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Director
Digital Innovation Center of Excellence

# Digital Engineering to Accelerate Advanced Reactor Development

Idaho National Laboratory

# Digital Engineering

## Definition

Digital Engineering (DE) embodies a deliberate transformational approach to the way systems are designed, engineered, constructed, operated, maintained, and retired.

## Federal Impact

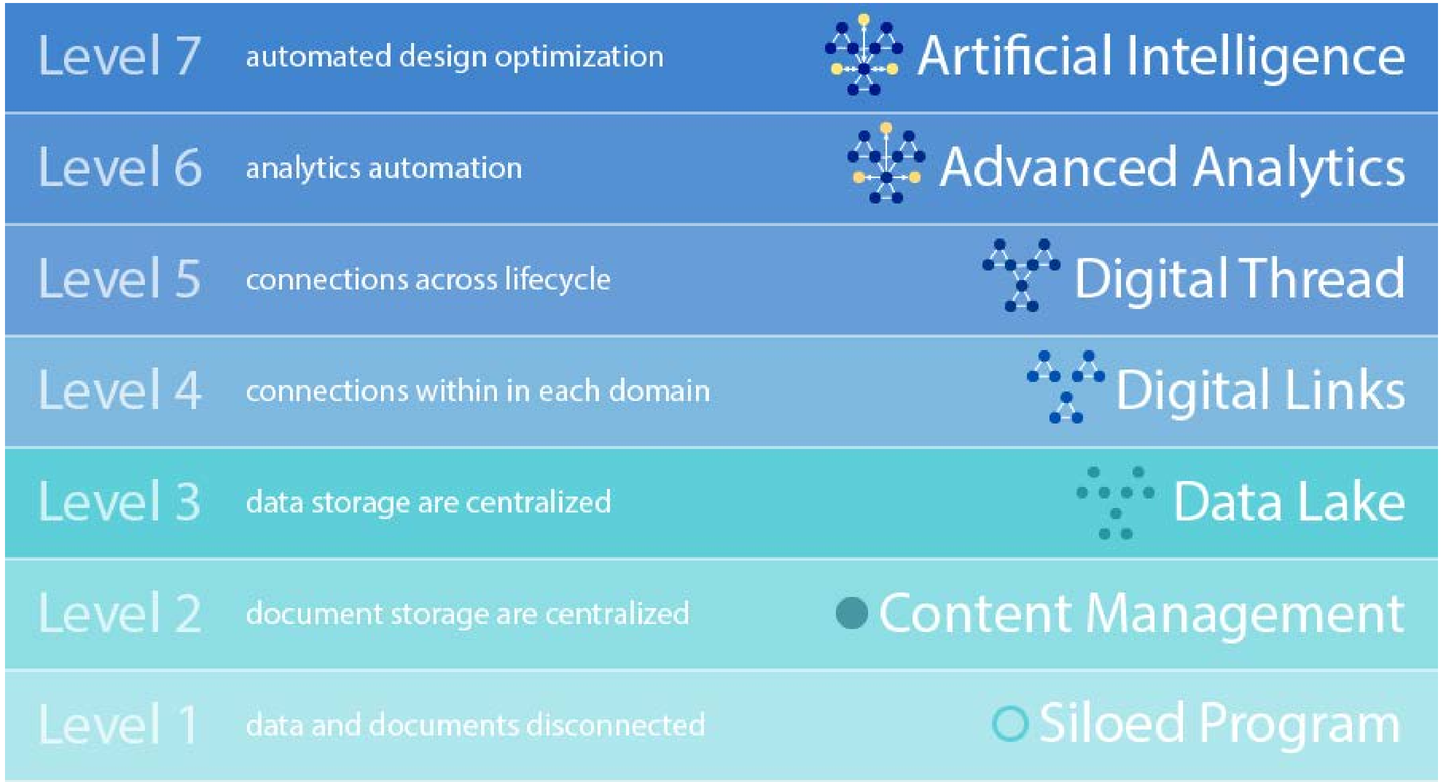
“Air Force flies 6th-gen stealth fighter – 'super fast' **with digital engineering**” [1] – Air Force has already built and flown a new sixth-generation stealth fighter jet originally scheduled for ~2030 (almost a decade early).

[1] https://www.foxnews.com/tech/air-force-flies-6th-gen-stealth-fighter-super-fast-with-digital-engineering
[2] https://www.defensenews.com/breaking-news/2020/09/15/the-us-air-force-has-built-and-flown-a-mysterious-full-scale-prototype-of-its-future-fighter-jet/

INL/MIS-21-61636

# Digital Engineering Opportunity

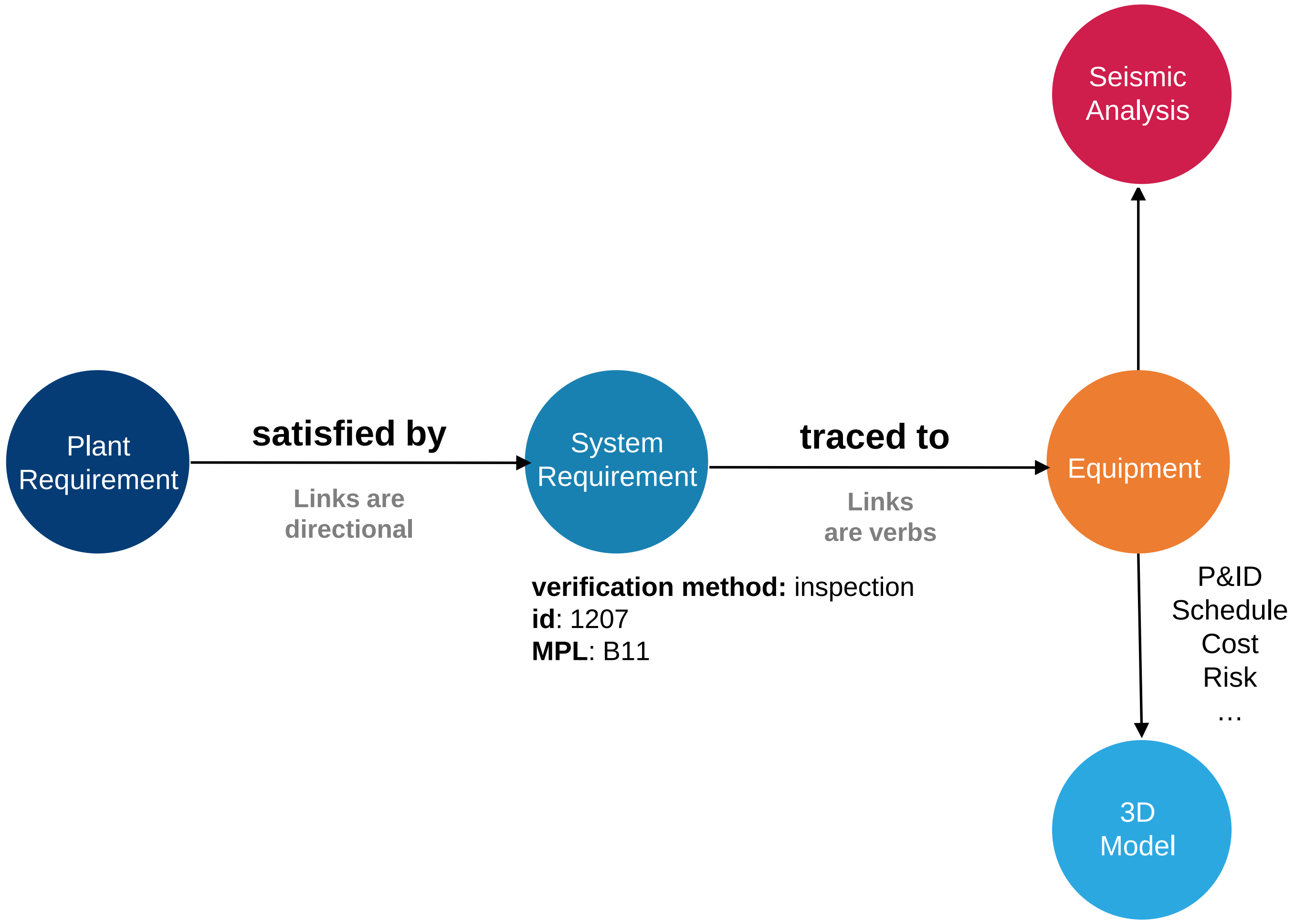
- Significant program impacts
  - Mortenson Construction: **600 days of cumulative schedule reductions** and **25% productivity increase**
  - **40% improvement** in first-time quality through use of digital twins (Boeing, Digital Twins)
  - **$1.05 billion** in cost avoidance (GE, Digital Twins)
- Program benefits
  - **Reduce silent error** as information flows through the lifecycle
  - **Predict project outcome** more accurately with digital engineering
  - **Communicate and collaborate** fully with an authoritative source of truth
  - **Improve future maintenance** with the full plant model carried through each lifecycle stage with the digital twin




