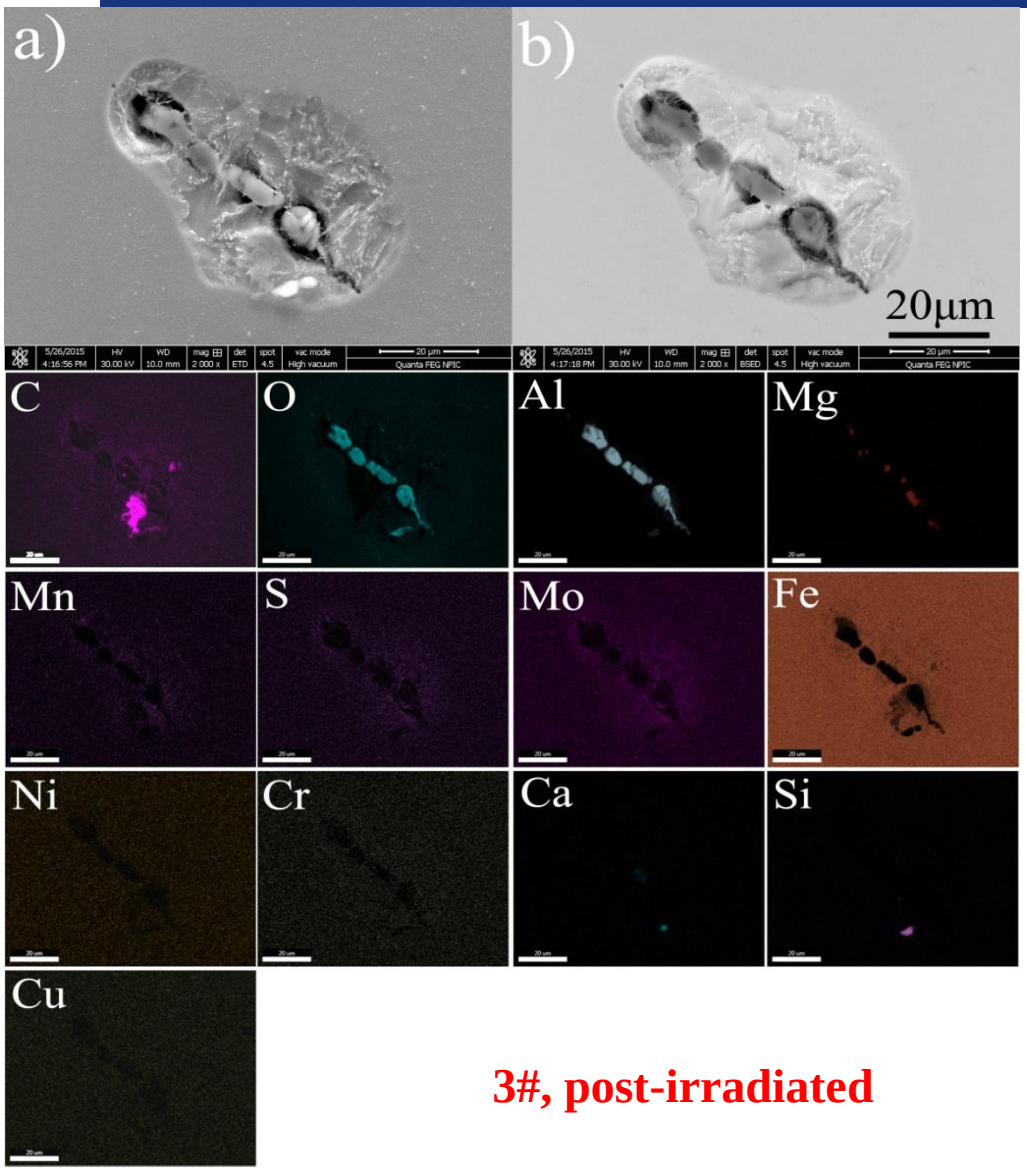
Results and Discussion



2#，post-irradiated **3#，post-irradiated**

Only 2 kinds of non-metallic inclusions existed in post-irradiated specimens: Al_2O_3 and Al-Mg-O ternary phase ($MgAl_2O_4$)

