NUSCALE™
Power for all humankind

Use of FPGAs for Real-Time Nuclear Power Display and Monitoring Applications

October 10, 2018

Chad Williams & Brian Arnholt
Instrumentation and Controls Engineering

Introduction and Agenda

- NuScale Presentation
  - Brief Overview of NuScale Plant Design
  - Introduction to NuScale I&C Architecture
  - Safety Display and Indication System
  - System Prototype
- Ultra Electronics Presentation
  - Project Challenges
  - Development Process flows
  - System Architecture
  - Display Interface Module Architecture
  - FPGA Graphical Architecture
  - Conclusions

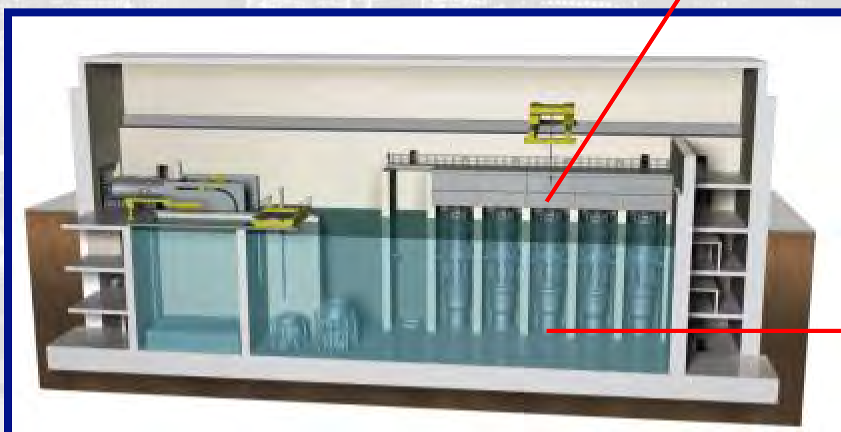
Acknowledgement & Disclaimer

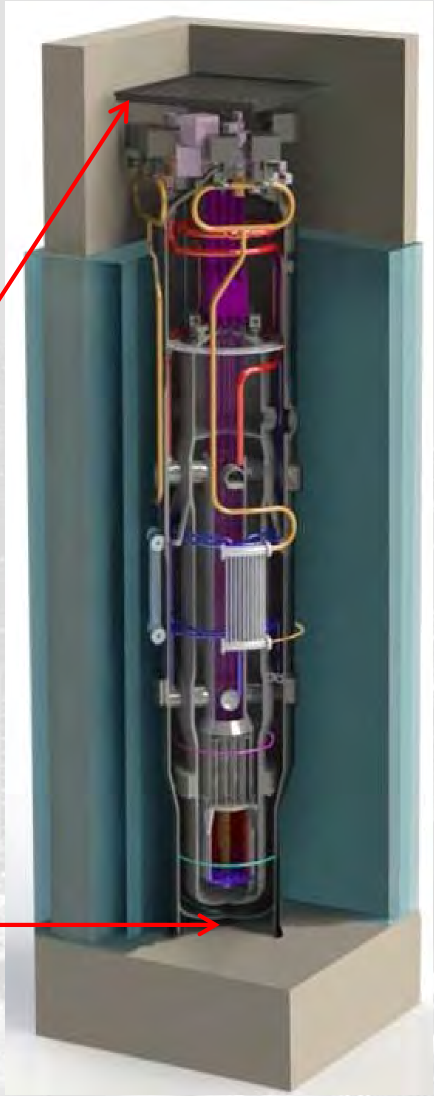
This material is based upon work supported by the Department of Energy under Award Numbers DE-NE0000633 and DE-NE0008742.

This report was prepared as an account of work sponsored by an agency of the United States (U.S.) Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

The NuScale Power Module

- A NuScale Power Module (NPM) includes the **reactor vessel, steam generators, pressurizer** and **containment** in an integral package that eliminates reactor coolant pumps and large bore piping (no LBLOCA)
- Each NPM is 50 MWe and factory-built for easy transport and installation
- Each NPM has its own skid-mounted steam turbine-generator and condenser
- Each NPM is installed below-grade in a seismically robust, steel-lined, concrete pool
- NPMs can be incrementally added to match load growth—up to 12 NPMs for 600 MWe gross (~570 net) total output