**Digital Engineering Maturity Model**

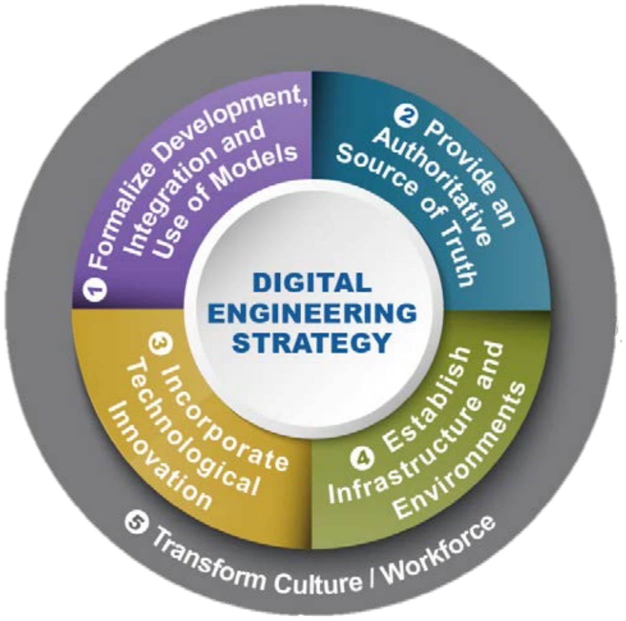
# Real World Example

- Kilopower Project KRUSTY Test
  - Design change from 316-L Stainless Steel to 304 Stainless Steel
  - Miscommunication between reactor and mechanical designers occurred for change in materials of shielding
  - Caused schedule delays, but the project was ultimately successful
- Example
  - Change in single upper-level requirement ripples through the design affecting seismic, pipe stress, 2D/3D models, construction schedules, risk, etc.

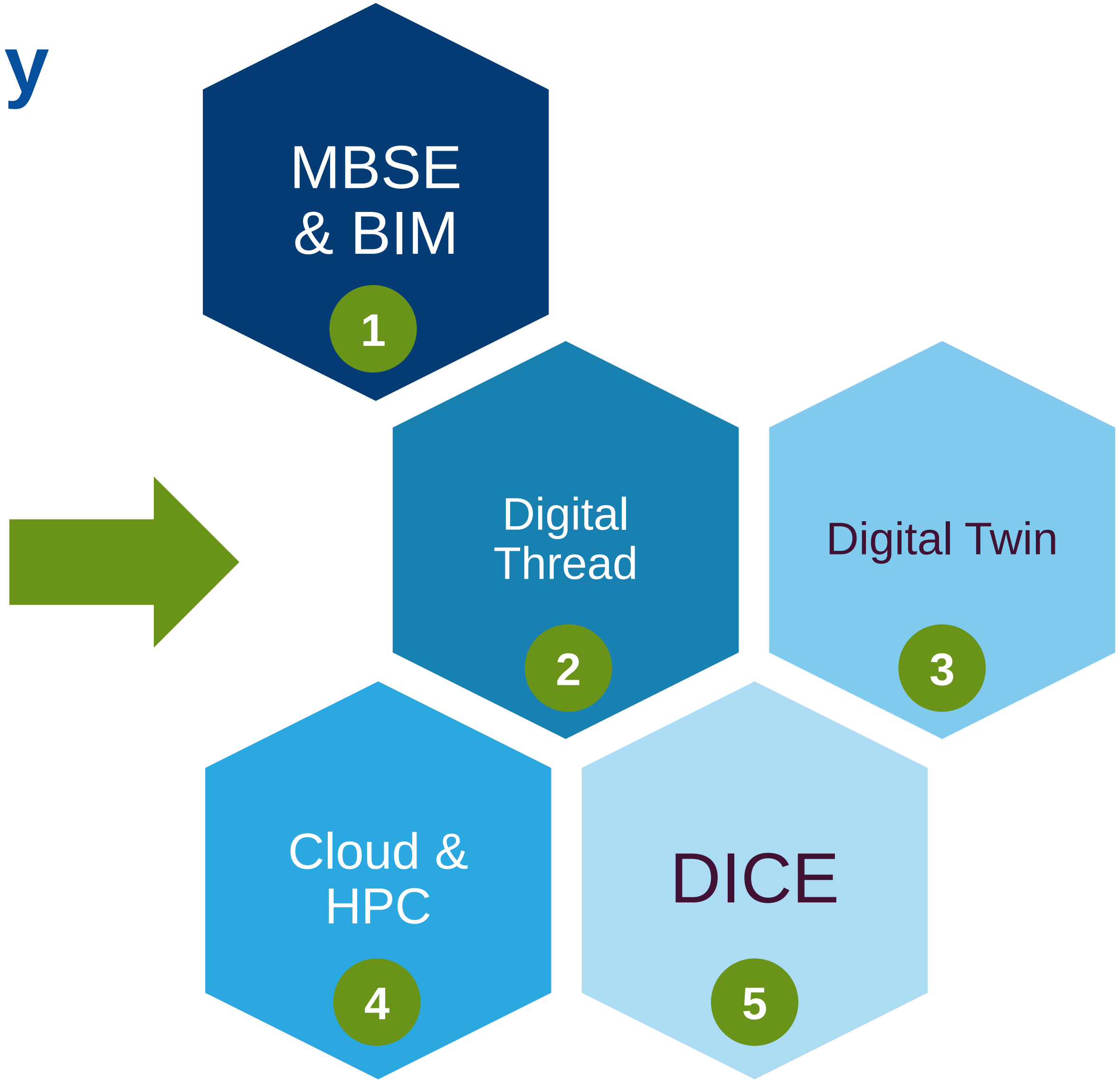



Piping and Instrumentation Diagram (P&ID)

