Presentation to ORNL MSR Workshop
5th Oct 2016

An Overview of the Integral Molten Salt Reactor

TERRESTRIAL ENERGY

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INTRODUCTION TO TERRESTRIAL ENERGY

- **Terrestrial Energy**
  - Commercializing a SMR for 2020s deployment
    - Cost-competitive with fossil fuel combustion
    - Ideal for industrial heat and SMR markets
- **Technology – next generation Molten Salt Reactor ("MSR")**
  - Proprietary MSR design – the Integral Molten Salt Reactor ("IMSR™")
  - High technology readiness
  - Conducting basic/preliminary engineering work
    - Concludes with construction and licensing of the first commercial IMSR power plant (400 MWth reactor)
- **IMSR development and deployment**
  - Supported by power utility industry and senior executives, industrial companies, environmentalists and the Canadian Government and DOE
  - Commenced VDR with Canadian Nuclear Safety Commission ("CNSC")
    - First MSR vendor to commence regulatory process

- **Terrestrial Energy is a leading advanced reactor developer in a fast developing cleantech sector**

TEI AND TEUSA

Terrestrial Energy USA Ltd (“TEUSA”)

- Founded in 2014, headquartered in New York
- Directors:
  - Simon Irish, CEO
  - Dr. Dave Hill. CTO
  - Dr. Ray Johnson. Former CTO of Lockheed Martin Corporation

TEUSA is developing IMSR for US market deployment

- Identifying sites for first US commercial IMSR plant construction

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TECHNOLOGY

ADVANTAGES OF MOLTEN SALT REACTORS

- **Safety**
  - Enhanced ability for passive decay heat removal
  - Inherent Stability from strong negative reactivity coefficients
  - Low pressure and no chemical driving force
  - Caesium and Iodine stable within the fuel salt
- **Reduced Capital Cost**
  - Inherent safety can simplify entire facility
  - Low pressure, high thermal efficiency, superior coolants (smaller pumps, heat exchangers). No complex refuelling mechanisms
- **Long Lived Waste Issues**
  - Ideal system for consuming existing transuranic wastes
  - Even MSR-Burners can ***close fuel cycle*** and see almost no transuranics going to waste
- **Resource Sustainability and Low Fuel Cycle Cost**
  - Thorium breeders obvious but MSR-Burners also very efficient on uranium use

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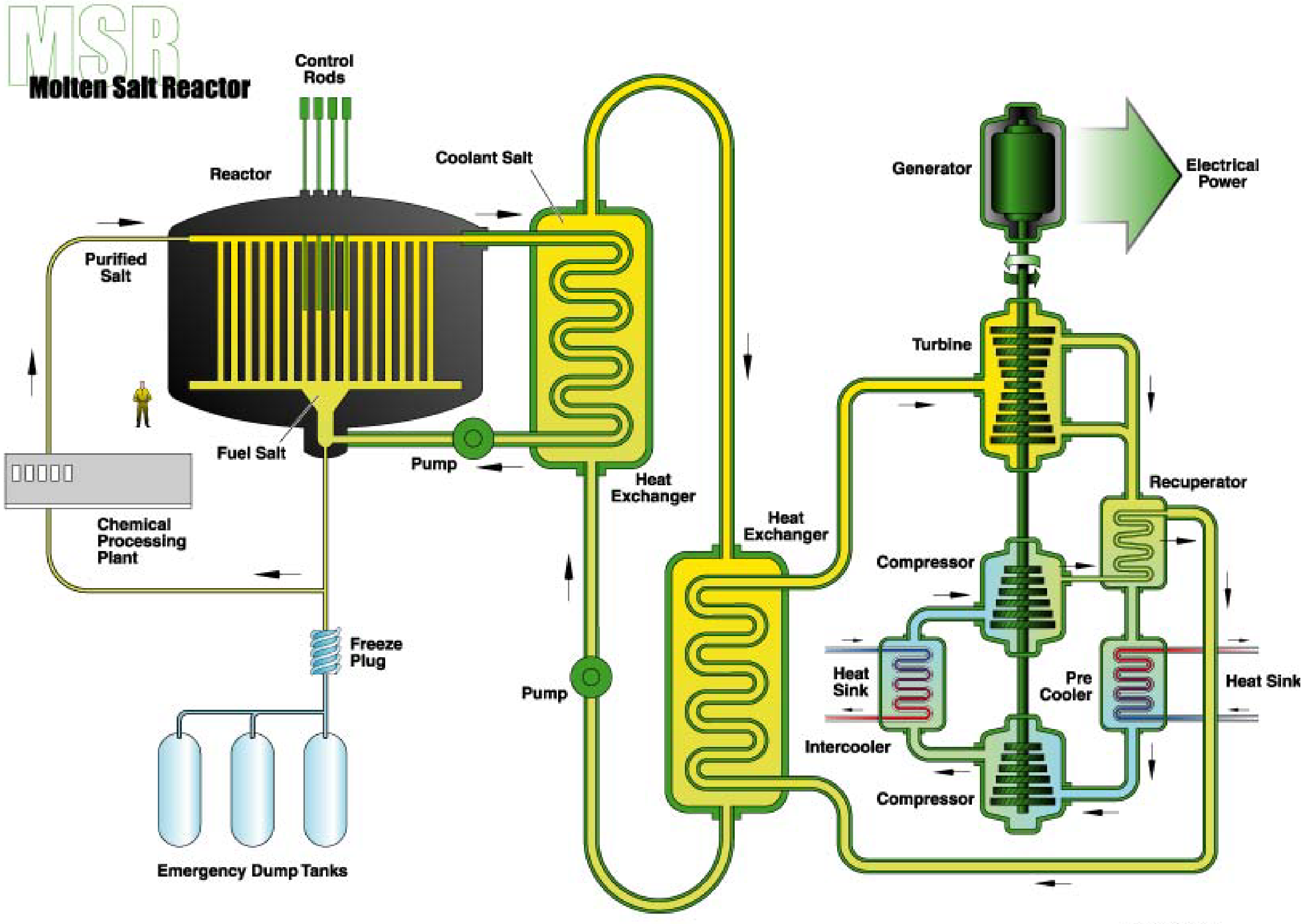
THE 1970s SINGLE FLUID, GRAPHITE MODERATED MOLTEN SALT BREEDER REACTOR (MSBR) – 1000 MWe