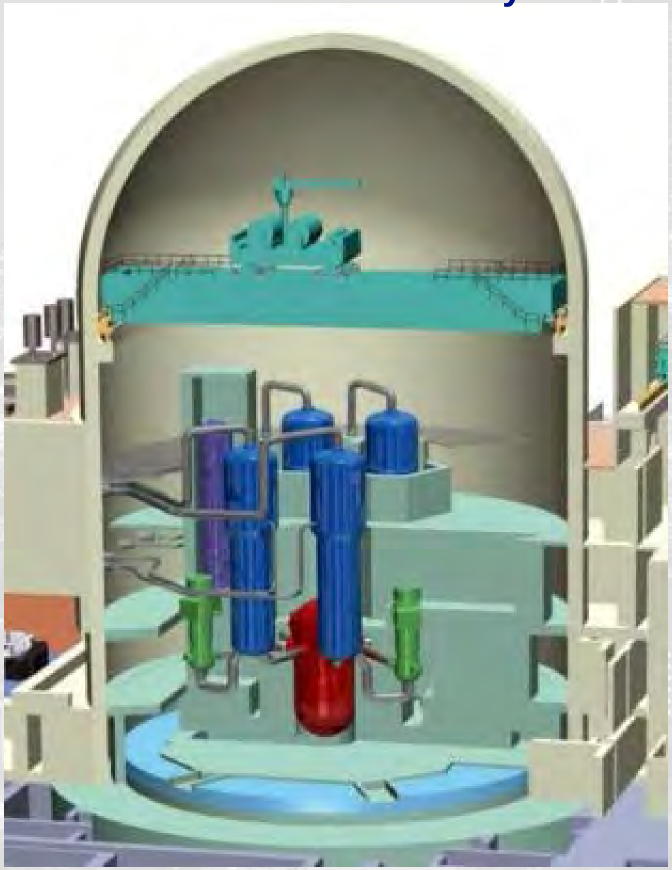




NUSCALE™ Power for all humankind

Size Comparison

Typical Pressurized-Water Reactor Containment & Reactor System



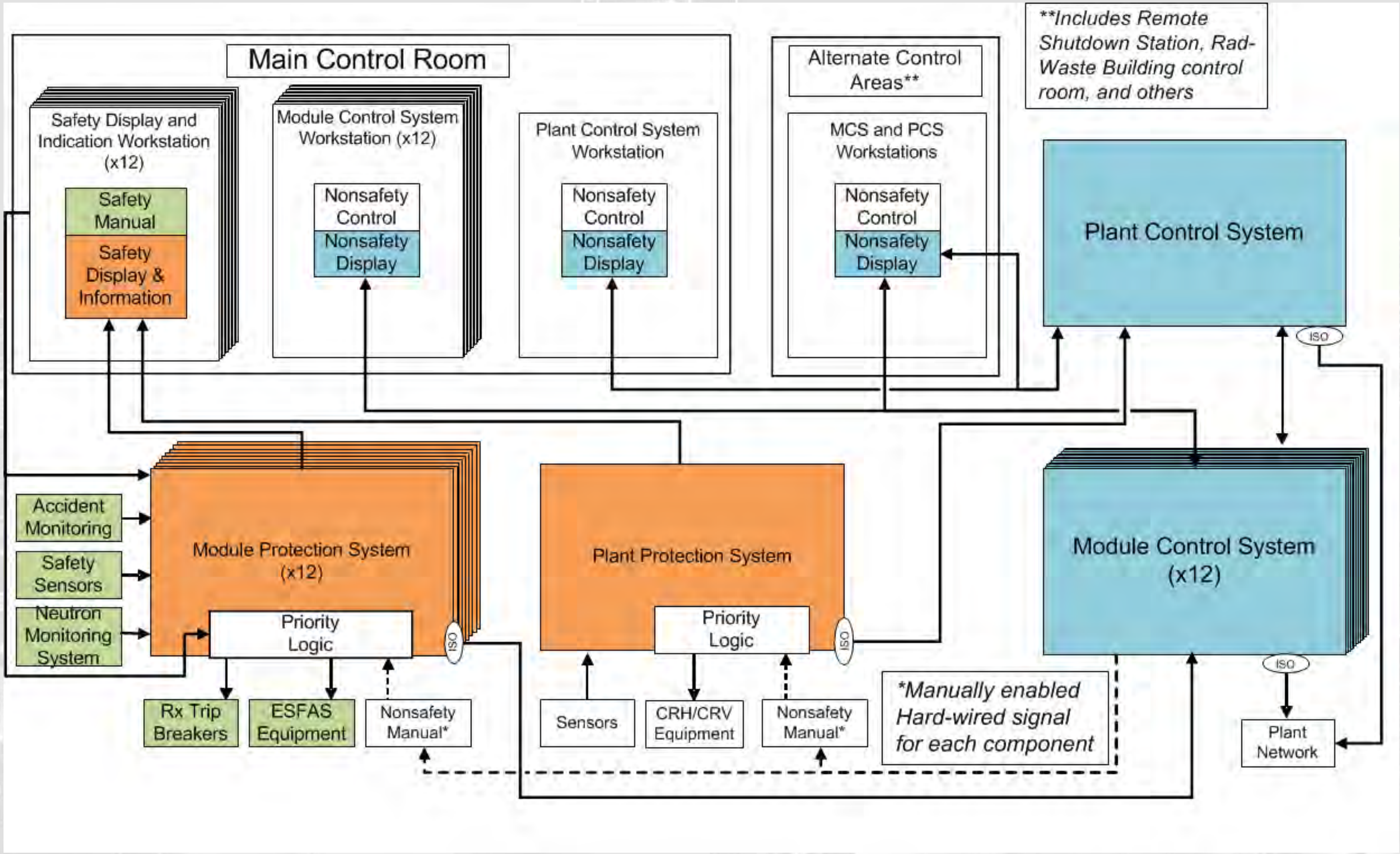
*Source: NRC

NuScale Power Module
Combined Containment Vessel and Integral Reactor System

Safety I&C Platform

- No safety related pumps or fans to control
- Provide Reactor Trip Breaker and Pressurizer Heater Breaker trip signals
- Provide trip signals to solenoid operated valves
- On loss of power, solenoids de-energize and associated valves fail in the safe position and Reactor Trip and Pressurizer Heater breakers open
- Passive safety features result in a simpler safety I&C platform
- Digital I&C system using FPGAs
- Use of FPGAs allows for diversification within the safety I&C platform
- A simpler and more diversified design results in a more reliable safety I&C platform

I&C Architecture Overview



NuScale Nonproprietary

Safety Display and Indication System (SDIS)

- The SDIS platform is designed based on basic fundamental design principles:
  - independence (divisional)
  - redundancy (two completely redundant, independent divisions)
  - diversity and defense-in-depth - D3 (different FPGA technologies across divisions)
  - predictability and repeatability (based on real-time deterministic performance of FPGAs)
- Provide accurate, complete, and timely information to operators
  - Plant operating within safety limits
  - Notification when setpoints are reached
  - Ensure the NPM is in a safe condition following an accident
  - Post-accident monitoring
- Not safety-related
  - No required operator action for safe shutdown
  - No Class 1E power
  - Could be used for safety-related applications at other facilities