# Digital Engineering Strategy



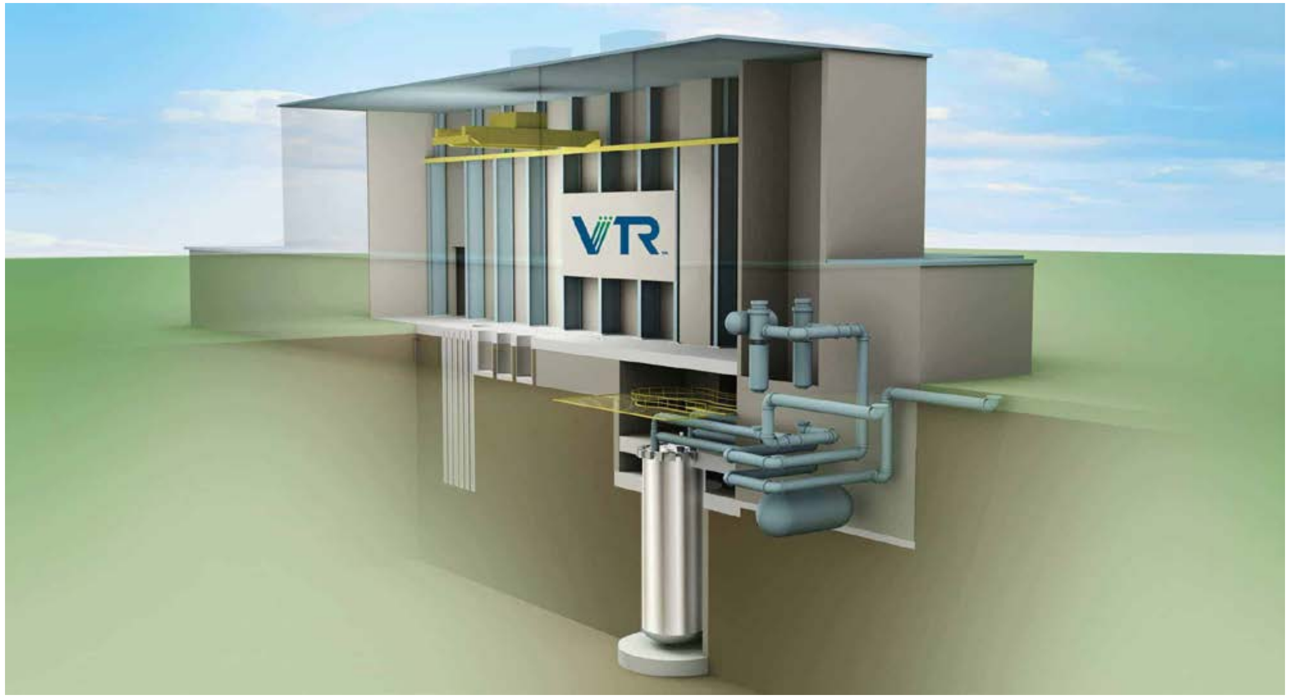

**DoD Digital Engineering**




Building Information Management (BIM)
Model-Based Systems Engineering (MBSE)
Department of Defense (DoD)
Digital Innovation Center of Excellence (DICE)

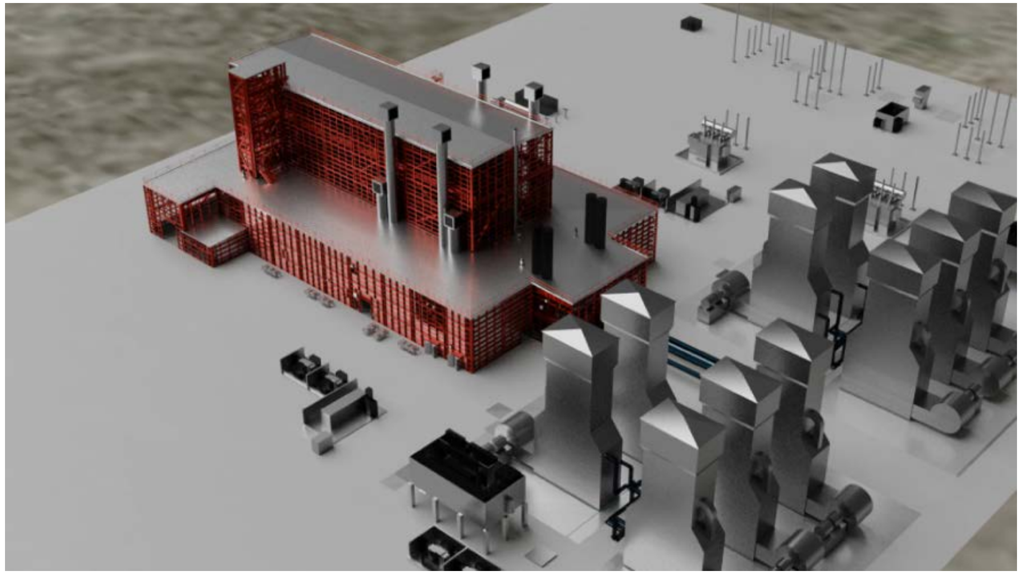
# Versatile Test Reactor Digital Engineering

- The VTR will provide support for progress in multiple important science and technology areas, including:
  - Testing and qualification of advanced reactor fuels
  - Testing and qualification of innovative structural materials
  - Testing of innovative components and instruments
  - Validation of advanced modeling and simulation tools, and the versatility to support future technical missions
  - Support for existing fleet of nuclear facilities
- Collaboration across lab, industry, and universities



# VTR: Digital Engineering and BIM Environment for Laboratory/Industry/University Team

- The VTR uses an advanced digital engineering ecosystem, hosted in a secure cloud, with the following components:
  - BIM tools and databases in the AVEVA system
  - Requirements Management (RM) and Systems Engineering (SE) tools in the IBM Jazz system
  - Integrated digital engineering platform from engineering design, physics, and documentation (Deep Lynx)
  - Integrated set of multiphysics codes using the open-source Advanced Reactor Modeling Interface (ARMI)
  - Collaboration across EPC partners GEH and Bechtel in addition to university/industry partners (~200 people):



