ICON - Control & Wireless in Nuclear

and other activities at the South West Nuclear Hub, Bristol, UK

Dr Guido Herrmann, Reader in Control & Dynamics, University of Bristol
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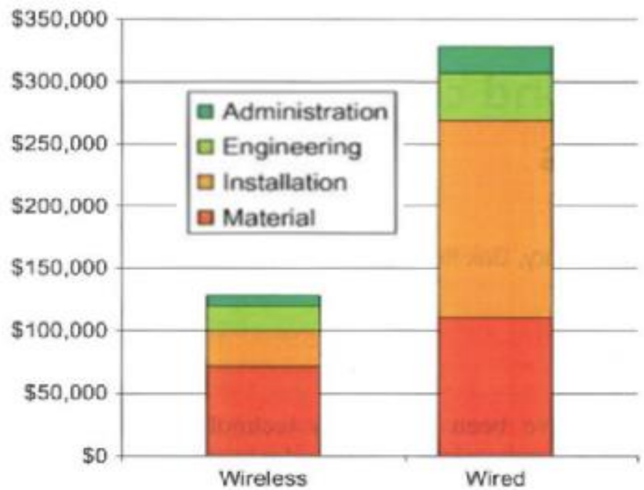
Seminar - Wireless in nuclear applications, Energiforsk, Stockholm, 8 March 2018

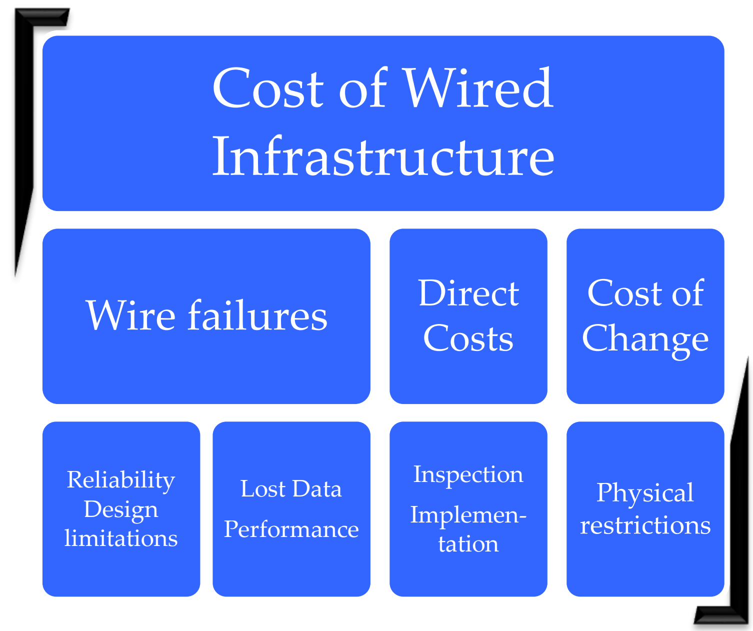
Overview

1. ICON - Control & Wireless in Nuclear
2. Outlook – Wireless in Nuclear – Future
3. South West Nuclear Hub
   at the University of Bristol

Motivation



Wired vs Wireless Sensors
Oak Ridge National Lab, P. Fuhr, **2016**



ICON - Objectives

Feasibility of using wireless technology in Nuclear Control Systems

- 1) Control Concept with architectures for wireless communication and wireless asset monitoring and security, (generic and) applicable for the Moltex SSR application
- 2) Development of interruption-tolerant signal and self-powering hardware architecture proposal, to be peer reviewed by ONR.
- 3) Safety assessment to substantiate claims that wireless C&I in SSR is a viable first-of-a-kind deployment for the technology.