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CHALLENGES OF 1970’S MSR-BREEDER DESIGN

- **Online Fission Product Removal**
- **Tritium Control**
- **Reactivity Temperature Coefficients (only weakly negative)**
- **Use of Highly Enriched Uranium**
- **Long Term Corrosion or Radiation Damage**
- **Graphite Replacement Operations**

ISSUES SOLVED BY THE MSR-BURNER APPROACH

- **Fission product removal**
  - No need for any salt processing (Recycle options when desired)
  - Salts used as batches with periodic fuel additions
- **Tritium Control**
  - Able to use non "FLiBe" carrier salts to curtail tritium production
  - NaF, RbK, ZrF_4 and KF among potential ingredients
- **Reactivity Coefficients**
  - MSR-Burners have superior reactivity coefficients
- **Proliferation**
  - Uranium always LEU (denatured), Pu content has high 240 and 242 content and never separated even if fuel eventually recycled

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REMAINING CHALLENGES ARE MATERIAL RELATED

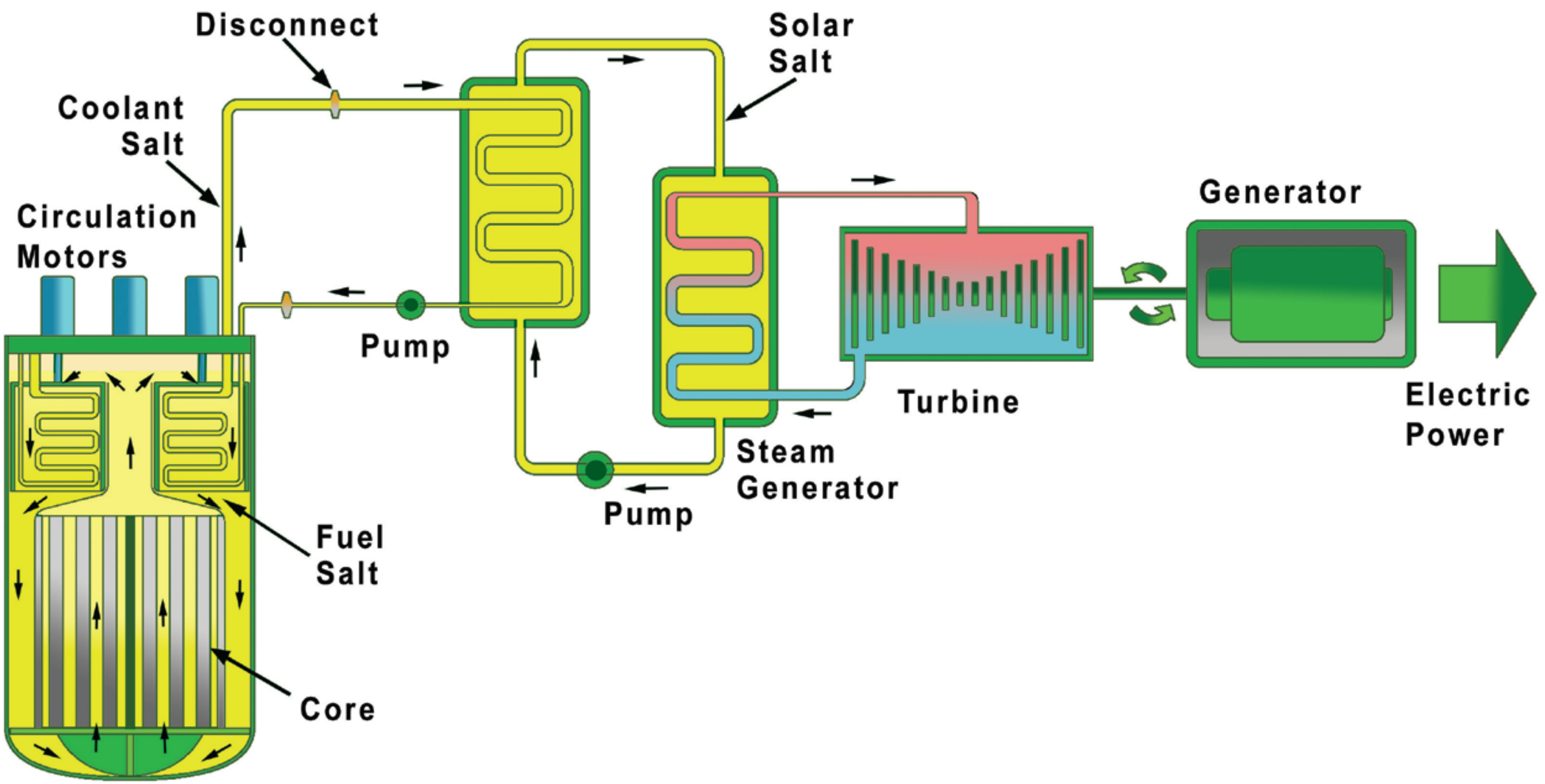
- **Long Term Corrosion or Radiation Damage**
  - High Nickel alloys or even stainless steels perform superbly but proving a 30+ year lifetime a challenge for both reactor vessel and primary heat exchanger
- **Graphite Replacement**
  - Unclad graphite use gives very strong advantages
  - Very low enrichment fuel (~2% enriched LEU)
  - Makes Out of Core Criticality virtually impossible
  - Protects vessel wall from high neutron flux
  - Its lifetime however is directly related to power density

WHAT IS TERRESTRIAL ENERGY'S IMSR?

Integral Molten Salt Reactor

- **LEU fueled MSR-Burner design like the 1980 DMSR**
- **Integrates all primary systems into a sealed reactor Core unit**
- **7 year Core unit "Seal and Swap" approach to graphite lifetime**
- **Shorter lifetime for vessel and HX simplify qualification**
- **Planned as 400 MWth (~ 192 MWe)**
- **Alternate salt and new off gas system**
- **New passive decay heat removal *in situ* without dump tanks**
- **Safety at forefront which leads to cost innovation**