Results and Discussion



3#, post-irradiated

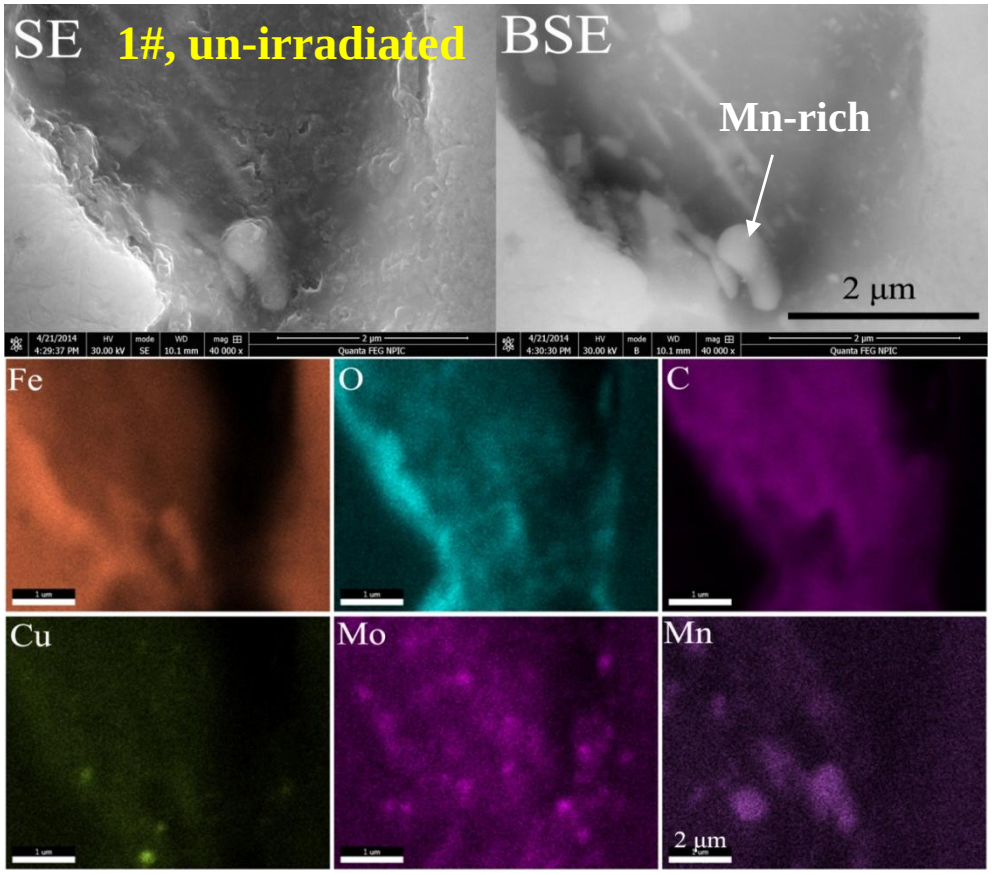
The evidence of MnS disappearred in post-irradiated specimens: the enrichment of Mn and S element among the edge of holes.

