Radiation Tolerant Materials for Advanced Nuclear Reactors

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Nuclear Energy

https://youtu.be/IAwdCP1-nRo

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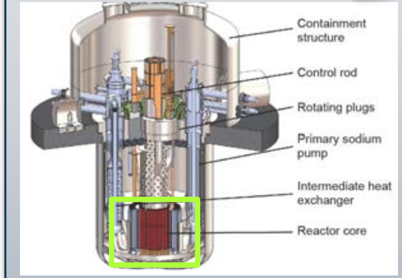
Advanced Nuclear Reactors

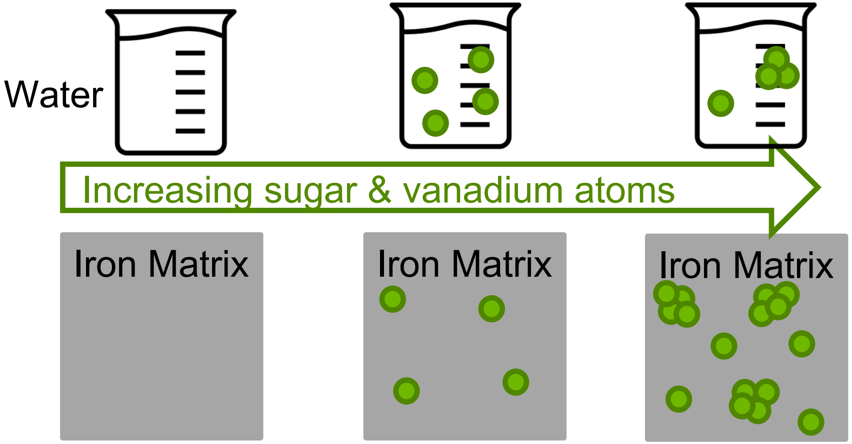
- Advanced nuclear energy is a **clean energy** option that can provide an abundance of **low carbon electricity**.
- The International Energy Agency projects that “without nuclear investment, **achieving a sustainable energy system will be much harder**.”
- However, **advanced reactors’ operability and lifetimes are limited** by the current capabilities of steel structural materials to withstand the harsh environment of the reactor cores.
- For these reactors to be viable, these **materials issues must be overcome**.

Core Structural Materials must withstand:

High temperature (>500°C)
High radiation damage levels
High stress
Corrosion



If unmitigated, these effects will lead to reactor shutdown from material failure. The negative effects can be mitigated by designing core materials to contain a high density of ***fine, stable precipitates***.



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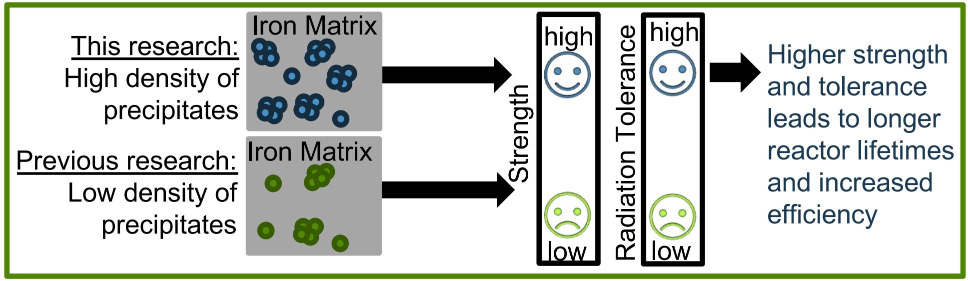
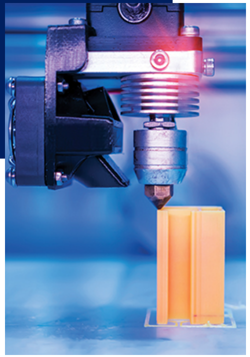
Utilize Additive Manufacturing



This experiment aims to:

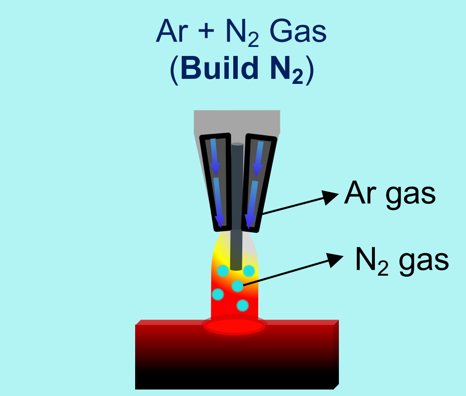
Control precipitation properties in steel with 3D printing