SCHEMATIC VIEW OF IMSR POWER TRAIN



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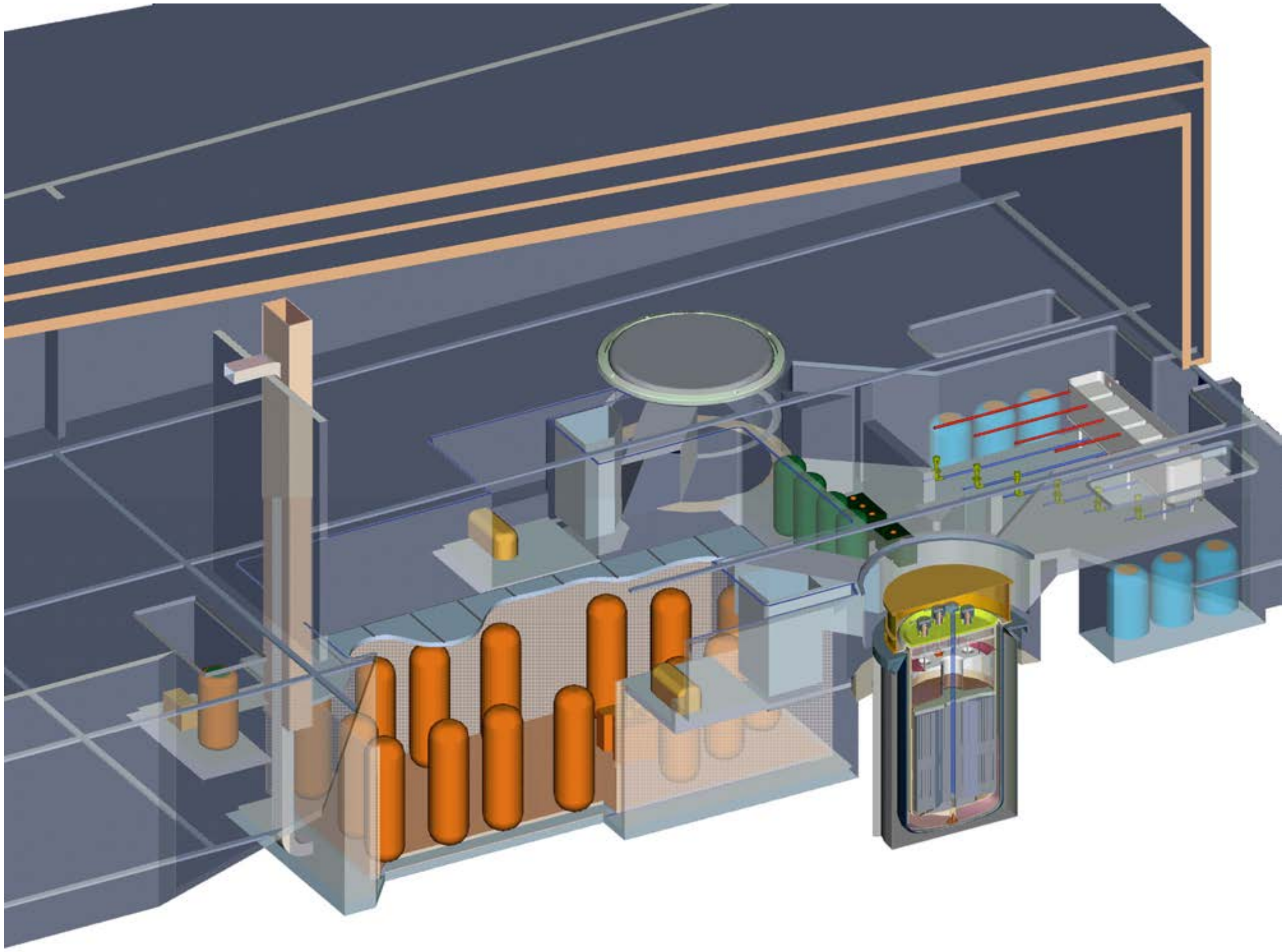