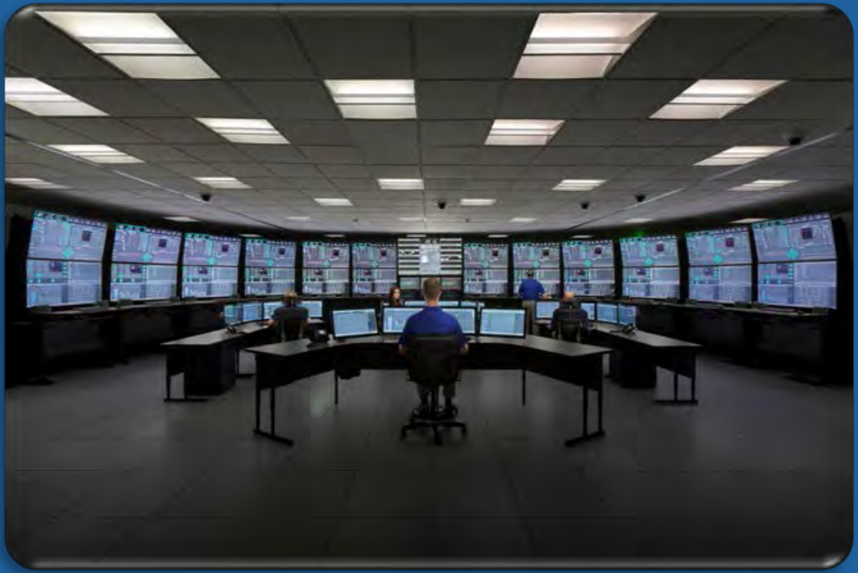
Simplicity → There is no executable software within the SDIS platform runtime environment

NuScale Main Control Room

Safety Display and Indication System

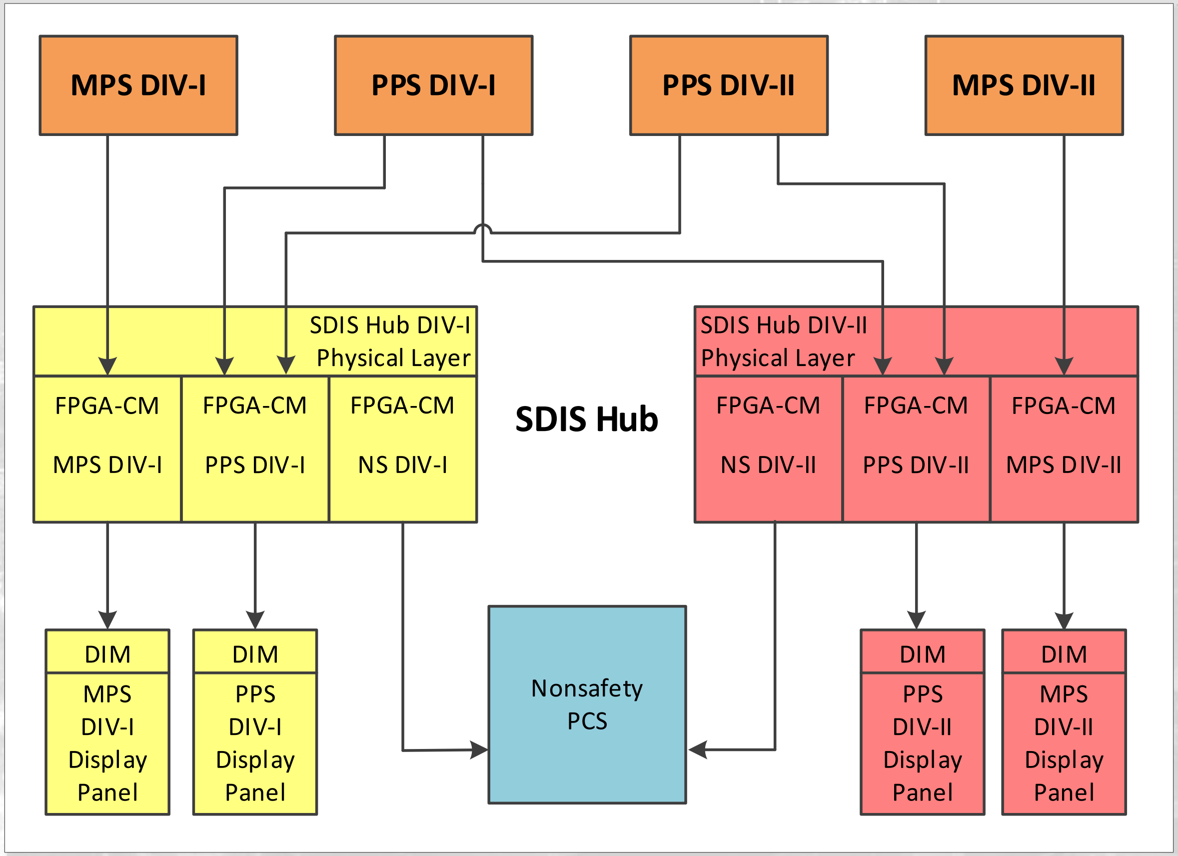
- 2 divisions of 12 module-specific displays
- 2 divisions of plant level displays

NuScale 12-Module Control Room Simulator



NuScale Nonproprietary

SDIS Architecture Overview



- Digital I&C Platform
  - FPGA diversity
  - No run-time software
- SDIS Communication Hubs
  - FPGA communication modules
- Display Interface Module (DIM)
  - FPGA driving display graphics
- Display Panels

SDIS Prototype Scope

- Develop a working prototype for unique NuScale design with two primary objectives:
  - Demonstrate that the DIM functional operation meets design requirements and specifications
  - Provide working prototype for demonstration and evaluation as part of the NuScale main control room simulator
- Simulate SDIS Hub
- Design and build DIM prototype