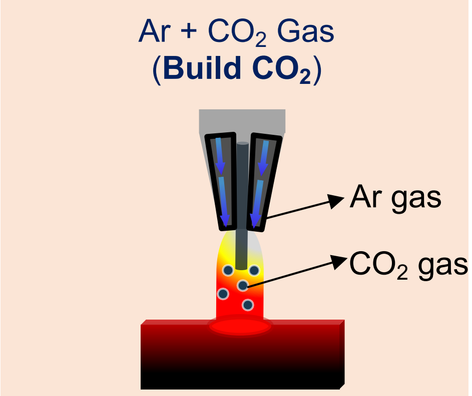


Build Samples with 3D Printing

3D print two bulk specimens:

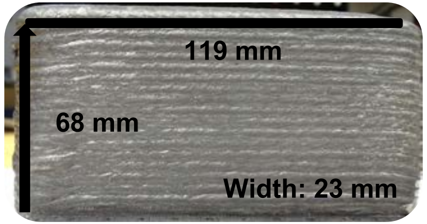
- Build N_2: printed in a gaseous atmosphere of argon and N_2 gas
- Build CO_2: printed in a gaseous atmosphere of argon and CO_2 gas





The gas circulates around the specimen during fabrication and its composition is hypothesized to affect final precipitate composition and structure.

Photo of Build N_2:



Characterize 3D Printed Samples

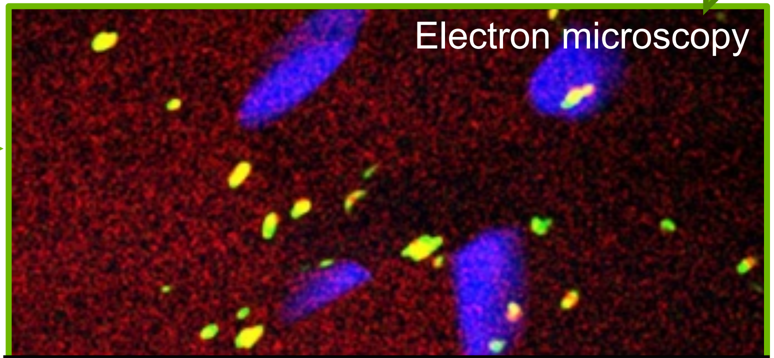
We want to probe the properties of the samples on the nanometer length scale. A nanometer (nm) is one billionth of a meter and is imperceivable by the human eye. With the use of electron microscopy, we can view nanoscale precipitation.

5 ft 4 in = 1,600,000,000 nm

Order of Length Analysis

10^{-2} m → 10^{-9} m

2.3 cm



The different colors in the map represent different elements.

Cr Nb V

250 nm

Resulting Precipitates

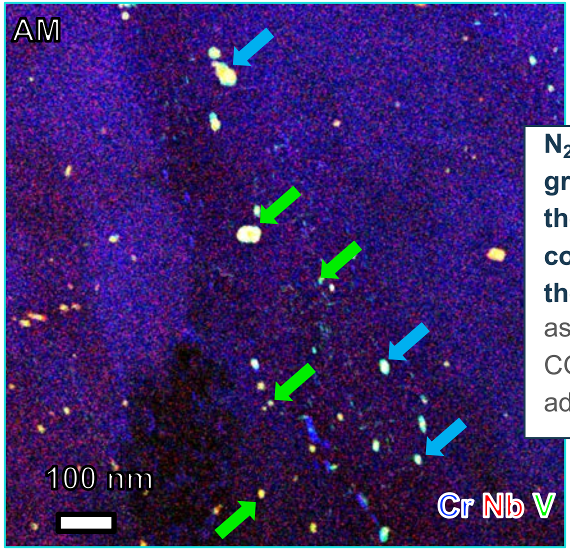
Three small types of precipitates formed in the materials:

Green arrows: VN

Red arrows: Nb(C,N)

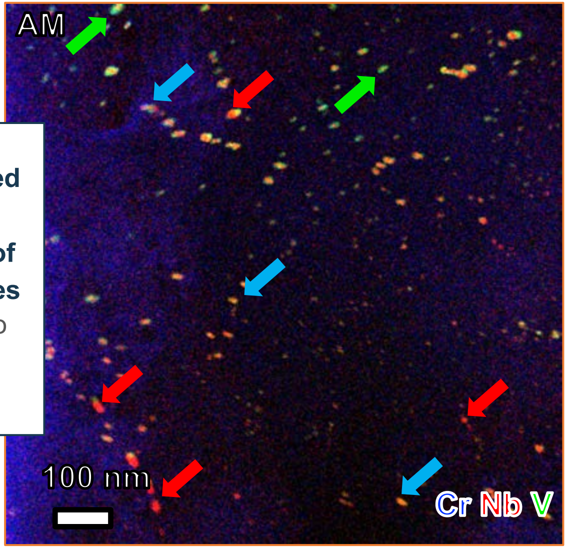
Blue arrows: (Nb,V)(C,N)