IMSR SINGLE UNIT, TWIN SILOS FOR SWITCHLOADING



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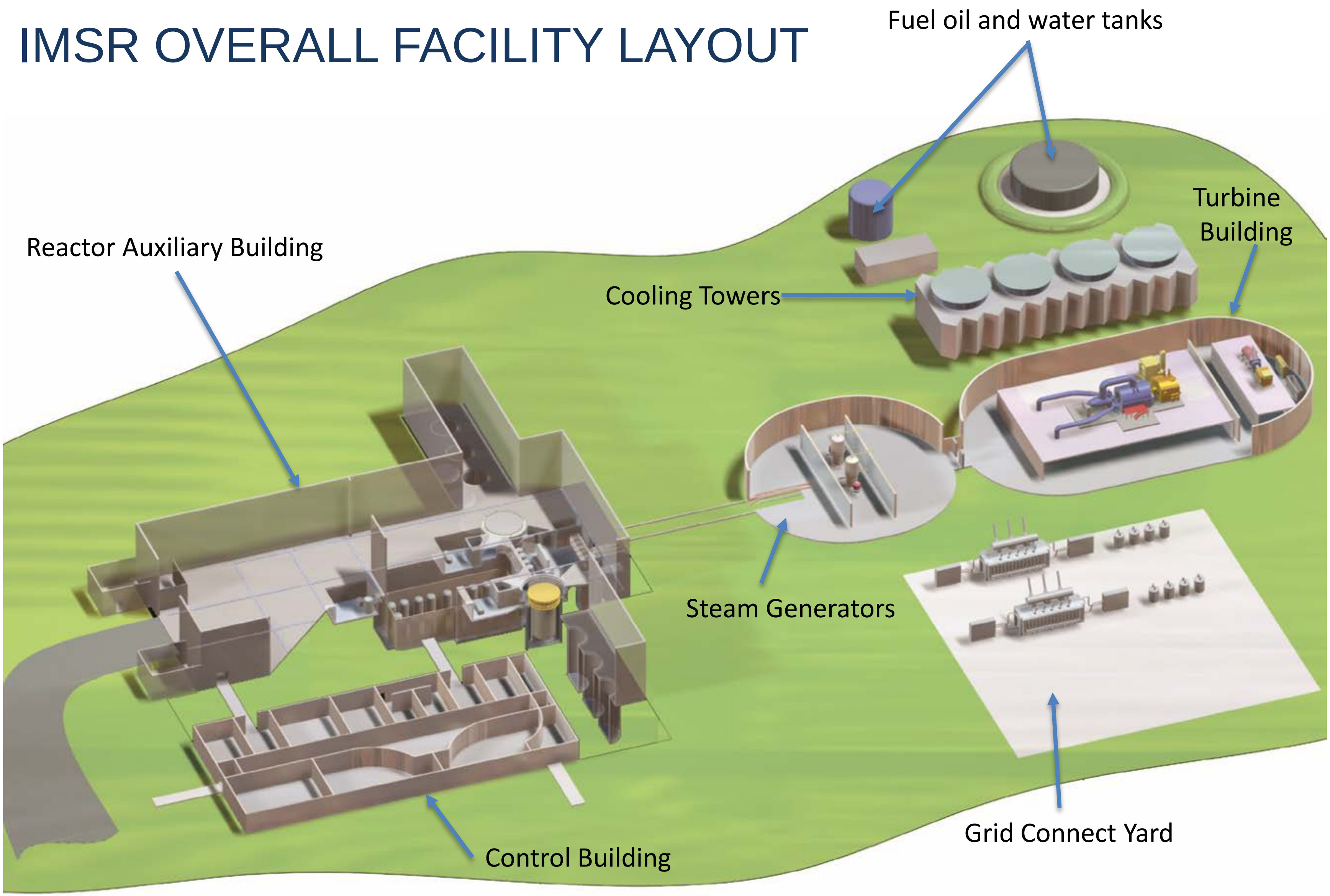
IMSR OVERALL FACILITY LAYOUT