Chad Williams
Brian Arnholt
Instrumentation and Controls Engineering
cwilliams@nuscalepower.com
barnholt@nuscalepower.com

Energy

Use of FPGAs for Real-Time Nuclear Power Display and Monitoring Application

Martin Harrison
Chief Systems Engineer

Ultra ELECTRONICS

Use of FPGAs in Real-Time NPP Display and Monitoring

AGENDA – "HOW"

- Project Challenges
- Development Process flows
- System Architecture
- Display Interface Module Architecture
- FPGA Graphical Architecture
- Conclusions

making a difference

Use of FPGAs in Real-Time NPP Display and Monitoring

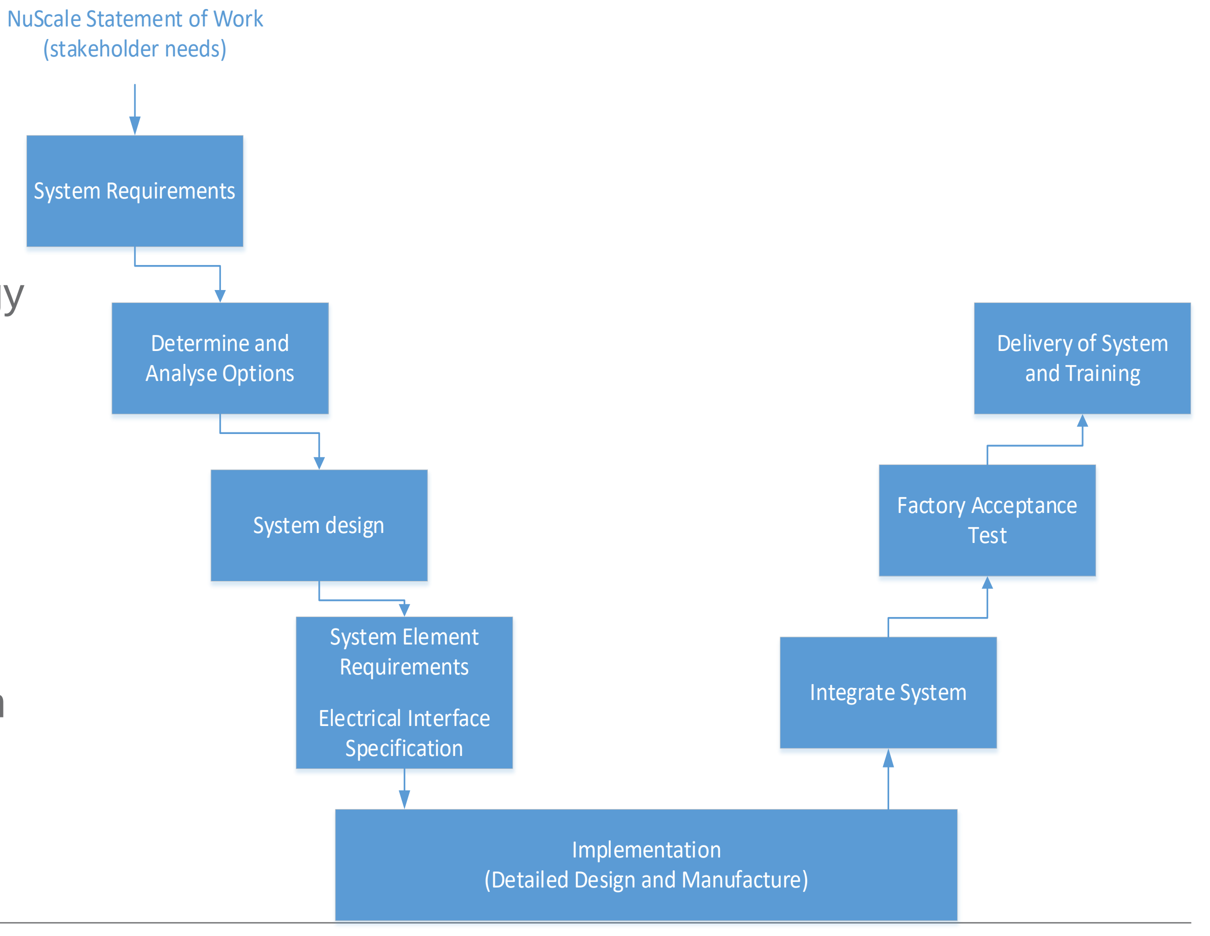
PROJECT CHALLENGES

- Can an FPGA-based solution without a processor/software efficiently generate graphically complex screen layouts:
  - For example can the solution realise trend line graphs with rolling real time on the x-axis (last 30 minutes), grid lines and two y-axis with different engineering unit scales
  - The conventional view is that complex Human-Machine interfaces are the domain of processors and software and not FPGAs
- Can a design be produced that can allow flexibility in changing screen layouts without or minimising RTL changes
- Can support tools, using COTS software as much as possible, be developed to configure different screen layouts
- Can a low power design be realised removing the need for any forced air cooling
- Can the design support future changes in flat screen technology and their interfaces with minimum impact
- Can acceptable quality of the graphics be achieved without the use of advanced graphical techniques such as anti-aliasing