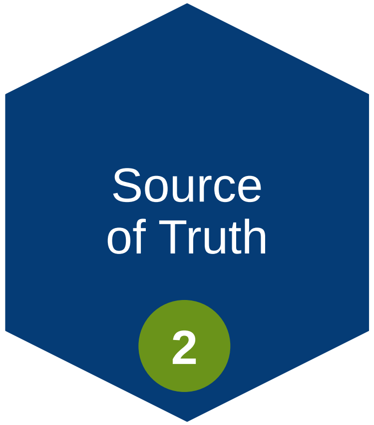
Use of Models

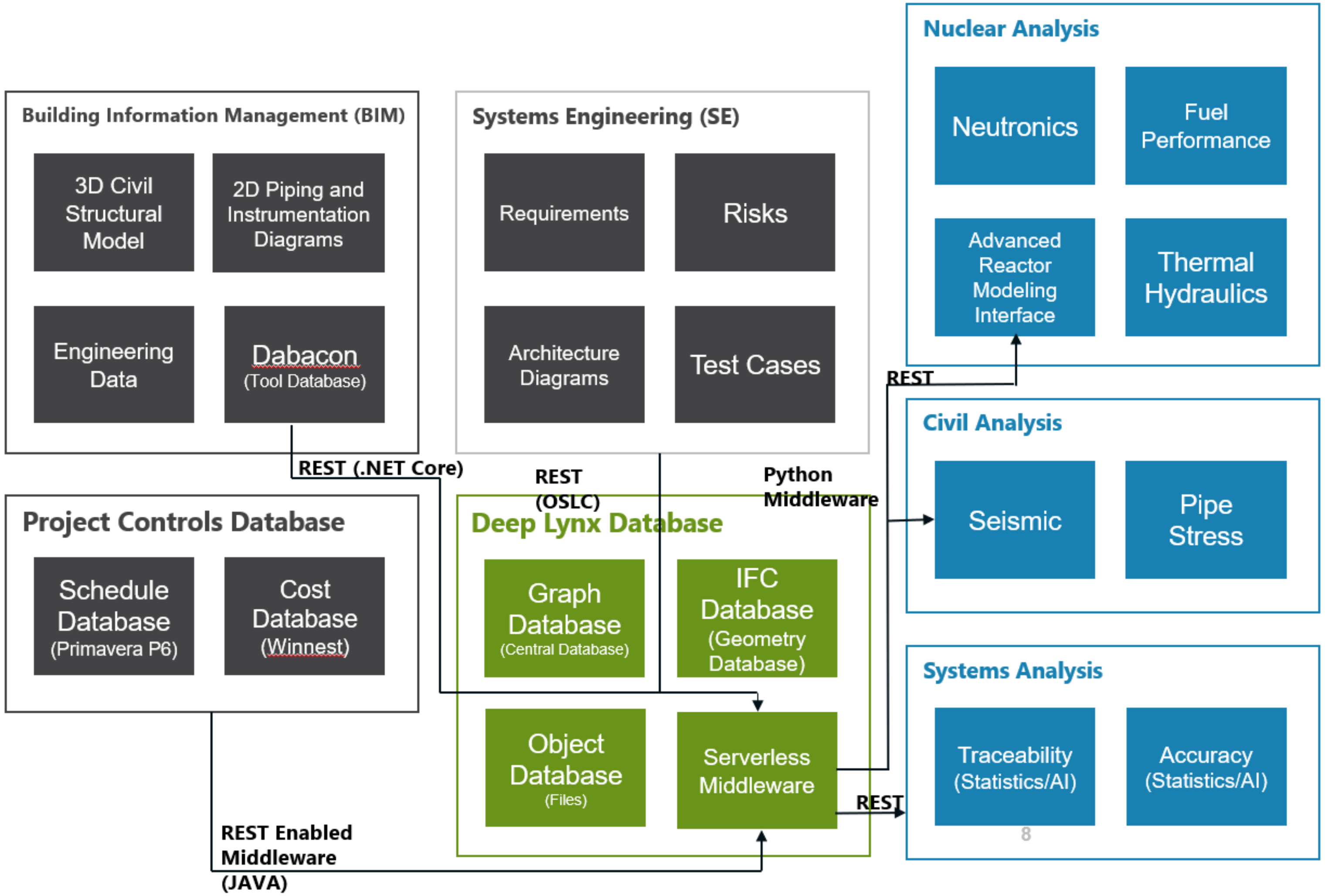
1

NC STATE UNIVERSITY VCU A&M TerraPower NAVAL POSTGRADUATE SCHOOL

# VTR: Digital Thread Across Large Plant Design

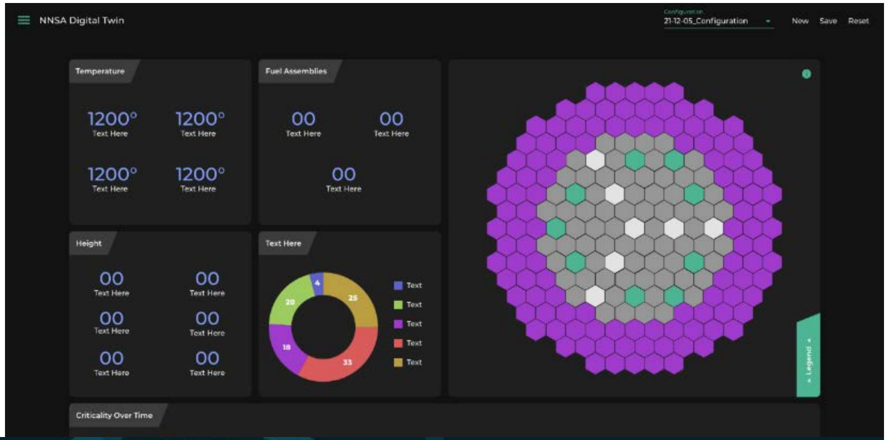
- **Ontology**: Utilizes DIAMOND for a standardized, common data model to enable a generic framework independent of tool/solution
- **Central Software Framework**: This allows for a common software framework to be shared, allowing for code re-use and minimal point-to-point integrations



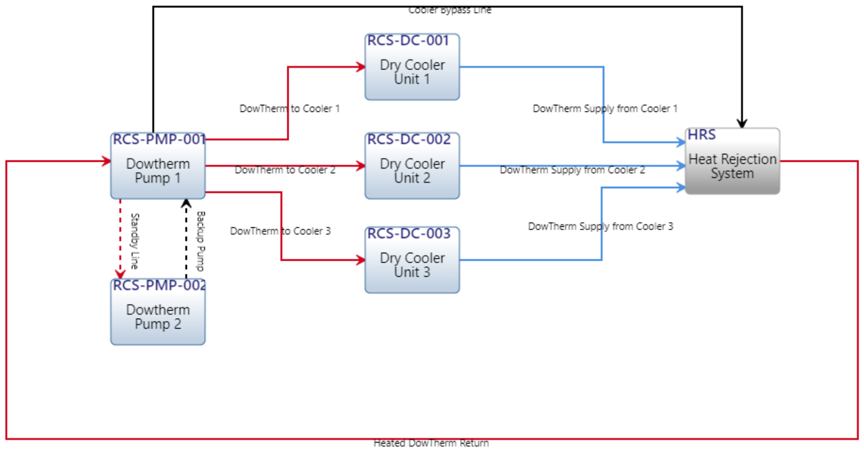
# Nuclear Projects Applying Digital Engineering

- In the next five years, the National Reactor Innovation Center (NRIC) will :
  - Enable demonstration of at least two advanced reactors
  - Prepare DOE/labs for continuing innovation and demonstration
    - Develop best practices for planning/construction/demonstration of nuclear projects
    - Develop enduring infrastructure and expertise
    - Establish methods for efficient coordination among laboratories
- TerraPower and Bechtel are applying digital engineering
- NNSA NA-22 Safeguards by Design Digital Twin
- DE is also applied at a smaller scale on the Strategic Thermal Irradiation Capability (STIC), Pele Project (DoD), MARVEL, NNSA DNN programs

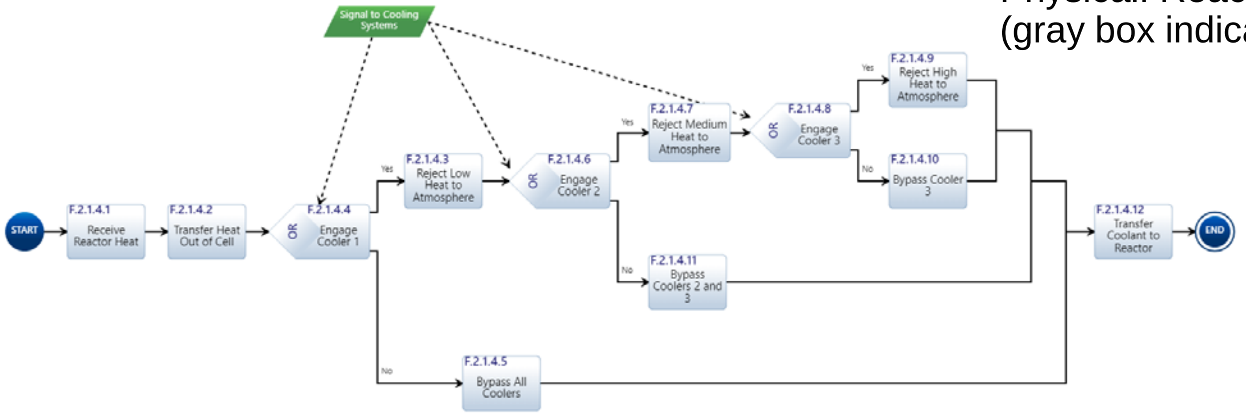



# NRIC: Model-Based Systems Engineering (MBSE) Environment for at NRIC for Laboratory/Industry Team

- Emphasis on development of functional analysis (activity diagrams) and physical analysis (asset, internal block diagrams) over document creation
- System models are linked to the requirements document in the same environment to provide system-level traceability
- Models are integrated across teams (from INL test beds through contractor design teams)




Physical: Reactor Cooling System (RCS) Asset Diagram (gray box indicates live contractor input)