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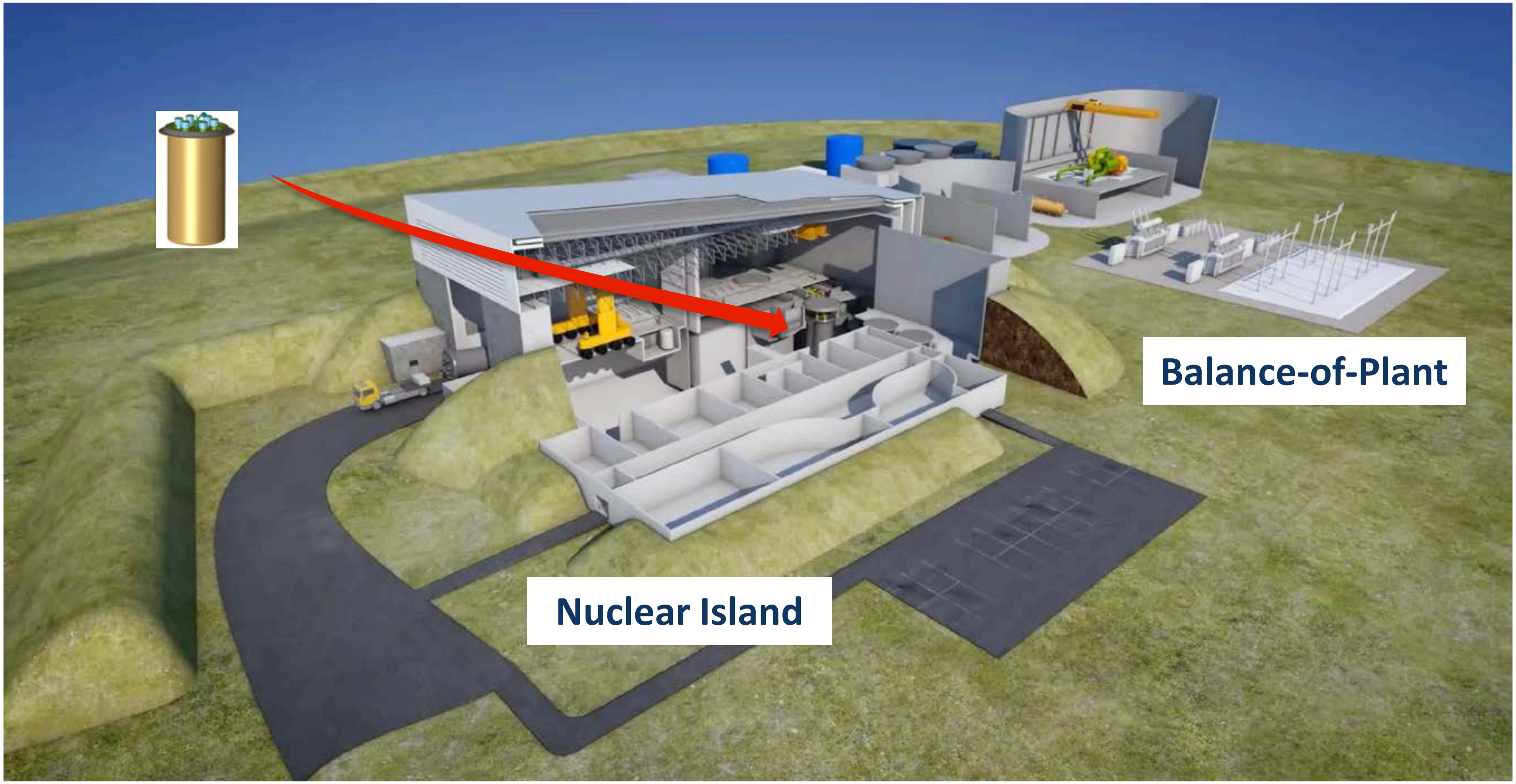
IMSR™ NPP CONSISTS OF NUCLEAR ISLAND AND BALANCE-OF-PLANT