Use of FPGAs in Real-Time NPP Display and Monitoring

PROTOTYPE DESIGN AND DEVELOPMENT PROCESS

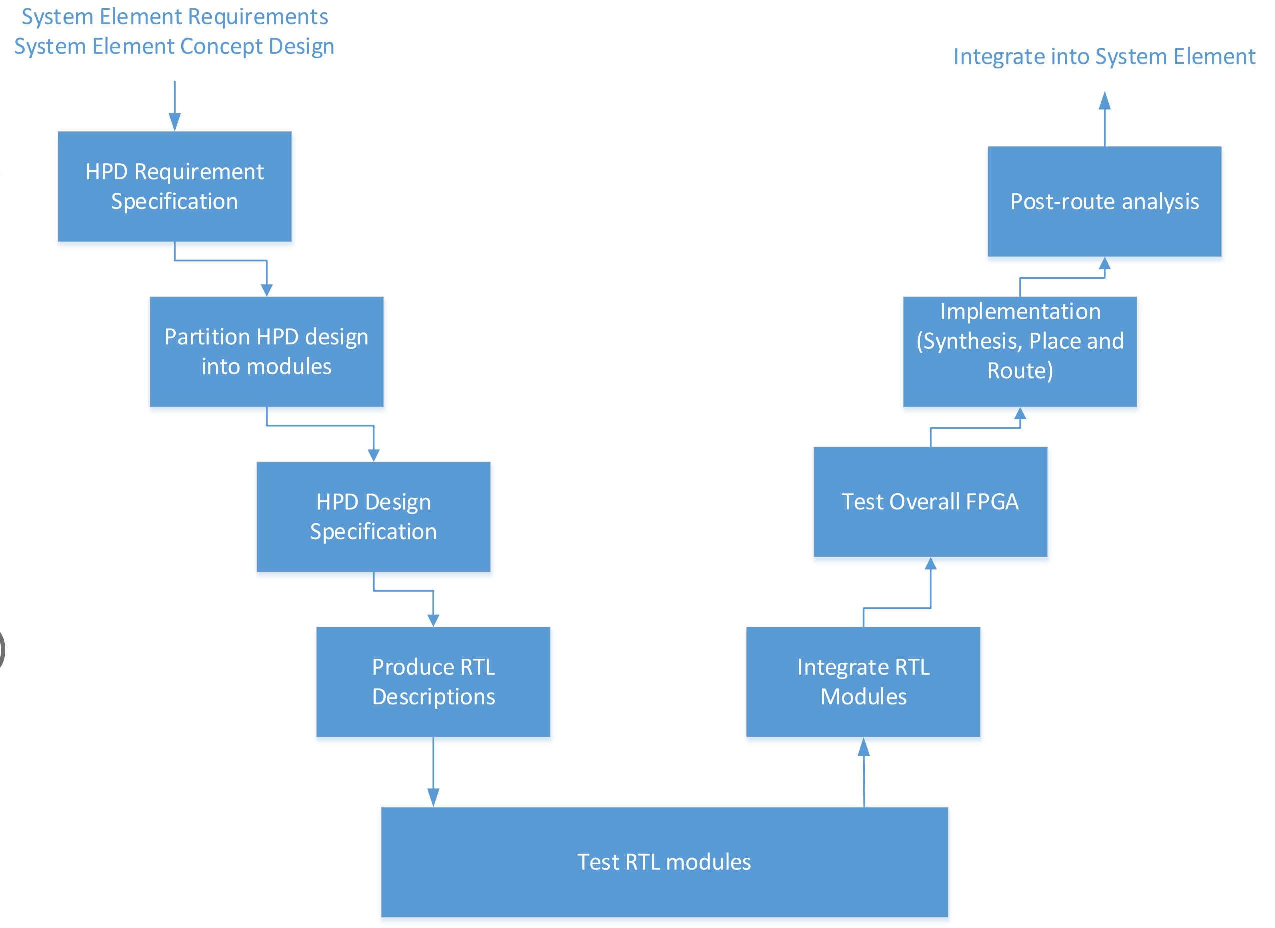
- Collaborative development with NuScale
- Detailed investigation phase:
  - Display Panel Technology
  - FPGA based graphics solutions (both hardware and software)
  - Fault detection (diagnostics)
  - Alternative solutions and diversity
  - Screen layout generation support tools



Use of FPGAs in Real-Time NPP Display and Monitoring

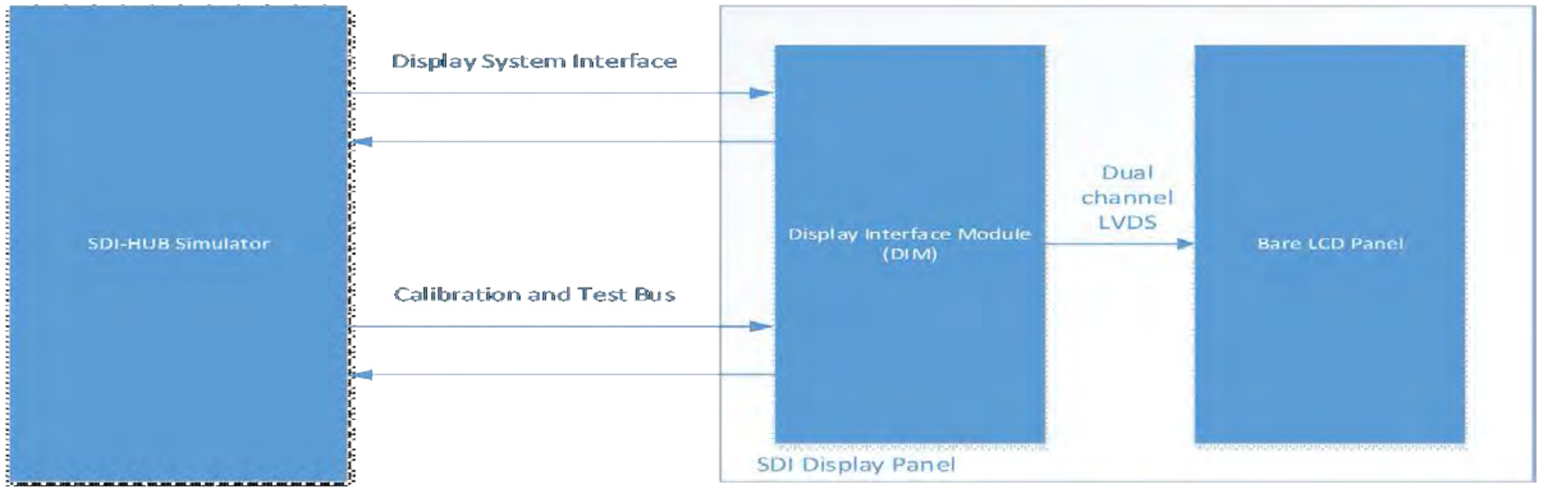
PROTOTYPE FPGA DESIGN AND DEVELOPMENT PROCESS