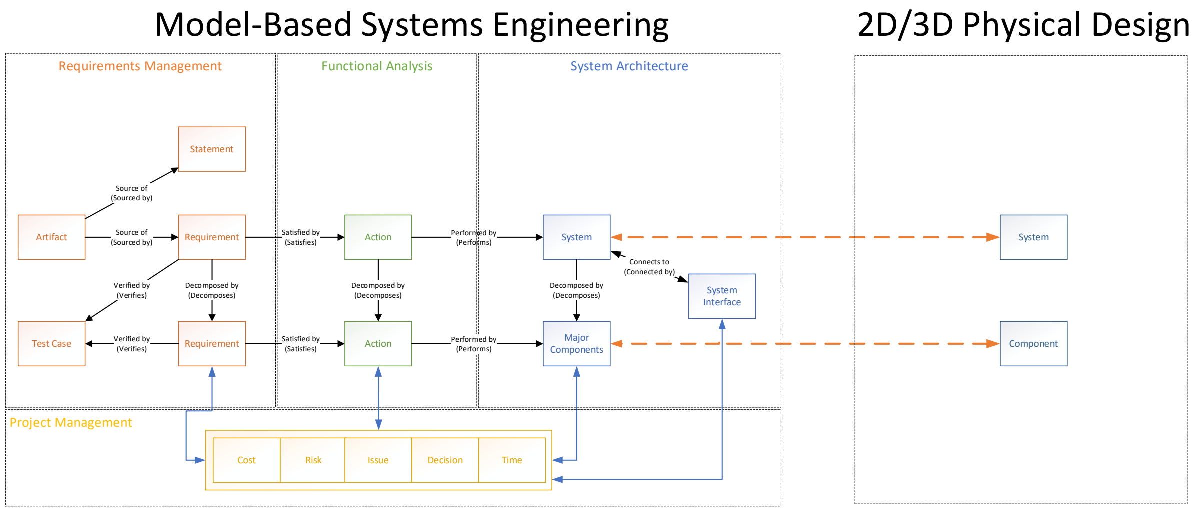



Functional: Remove 50 - 500 kW Reactor Thermal Energy

Use of Models

1

# NRIC: Digital Thread from MBSE to Digital Engineering for Microreactors




**Develop fully traced model-based systems engineering model (digital thread)**

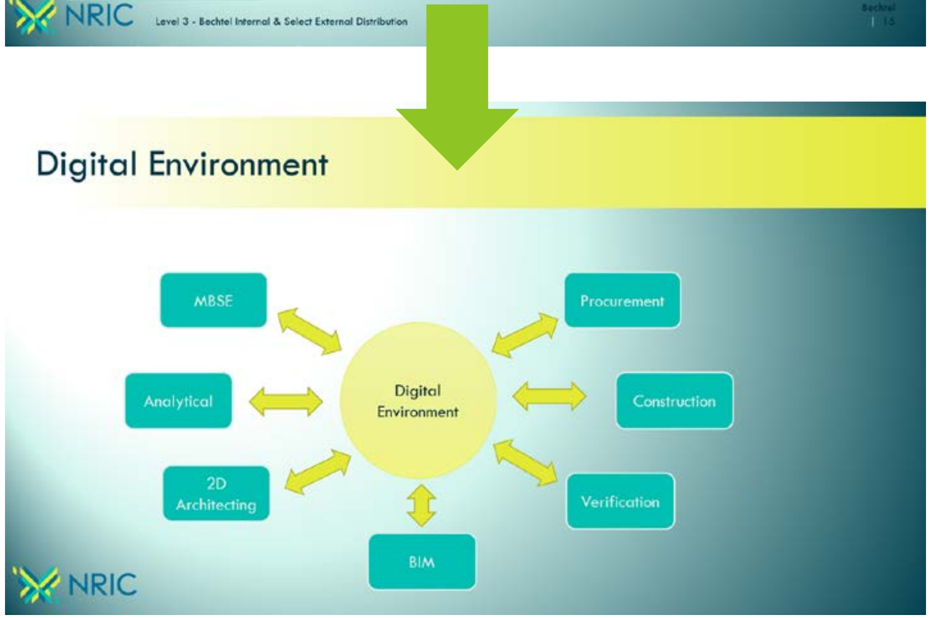
**Demonstrate CAD elements to/from systems design for demonstration test bed**

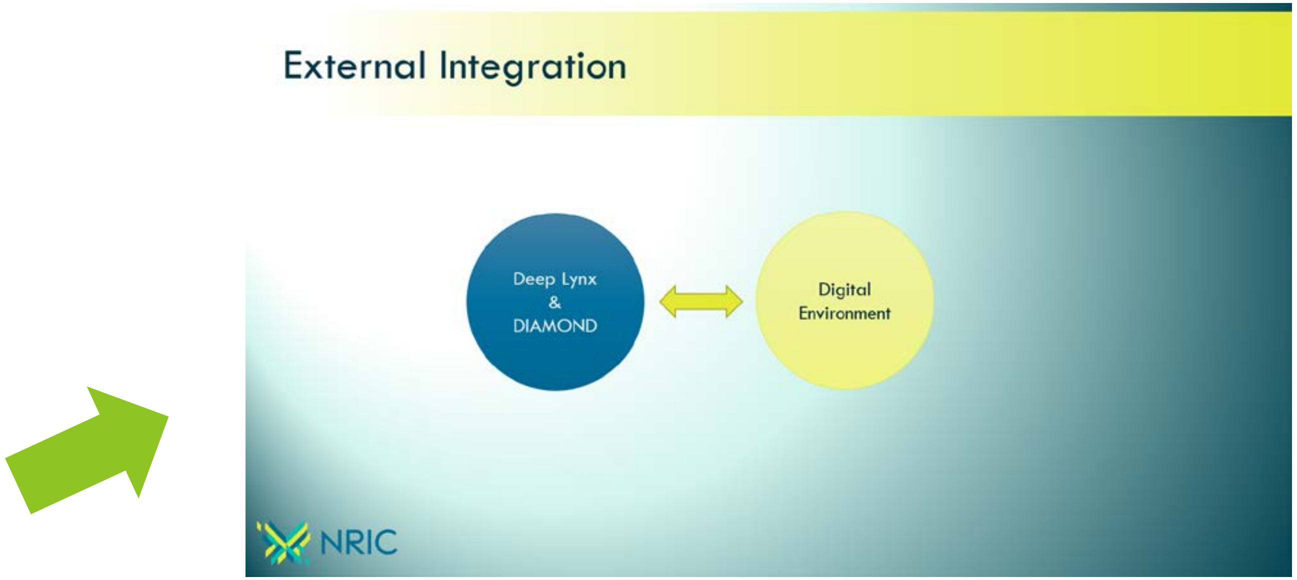
Source of Truth

2

- Integrate between Computer Aided Design (CAD) and MBSE models bidirectionally to **reduce silent error** transferring from systems through detailed design
  - Focus on tools applied successfully in aerospace (ex. **MBSE**)
  - Focus on **cost-effective CAD** (ex. Revit)
  - Focus on **industry integration** in cloud
  - Vision on full digital engineering environment for the **entire nuclear industry**
- **Automate documentation** needs at the system level in lab/industry formats
- **Integrate with the overall digital engineering ecosystem** built on VTR with interfaces for system, civil, and nuclear physics codes
- Plan to integrate this system (used in design) with operating facilities to enable a **full digital twin**

# Digital Engineering at Bechtel

# Digital Engineering at TerraPower

## What does a "Model-Based Solution" Look Like

Use of Models

1

- In all honesty, a "model" looks like a bunch of boxes, lines, and text.

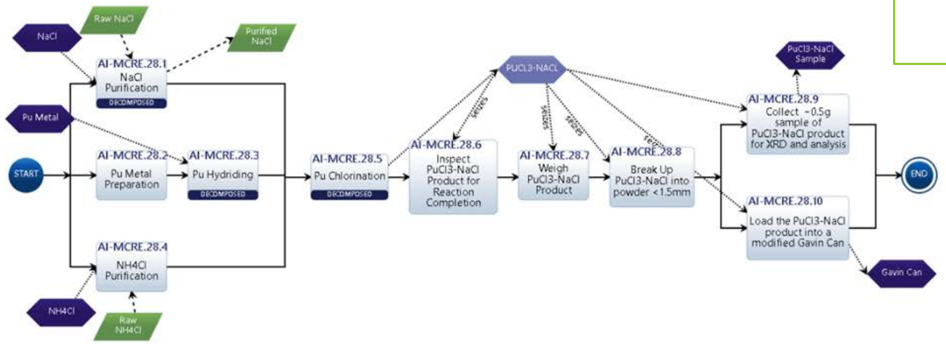

- You enter data into the visual *model*.
- That data from the visual model is stored in the central database.
- You can query the database for literally anything within it.
- The end goal is to have a centralized mega-database that reduces the amount of data re-entry and finger fudging across the program.