IMSR™ Nuclear Island produces 600°C industrial heat. Balance-of-Plant can be a broad range of industrial applications – not just power provision

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IN-SITU DECAY HEAT REMOVAL – NEW INNOVATION

- **Freeze Valve and Dump Tank the “traditional” approach**
- **Results in unwanted lower penetrations and regulator likely to assume failure to drain is possible**
- **IMSR approach has long been in-situ decay heat removal**
- **Convection and natural circulation brings decay heat to vessel wall**
- **Radiant transfer to Guard Vessel (Guard=Containment)**
    - 700 C surface 9x radiant heat compared to 300 C
- **From there, water jacket options or PRISM type RVACS**
- **Reactor Vessel Auxiliary Cooling System**

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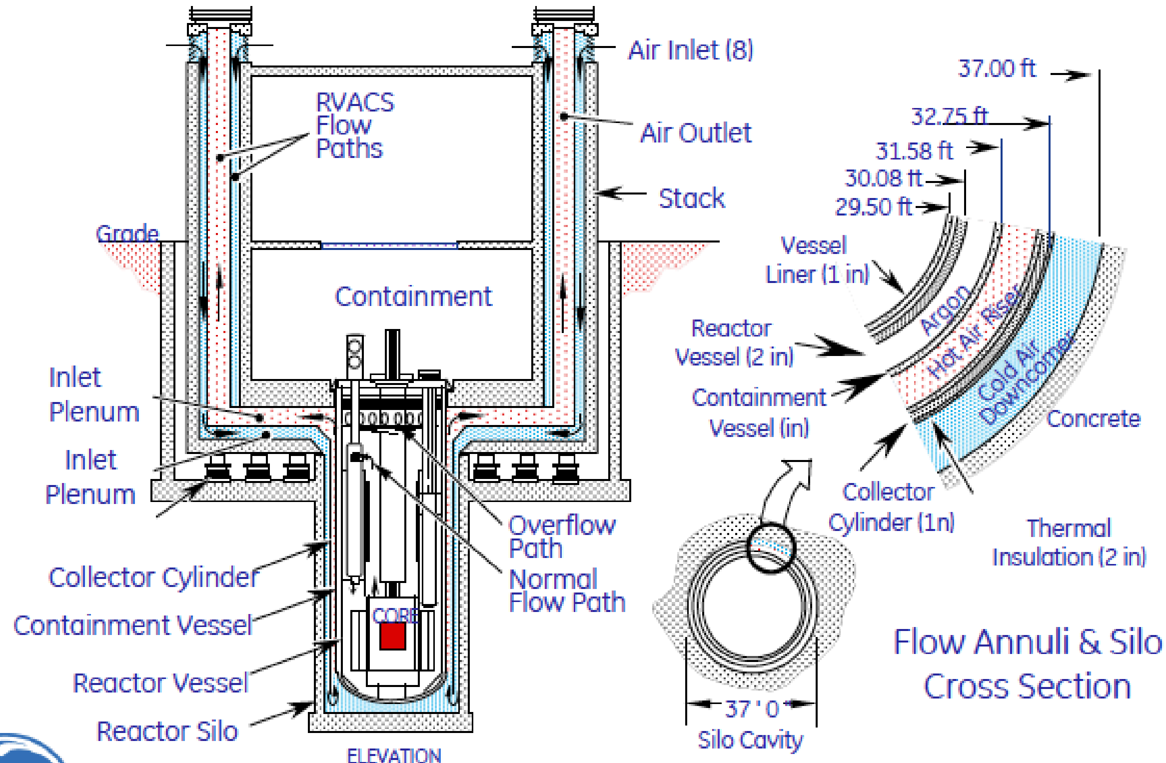
PRISM RVACS Well Studied and Accepted

Passive Systems versus Active Systems



HITACHI

Reactor Vessel Auxiliary Cooling System (RVACS)