- Proven IEC 62556 based process, optimised for prototype work
- RTL Descriptions compliant with Ultra's Nuclear Safety Coding Guidelines
- Testbenches produced using Open Source VHDL Verification Methodology (OSVVM)



Use of FPGAs in Real-Time NPP Display and Monitoring

SYSTEM ARCHITECTURE



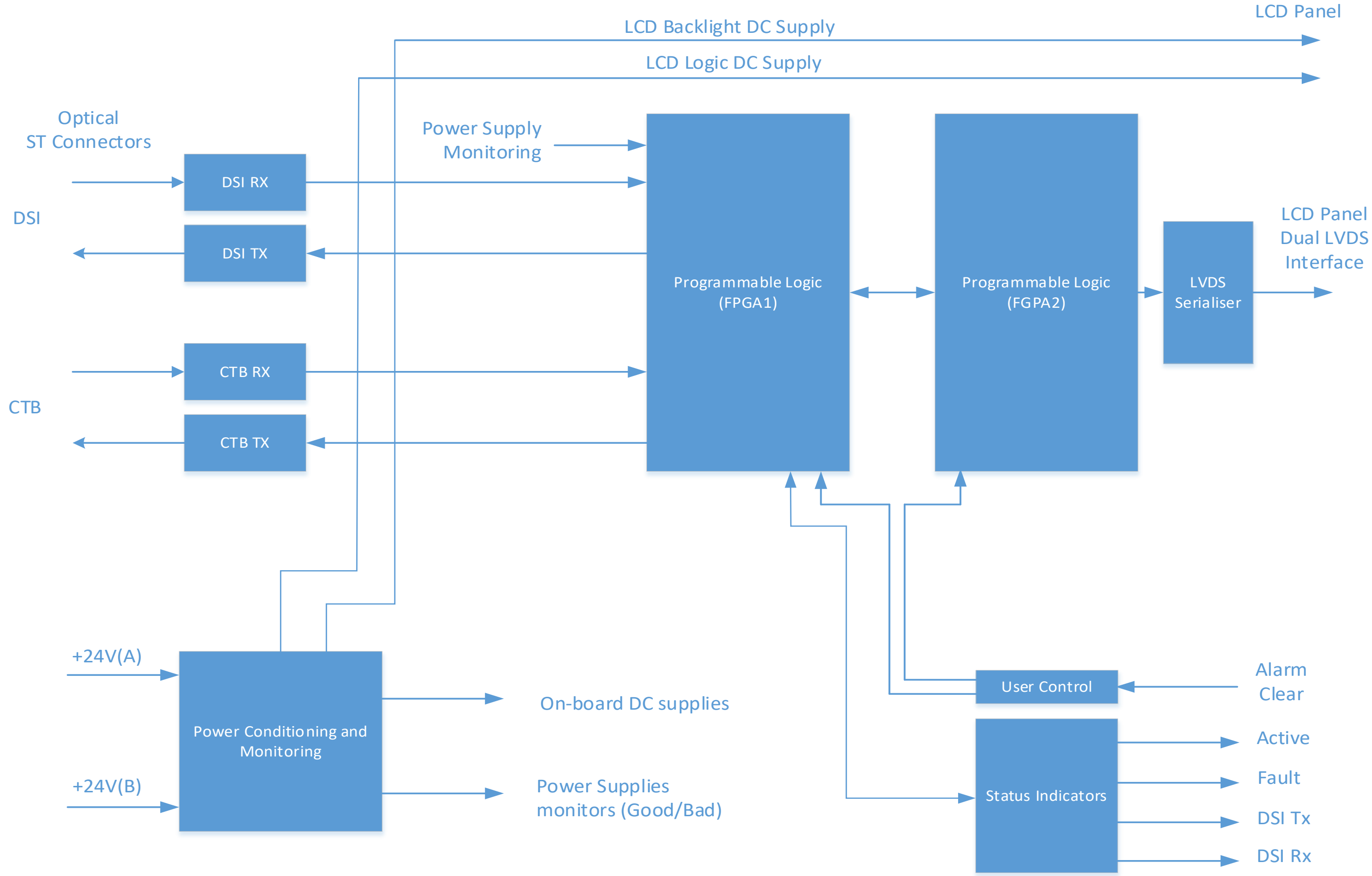
- SDI-Hub Simulator
- SDI Display Panel
  - Display Interface Module
  - 24 inch 1080P LCD Panel
  - Optical interfaces