TerraPower

## Functional Diagram (1/2)

- The example below is a functional diagram for fuel salt



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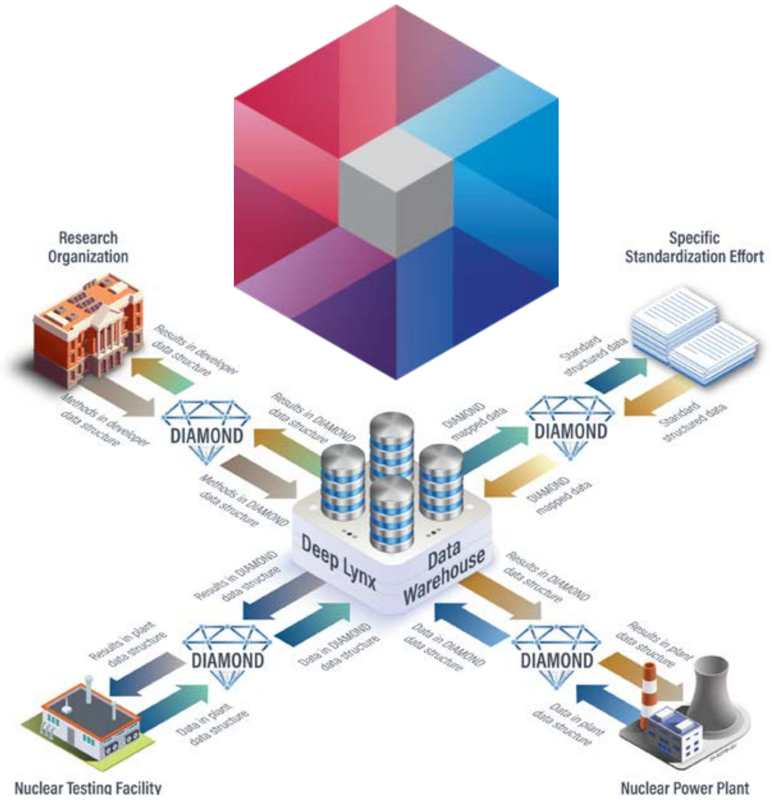
# Laboratory: Digital Innovation Center of Excellence




The Idaho National Laboratory (INL) Digital Innovation Center of Excellence (DICE) serves as a virtual center to formalize and coordinate digital engineering, digital twinning, and digital transformation activities across next generation energy systems. DICE will serve the following key functions:

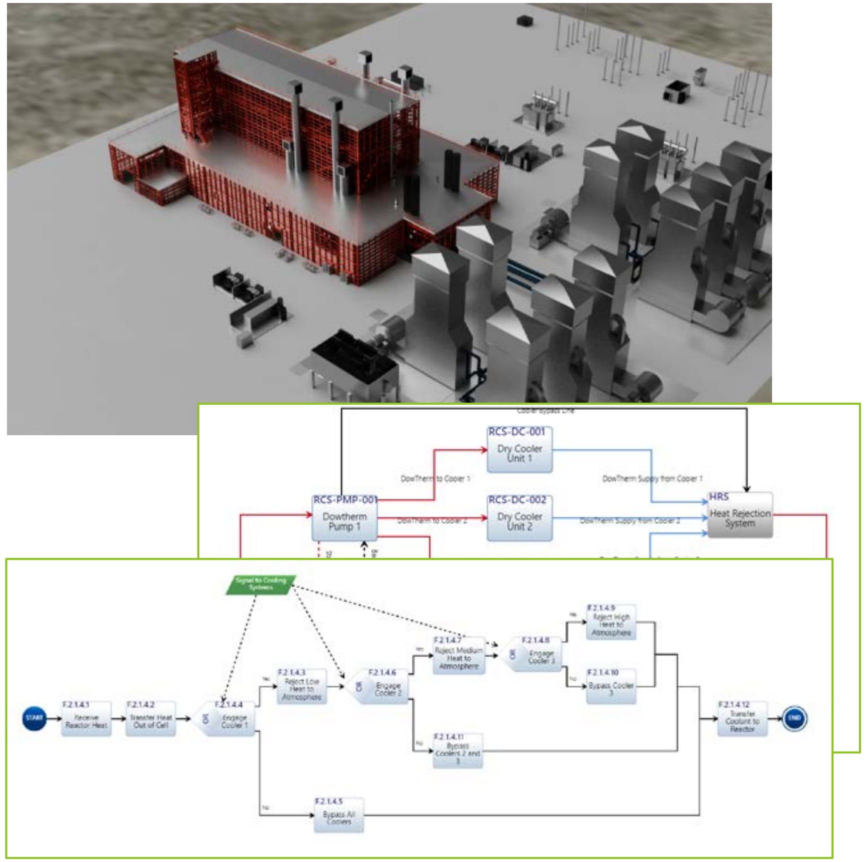
- **Leadership** for a strategy on digital innovation for the world's energy future
- **Recognition** as a national center of excellence through **research accomplishments**
- **Capture** of **external and internal proposals** with multi-directorate collaboration
- **Coordination** to share community best practices across the laboratory
- **Promote** multi-directorate scientific publications by center members
- **Outreach** to universities, industry partners, and other national laboratories
- **Enhance training** and **education** materials on digital engineering and digital twinning

Training & Culture

5

# Summary

- **Transformational approach** to development and demonstration across next generation nuclear
- Proven to significantly **reduce costs/schedule/risk** in defense, aerospace, and construction industries
- Enhancements under development to close “sneaker net” integrations to **reduce silent errors** in design
- Digital engineering is critical to the success of the laboratory, industry, and university teams at NRIC and the VTR
- Developments in industry are looking to integrate with a **common, open platform** originally developed on the VTR
- Deployed and **advanced ecosystem in development** at NRIC and the VTR with smaller applications underway across a wider set of projects
- Vision on full digital engineering environment for the **entire nuclear industry**
- VTR has **sustained milestone performance** across a geographically dispersed team due to our digital engineering strategy