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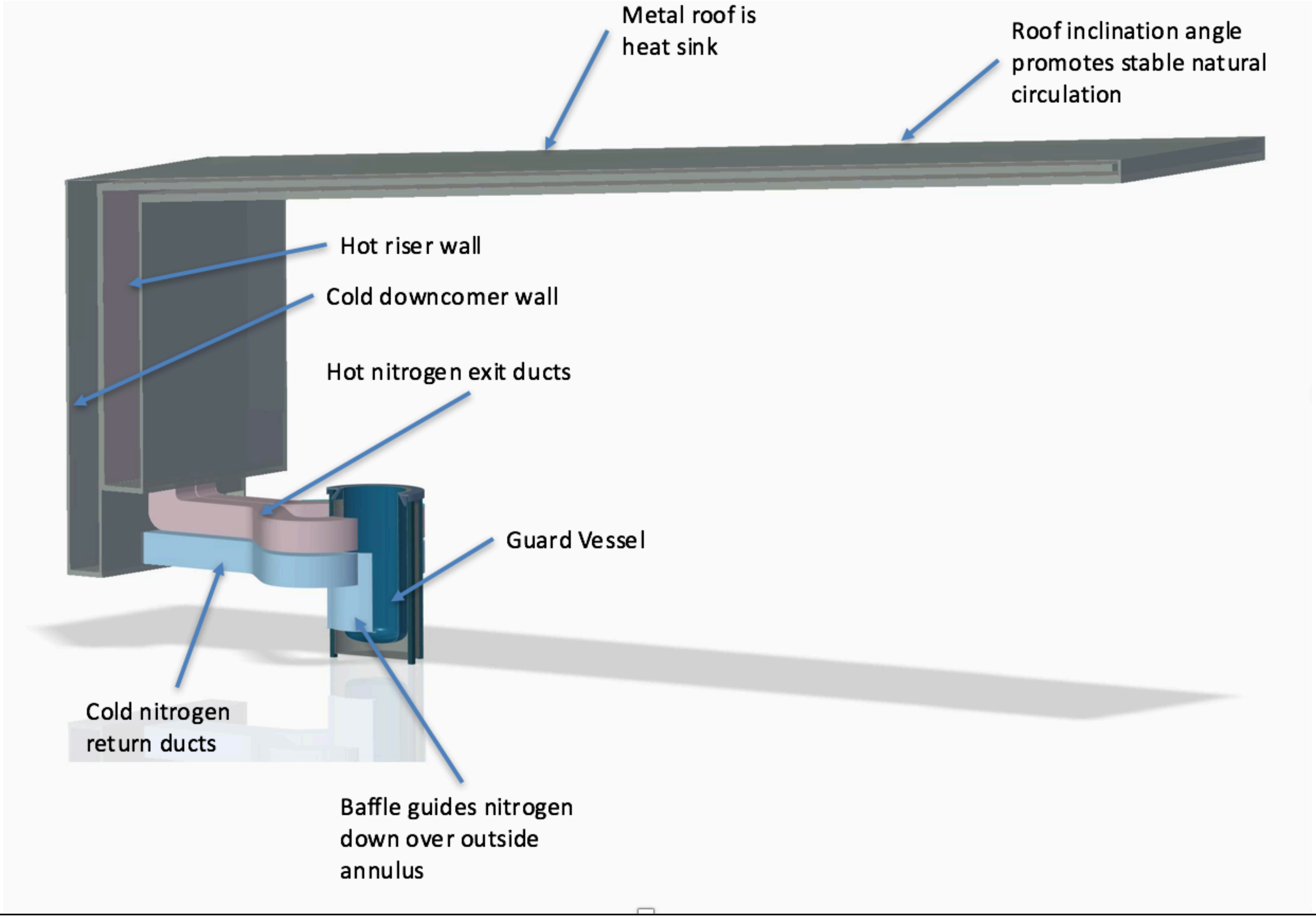
DRAWBACKS OF RVACS DESIGN FOR MSR USE

- **Drawbacks of RVACS include the potential activation of passing air to Argon41 (110 min half life)**
- **Significant neutron shielding required to bring Ar41 rates to acceptable (and what level is publically acceptable?)**
- **As well, any remote possibility of breach of containment (Guard Vessel) means a relatively direct pathway for radionuclides**

