# Neutron/Proton Round Robin: What role does irradiation type play in enhancing ordering in Ni-Cr-based alloys?

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**ABSTRACT:**

High Cr, Ni-based alloys are an important class of nuclear structural materials due to their strength, toughness, and excellent corrosion resistance. Alloys such as 690 and 625 are already used in existing light water reactors (LWRs) in steam generators, reactor pressure boundary structures, and/or core internals. The Ni-Cr binary system exhibits a long-range ordered (LRO) phase at temperatures below 590°C when the Ni:(Cr+Mo) ratio is around $Ni_2Cr$. There is concern that commercial alloys with similar Ni:(Cr+Mo) ratios may undergo the same embrittling LRO phase transformation after many years in service at elevated temperatures and under irradiation.

Ni-Cr model alloys can order in as little at 2000 hours at 475°C but Fe-containing commercial alloys have lower critical temperature and minor alloy additions can bind to vacancies and slow diffusion. These factors result in isothermal aging studies of commercial Ni-Cr alloys lasting for years before observing LRO. This phase transformation can be enhanced using irradiation, which provides valuable insight for the phase stability of components both in-core and out. Previous studies have shown that LRO can be formed with electron, proton and neutron irradiation. However, our previous studies using heavy Ni-ion irradiation did not result in ordering, indicating that there is a trade-off between ballistic mixing and enhanced diffusion that may produce flux and cascade size dependent microstructures. This innovative NSUF R&D project will be dedicated to uncovering the roles of irradiation-type (neutron and proton) in promoting LRO in Ni-Cr based alloys. This understanding will allow us to use irradiation as a tool to accelerate LRO in commercial alloys and predict detrimental changes to their properties. Furthermore, we will also learn about the rate of LRO in irradiation environments so that we can predict degradations for in-core components.

This project will include neutron irradiation at the Massachusetts Institute of Technology reactor (MITR) and proton irradiation at the University of Wisconsin-Madison (UW) ion beam laboratory. This will allow us to quantify the amount of acceleration expected from each particle type. We will be targeting doses of up to 2.6 dpa for both the proton and neutron irradiated samples based on previous irradiations of similar alloys. Specific materials of interest will include model Ni-Cr and Ni-Cr-Fe alloys as well as several commercial Ni-Cr based alloys 690, 625, 625+, 52 and 152. All alloys have undergone or are currently undergoing isothermal aging and will reach 50,000+ hours during the first two years of this project. All specimens will be characterized via synchrotron x-ray diffraction (XRD) to identify phases present and to quantify the phase fraction and size of $Ni_2Cr$ precipitates. Additionally, we will leverage the Idaho National Laboratory high performance computing resources to perform atomistic and mesoscale modeling to explain the role of irradiation type on ordering rate. This study will include both model and commercial Ni-Cr-based alloys to elucidate the role of minor alloying elements.