Build N_2:
Increase in N content from the N_2 additions



N_2 additions greatly affected the composition of the precipitates as compared to CO_2 gas additions

Build CO_2:
Increase in C content from CO_2 additions



Chemical Analysis of Precipitates

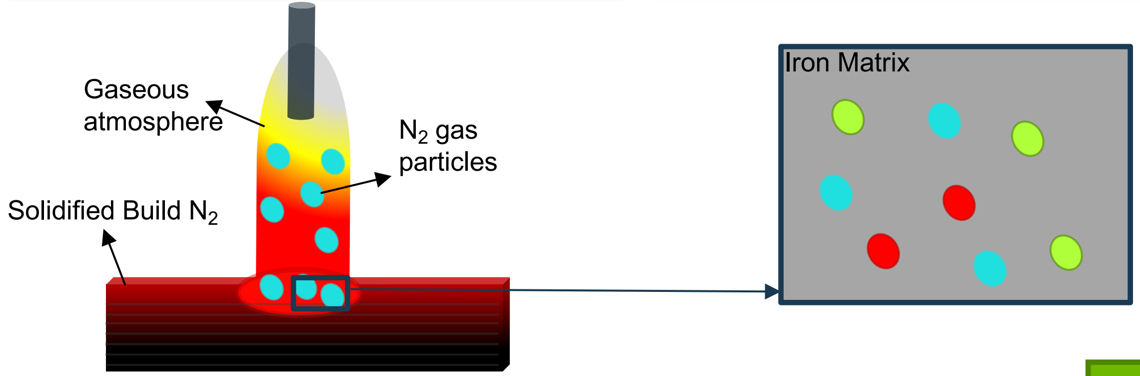
Why did the two builds show different types of precipitates?

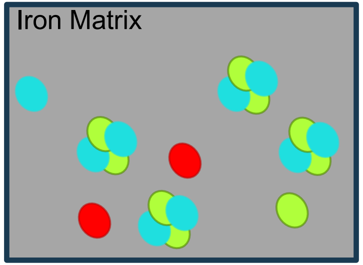
Take Build N_2 as an example:

The N_2 particles are added to the gaseous atmosphere during 3D printing.

N_2 particles are absorbed into the material.

As the material continues to cool after printing, the N_2 particles “attach” to other metallic elements to create precipitates. N has a greater affinity for V, therefore making more VN precipitates.





Build CO_2 had more C, which has a greater affinity for Nb. This caused more Nb-containing precipitates to form in Build CO_2.

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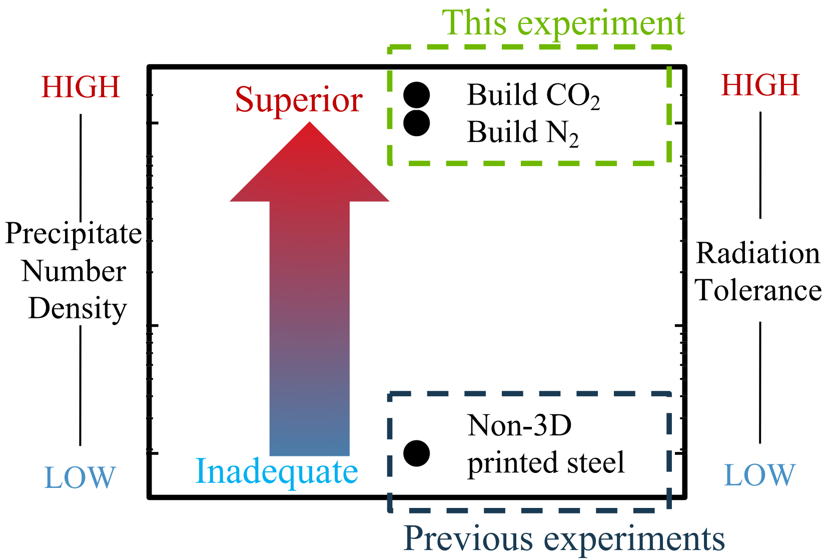
Precipitate Effect on Radiation Tolerance

A high radiation tolerance can be achieved through an increase of precipitate number density, as was shown with this experiment.