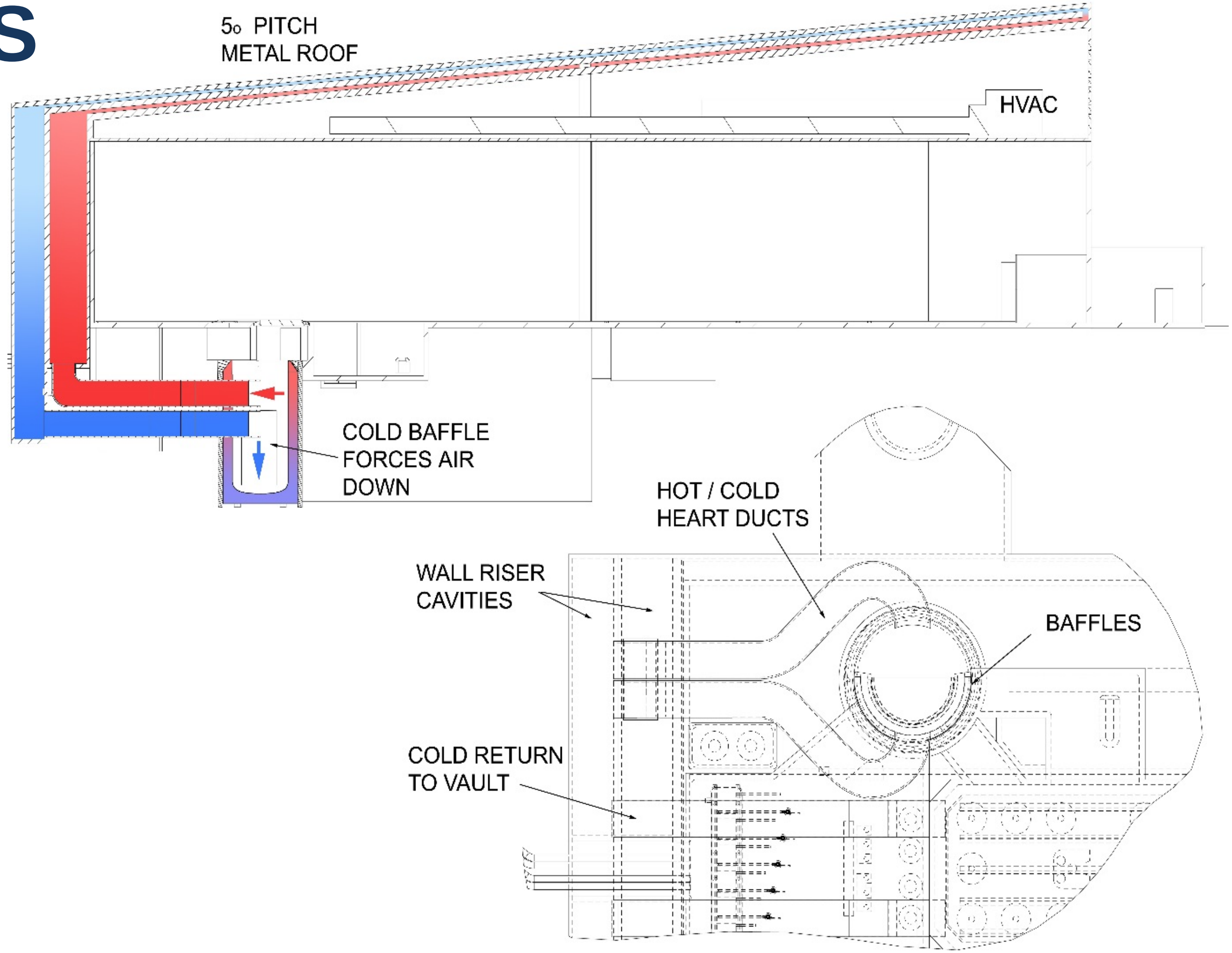
TERRETRIAL ENERGY'S NEW "IRVACS"

- **IMSR utilizes a new innovative concept, proving extremely robust**
- **Basic concept is a closed cycle innovation of RVACS that retains a further barrier to the outside world**
- **New "Internal" RVACS or IRVACS moves heat by a closed cycle flow of nitrogen to a false roof acting as a large heat exchanger above the structural roof**
- **"Fails Better" If roof penetrated, outside air improves performance**
- **Modeling (including 140 million mesh CFD) showing excellent behaviour for even most severe accident scenarios of losing all secondary heat transfer**

IRVACS


Metal roof is heat sink
Roof inclination angle promotes stable natural circulation
Hot riser wall
Cold downcomer wall
Hot nitrogen exit ducts
Guard Vessel
Cold nitrogen return ducts
Baffle guides nitrogen down over outside annulus

IRVACS



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CHALLENGES SOLVED WITH IMSR

- **“Sealed for life” offers enormous regulatory advantages to accelerate development**
- **Airborne release risk during graphite swap eliminated**
- **Long cool down time before moving unit**
- **Material lifetime and corrosion issues greatly eased**
- **Good fuel economy on Once Through**
- **Future recycling to “close” fuel cycle and improve fuel economy commercially attractive**
- **Offers obvious “razor blade” analogy of continuous sales to attract industrial partners**

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