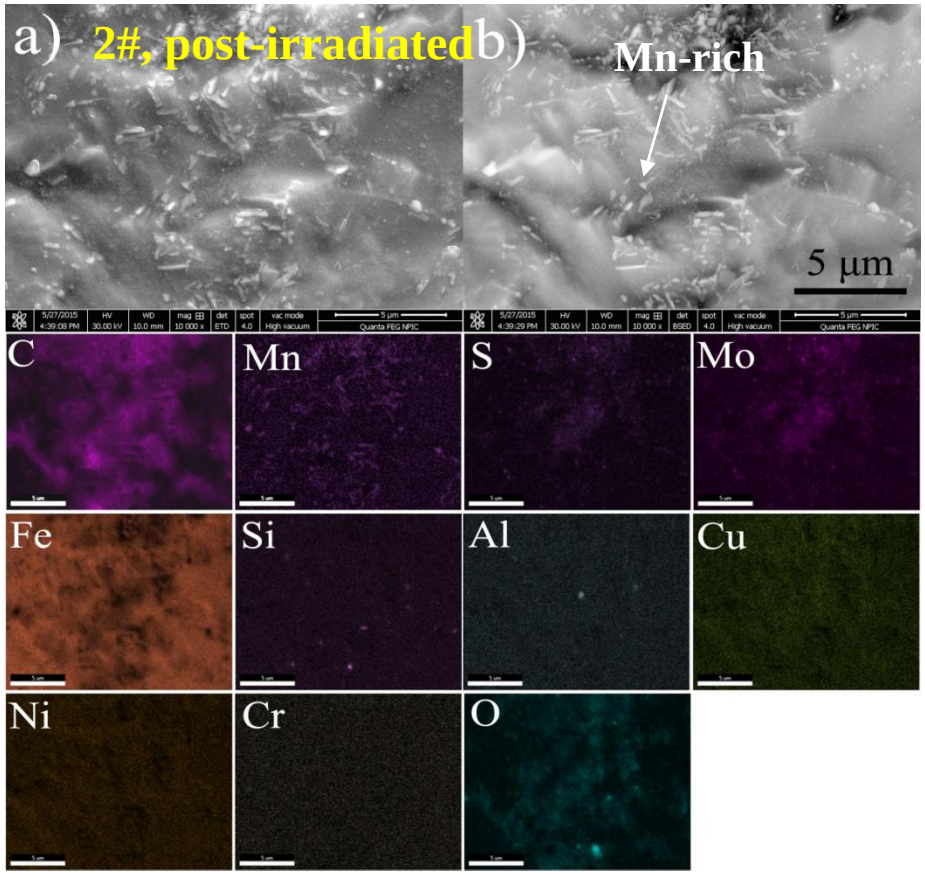
Reasons:

Compare with Al_2O_3 and $MgAl_2O_4$, the melting temperature of MnS is quiet lower. MnS is easier to decompose under the hot peak during cascade. In addition, combine with the effect of irradiation enhanced diffusion, S and Mn atoms move to boundaries.

In the other hand, Mn atoms transmutation into Fe atoms by nuclear reaction, MnS decompose .

Results and Discussion





- ✓ **Because of low Copper concentration（0.03 wt.%）, very limited Copper clusters could be observed both in un-irradiated and post-irradiated samples**
- ✓ **Manganese and Molybdenum clusters exist after irradiation**




Conclusions

- ✓ *No obviously change in the bainite structure and grain size of the A508-3 steel could be observed by OM under this irradiate conditions (fluence of neutron is 2.97×10^{19} n/cm^2, and irradiation temperature is 290℃±15℃), which could not causing impact energy abnormally.*
- ✓ *The direct reason probably is the differences in fraction volume of the defects(holes) in the matrix, which formed during solidification process.*
- ✓ *The defects could be divided into two types, one is filled with layer-like Al_2O_3, MnS, and Al-Mg-O ternary non-metallic inclusions combining together, and the other is holes.*
- ✓ *Boundary between these non-metallic inclusions and matrix is quite loose, which is easily to decrease the impact toughness.*
- ✓ *Except MnS phase, the morphology and composition of the Al_2O_3 and Al-Mg-O ternary non-metallic inclusions in defects were not modified by neutron irradiation significantly under this irradiate conditions.*

Conclusions





Next steps:

- ✓ **EPMA observation, micro-composition analysis**
- ✓**FIB +TEM observation, microstructure analysis**
- ✓**Semi in-situ observation**




Thank you for your attention!