making a difference

Use of FPGAs in Real-Time NPP Display and Monitoring

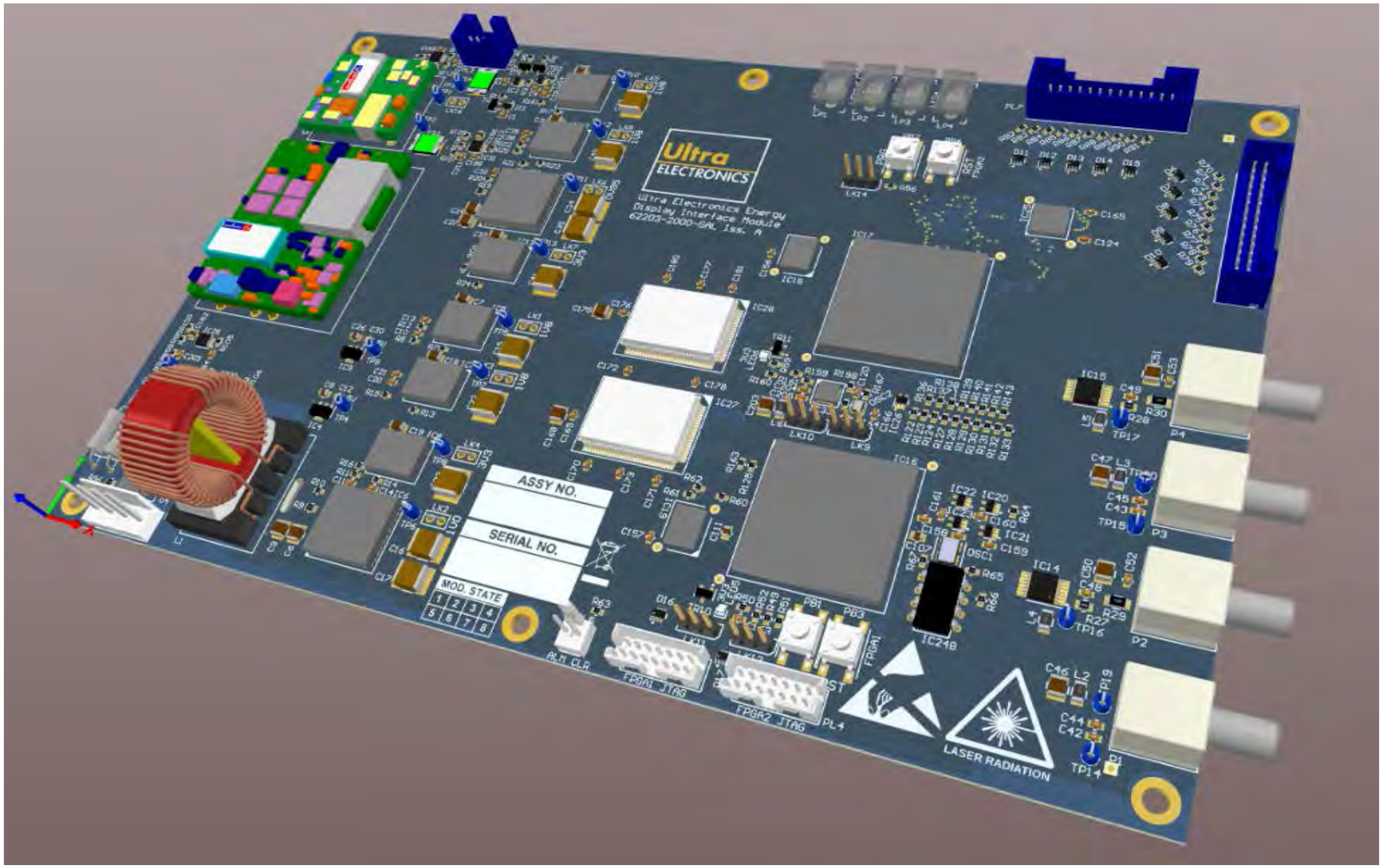
DISPLAY INTERFACE MODULE ARCHITECTURE

- Hardware
  - Optical Interfaces
  - Dual redundant DC input supplies
  - On-board DC to DC converters with voltage monitoring
  - Two Xilinx FPGAs
  - LVDS Serialiser
  - User control and status indication



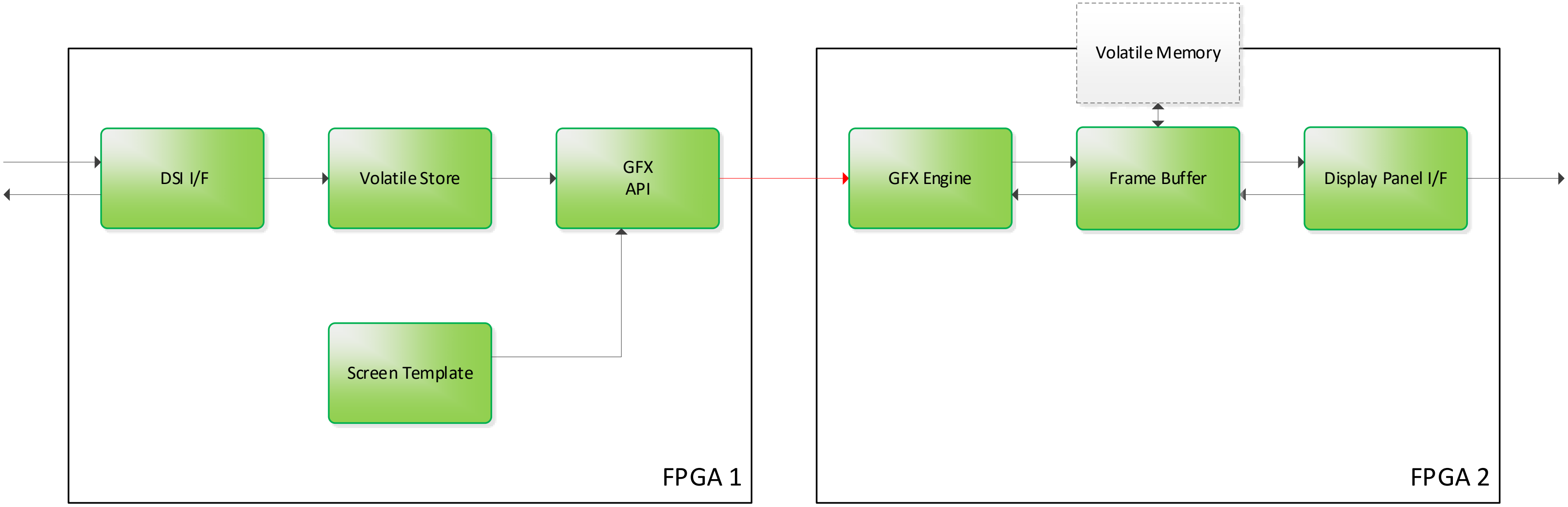
Use of FPGAs in Real-Time NPP Display and Monitoring