ICON – Partner – University of Bristol

- Founded in 1909
- Ranked 44th in the world by QS

Nuclear Research Centre

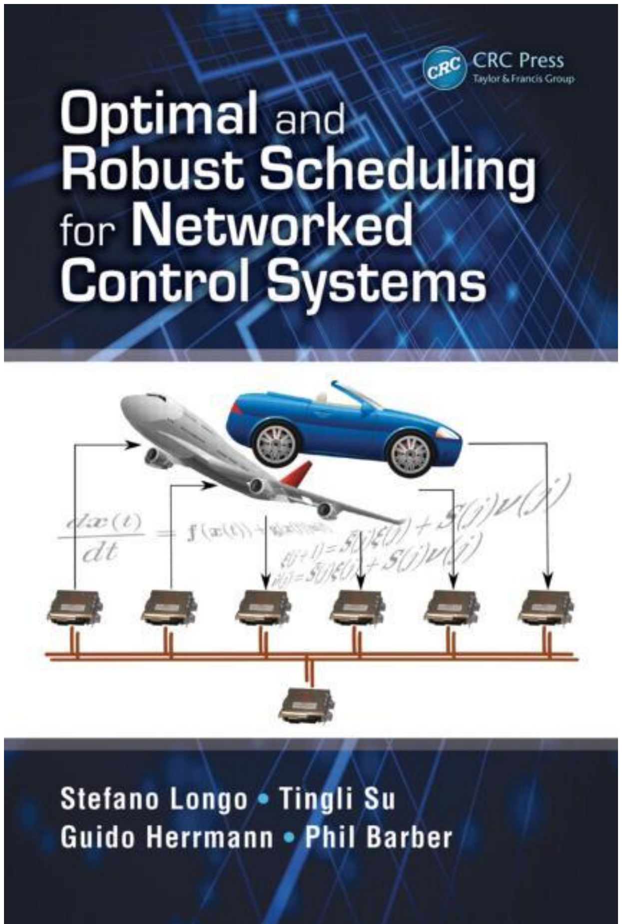
University of BRISTOL — UNIVERSITY OF OXFORD

SOUTH WEST NUCLEAR HUB

Dynamics & Control Group

Communication Systems & Networks Group

ICON – Bristol Partner – Dr Guido Herrrmann



Stefano Longo
Cranfield University
IET 2011 Control PhD Award

Tingli Su
Beijing Institute of Technology & BTBU

Guido Herrmann
University of Bristol

Phil Barber
Jaguar Land Rover

JAGUAR LAND ROVER

ICON – Bristol Partner – Dr John May

Reader in Safety Systems

- leads research in the Safety Systems Research Centre and the reliability, security and risk research theme of the South West Nuclear Research and Teaching Hub
- Steering committee member of South West Nuclear Hub.
- organisational resilience and safety culture research
- new statistical reliability testing techniques for software to critical programmable nuclear systems, including reactor protection systems and smart devices.
- new method to evaluate risk, based on the 'J-value'. This can be used to prioritise mitigation activities and understand where best to allocate the costs of protecting against disasters.

Chen, L., & May, J. (2017). Theoretical Feasibility of Statistical Assurance of Programmable Systems Based on Simulation Tests. In Proceedings - 2017 IEEE International Conference on Software Quality, Reliability and Security Companion, DOI: 10.1109/QRS-C.2017.123

Chen, L., & May, J. H. R. (2015). A Diversity Model Based on Failure Distribution and its Application in Safety Cases. IEEE Transactions on Reliability. DOI: 10.1109/TR.2015.2503335

ICON – Bristol Partner – Dr Robert Piechocki

Reader in Wireless Communication

- statistical signal processing, information and communication theory for wireless communications.
- development advanced distributed algorithms for Analogue VLSI.
- Ultra Low Power Communications
  Lead of the development of connectivity and sensing for the Sphere project (http://www.irc-sphere.ac.uk/) – UK's flagship EPSRC funded eHealth IoT project and the winner of 2016 World Technology Award
- Lead of several UK funded projects developing connected technology for Autonomous Vehicles

Fafoutis, X., Elsts, A., Oikonomou, G., Piechocki, R., & Craddock, I. (2017). Adaptive Static Scheduling in IEEE 802.15.4 TSCH Networks. 2018 IEEE 4rd World Forum on Internet of Things (IEEE WF-IoT).
Tsimbalo, E., Tassi, A., & Piechocki, R. (2018). Reliability of multicast under random linear network coding. IEEE Transactions on Communications. DOI: 10.1109/TCOMM.2018.2801791.