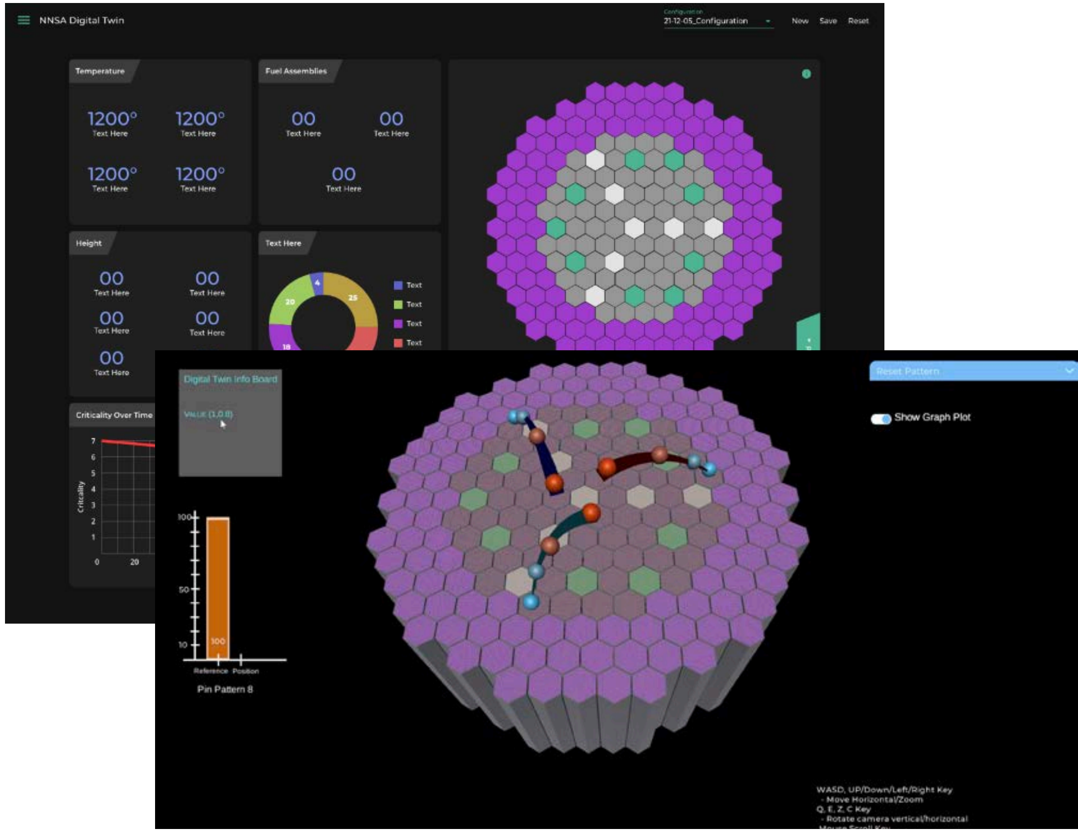


# Back Ups

# NA-22: Integrated Digital Twins (Safeguards by Design)

## What is a Digital Twin?

Digital Twins represent the merging of digital thread, controls theory, artificial intelligence, and online monitoring into a single cohesive unit, a virtual model that comprehensively captures all relevant aspects of the underlying system, utilizing bidirectional communication to track and trend both simulated and measured physical responses.




NNSA Safeguards by Design
Digital Twin Project

Innovation

3

# VTR/Lab: Cloud and High-Performance Computing

- Microsoft Azure for Government Environment **Cloud**
  - Originally Developed to Support VTR
  - Single Sign-On for Industry
  - Secure Environment (OUO/ECI)
  - Hub/Spoke Deployment Model
  - Interconnection to HPC (in process)


- Access to INL **HPC** Resources
  - Funded through NSUF
  - Sawtooth (5.6 Petaflop/s)
  - Lemhi (1.0 Petaflop/s)
  - Falcon (1.1 Petaflop/s)


Infrastructure & Environment

4

# Bechtel Corporation

Family-owned since 1898, Bechtel's four global business units are trusted engineering, construction, and project management partners to industry and government. We align our capabilities to our customers' missions with safety, quality, ethics, and integrity.

## Nuclear, Security & Environmental

- 80% of nuclear plants in the U.S., and 150 worldwide designed, serviced, or delivered by Bechtel
- Construction and operation of national security facilities
- Building the world's largest and most complex radioactive waste treatment plant

## Oil, Gas & Chemicals

- 1/3 of global LNG capacity currently under construction
- 275+ refinery expansions and modernizations
- 50,000 miles (80,500 km) of pipeline systems
- 380+ major chemical and petrochemical projects

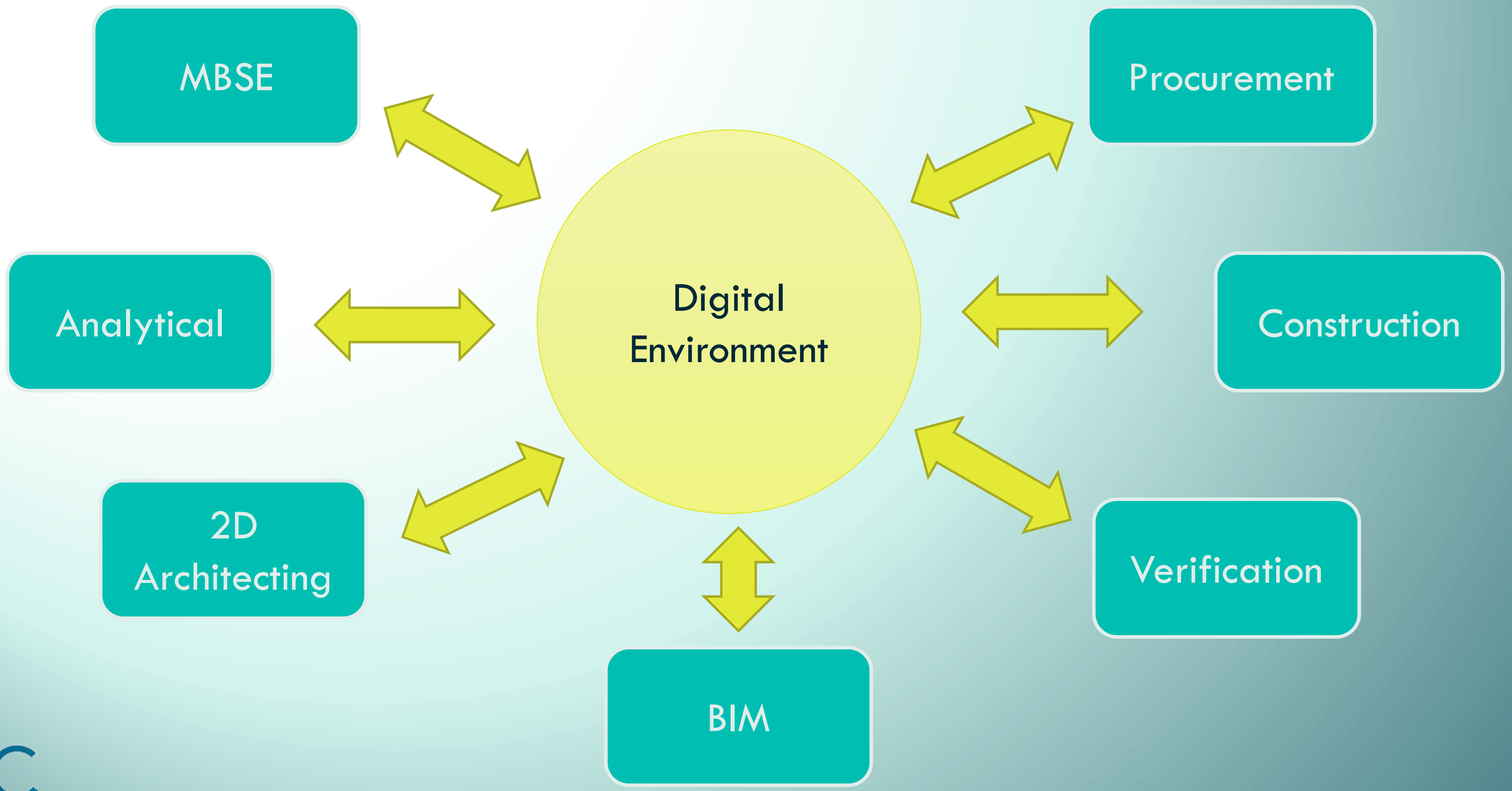
## Mining & Metals

- 200 million metric tons per annum of installed iron ore productions
- 42 major copper projects
- 30 aluminum smelter projects
- 8 alumina refinery projects