PROTOTYPE DIM HARDWARE



Use of FPGAs in Real-Time NPP Display and Monitoring

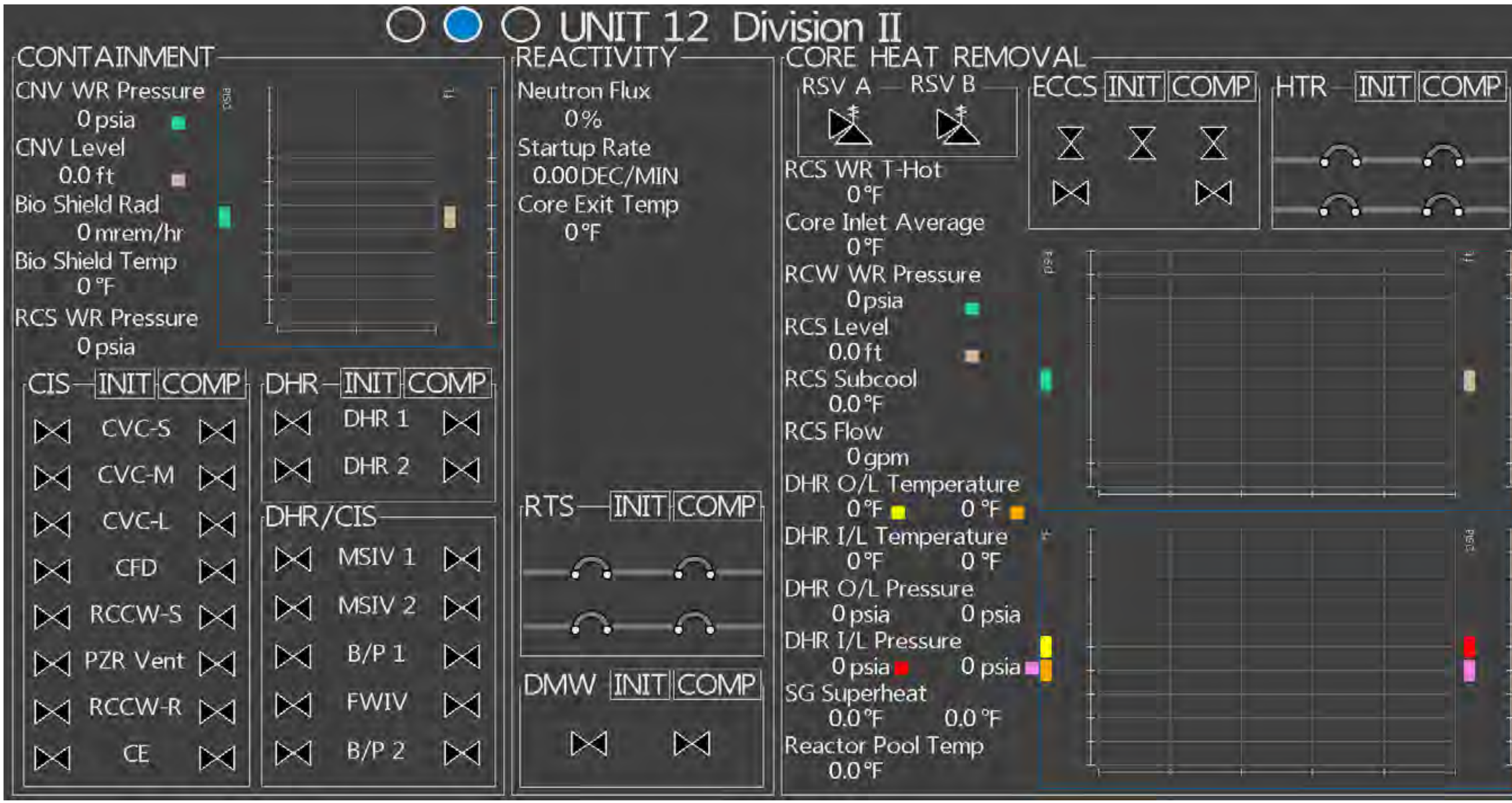
FPGA GRAPHICS ARCHITECTURE



- Graphics modules
  - Graphics API
  - Graphics Engine
  - Frame Buffer
  - Display Panel Interface
  - Screen Template

Use of FPGAs in Real-Time NPP Display and Monitoring

SCREENSHOT



Use of FPGAs in Real-Time NPP Display and Monitoring

CONCLUSIONS

- As we near the end of the NuScale and Ultra prototype development, with the factory acceptance scheduled in December 2018, the following conclusions can be made:
  - An efficient FPGA based Real-Time Nuclear Power Display and Monitoring System can be realised without the use of processors or software
  - It can support complex screen layouts including trend-lines.
  - The screen layout can be changed, using the Ultra developed support tools, without any changes to the RTL code
  - The impact on future screen technology and interface changes to the FPGA has be minimised
  - The NuScale architecture was optimised by Ultra to remove unnecessary hardware
  - The Technology Readiness Level (TRL) will be advanced
  - Required performance of updating the displayed data every 2 seconds is achievable
  - Required low power dissipation is achievable
- The delivered prototype allows NuScale to review the quality of the graphics and identify any possible future enhancements