ICON – Project Lead – **ALTRAN**

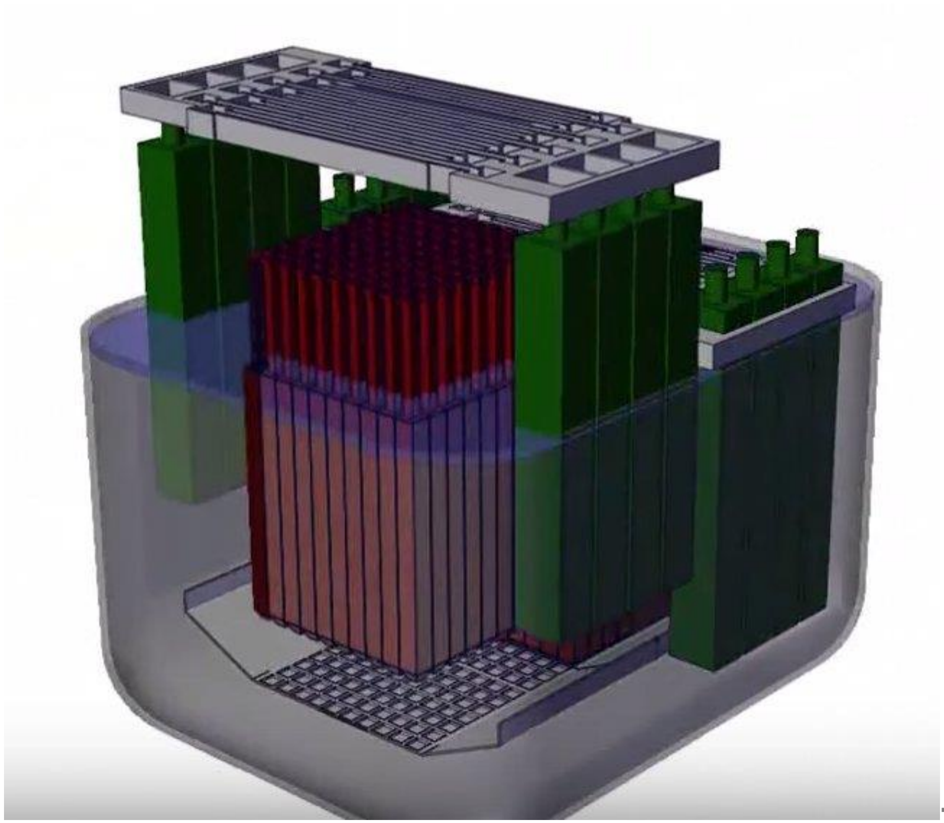
- a global leader in Engineering and R&D services (ER&D)
- founded in 1982
- world-leading in innovative, modern, safety-critical control systems
- in Civil Nuclear, UK’s Office of Nuclear Regulations (ONR) relies on Altran’s competence to peer review new technology designs
- wireless C&I are a natural growth opportunity in Civil Nuclear.

ICON – Partner – **Moltex Energy Ltd**

- a privately-funded, UK SME.
- to commercialise its breakthrough molten salt reactor design, the Stable Salt Reactor
- Stable Salt Reactors the most promising MSR technology for the UK from assessment of six Molten Salt Reactors (MSR)
- Phase 1 and Phase 2 of the Canadian Vendor Design Review process as a first step to building a first commercial reactor within the next 10 years in Canada