Increase gained from N_2 and CO_2 gas used during 3D printing

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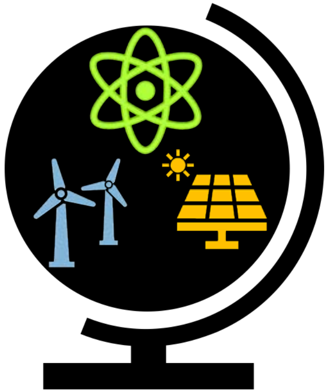
Conclusions

Contributed significant findings for 3D printing to be used in the development of advanced reactors.

Lifetime of advanced reactors increased due to material improvements from AM, contributing to increased nuclear energy adoption and hence to a balanced, low carbon energy mix worldwide.



Thank you!

The findings of this research have been submitted for peer review.

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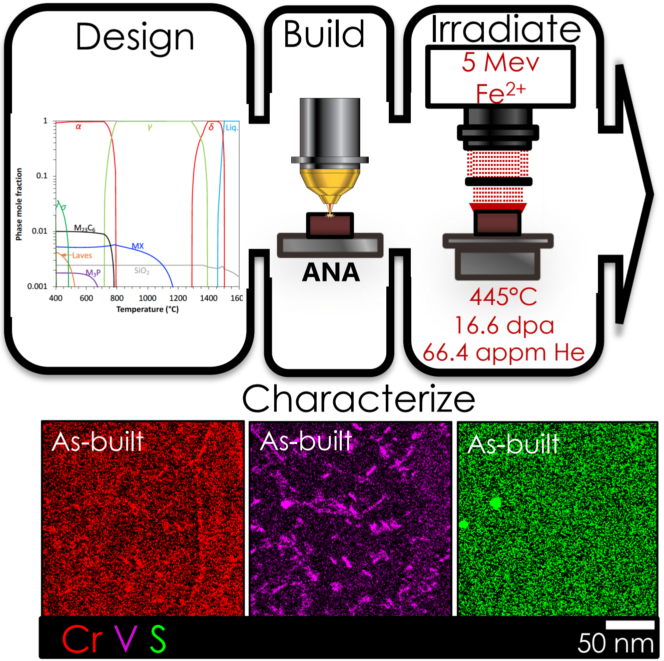
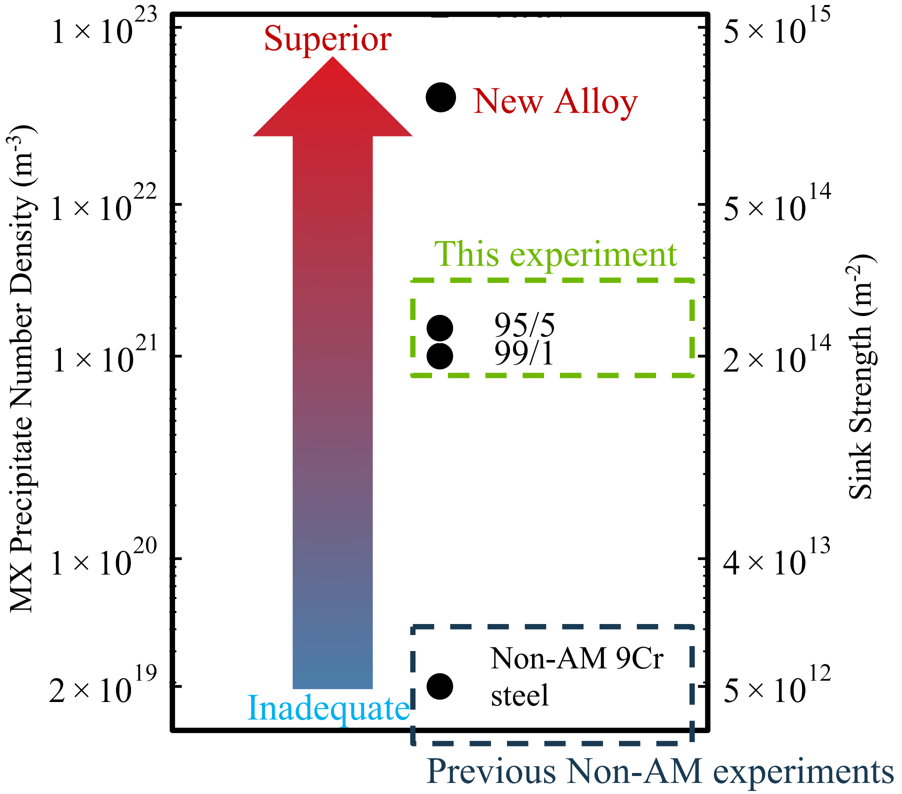
Future work

Apply knowledge from this experiment to a novel alloy fabricated with AM for increased radiation tolerance.





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Acknowledgments

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