## Infrastructure

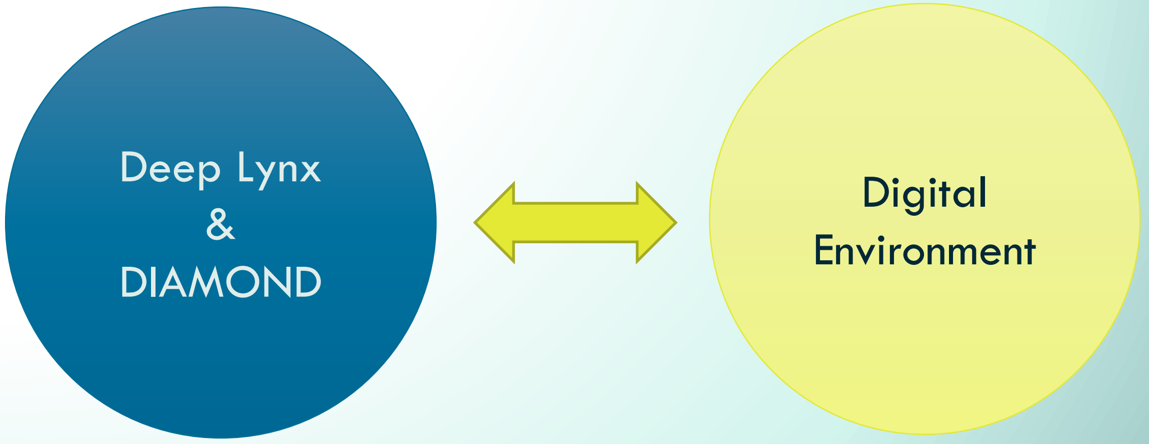
- 300 subway and rail projects
- 17,200+ miles (27,700 km) of highways and roads
- 6,200+ miles (10,000 km) of railroads
- 390 individual power plants

# Digital Environment




NRIC

# External Integration




NRIC

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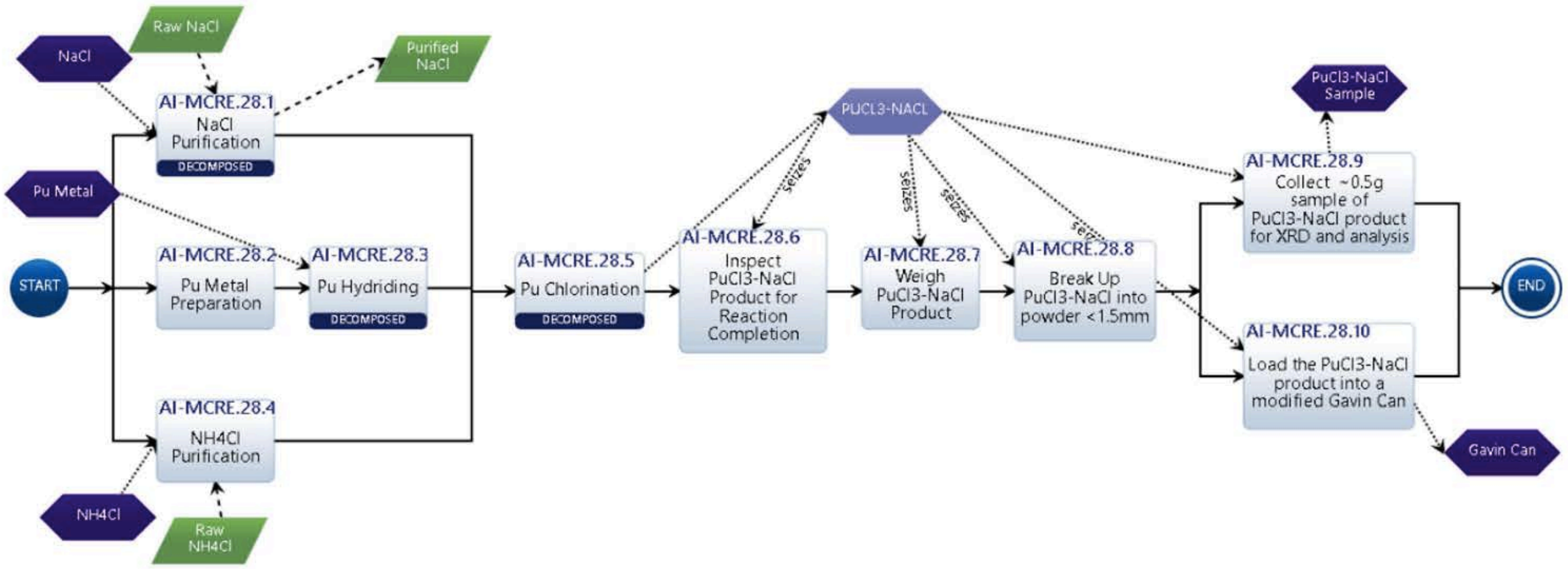
# Functional Diagram (1/2)

Use of Models

1

- The example below is a functional diagram for fuel salt synthesis



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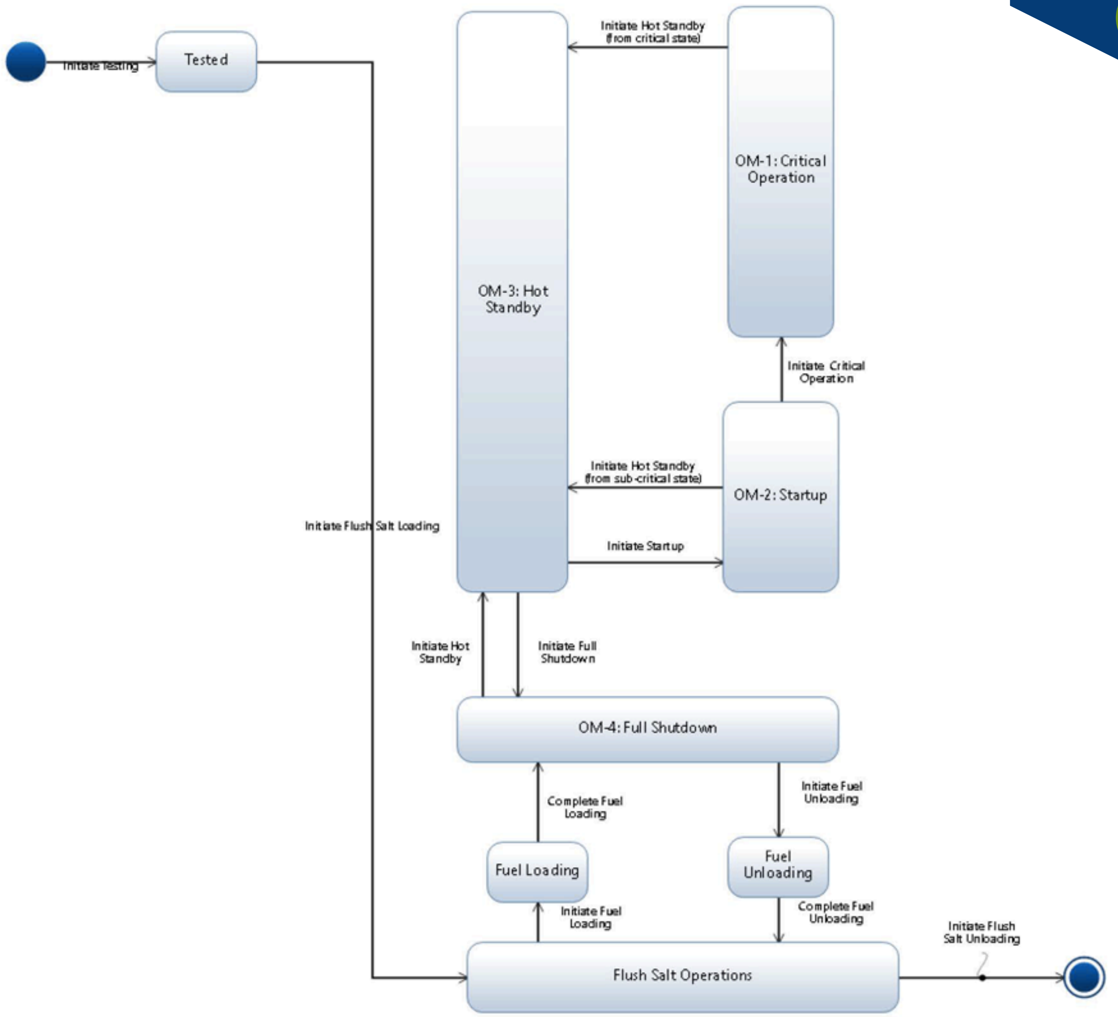
# Functional Diagram (2/2)

Use of Models

1

- The example shown here is a State Machine Diagram (i.e. States and Modes) for a reactor experiment
- You can add as much detail as you desire.



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