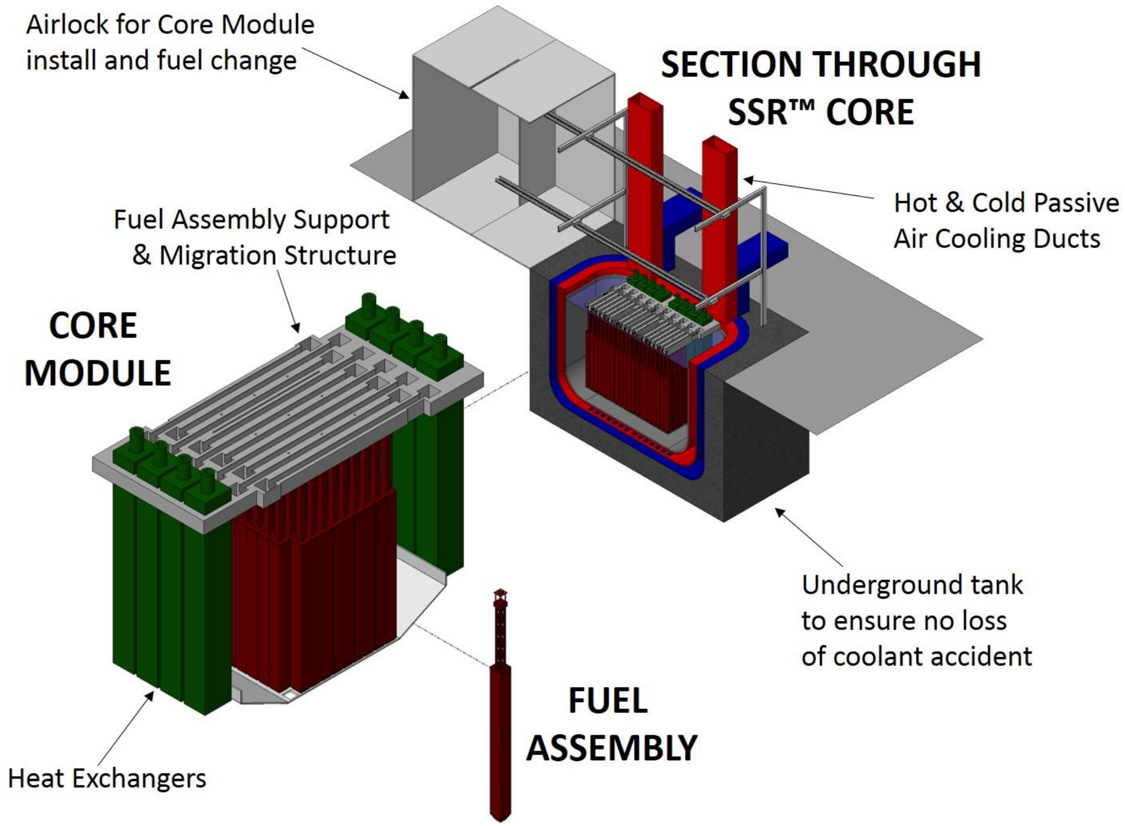
ICON - Moltex' Stable Salt Reactor

Molten Salt Reactor by ***MOLTEX Ltd:***



- modular assemblies of 300 MW each
- negative temperature coefficient of reactivity
- hazardous volatile iodine and caesium eliminated
- xenon and krypton leaves, but trapped until their radioactive isotopes decay
- Atmospheric pressure
- Fuel: sodium chloride, plutonium & lanthanide/actinide trichlorides

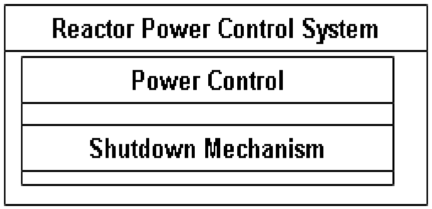
ICON - Moltex' Stable Salt Reactor

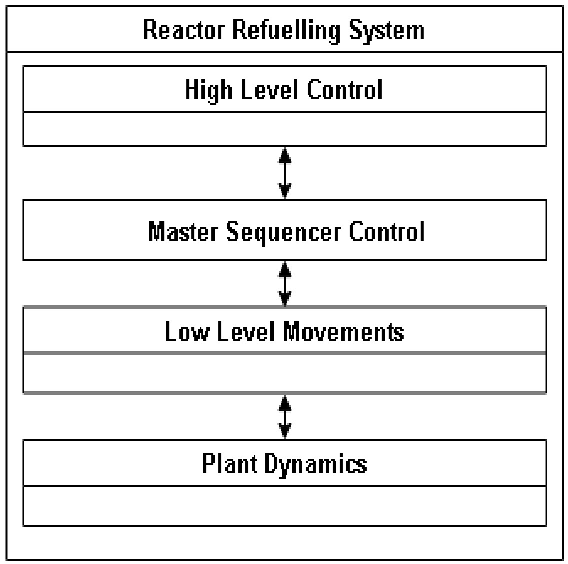


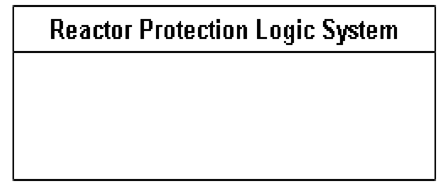
Three Control Systems of SSR by ***MOLTEX Ltd***

- Reactor Power Control
- Reactor Protection Logic
- Refuelling System

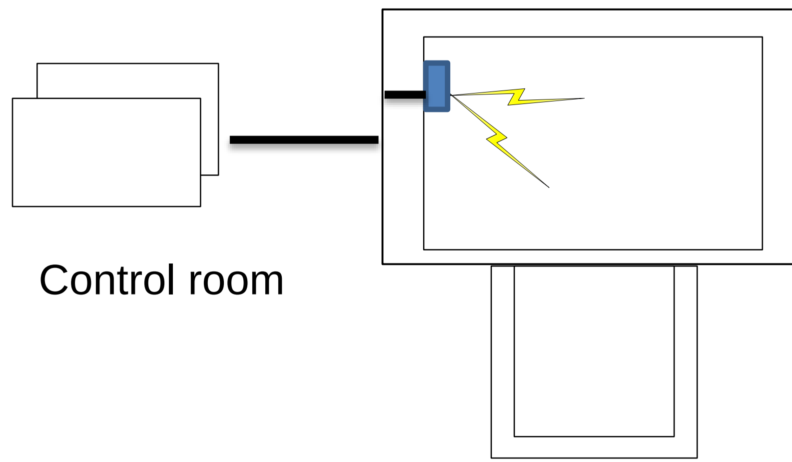
ICON – Architectures for Control







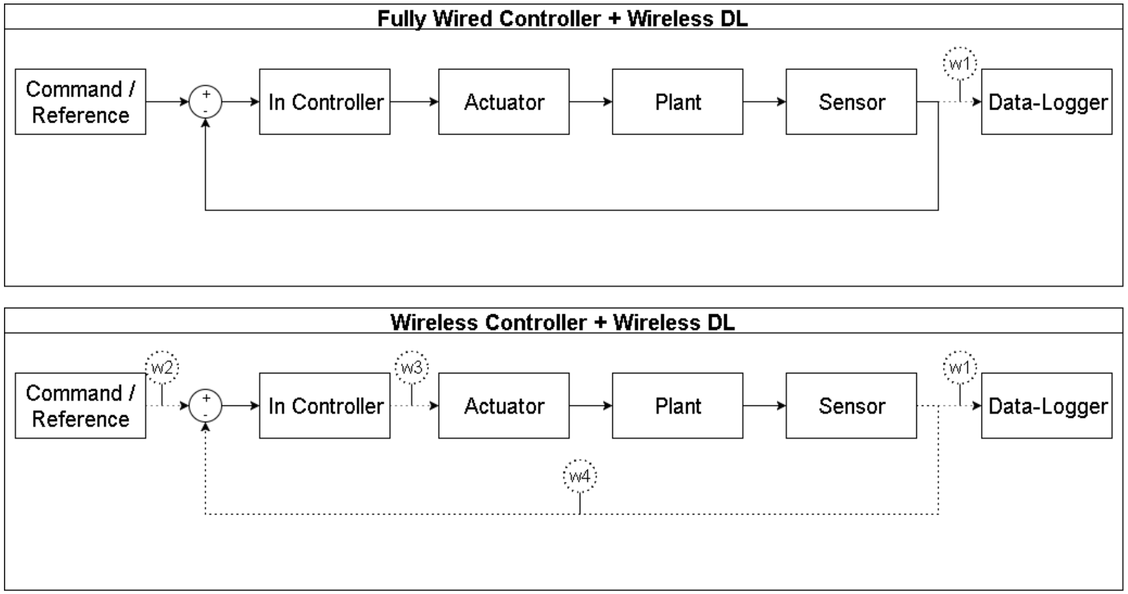
- Control systems for SSR-W300 analysed
- Focus on Reactor Refuelling System, for generality and completeness purposes



Control room

Fuel and reactor system.

ICON – Architectures for Control



- **w1:** Communication channel from sensed variable to outside instruments.
- **w2:** Communication channel from outside instruments to local controller.
- **w3:** Communication channel from local controller to actuator.
- **w4:** Communication channel from sensed variable to control loop.

- Different parts of the control loop that could become wireless were detected
- Data-logging capabilities do not affect the control loop, but they were reviewed

ICON – Architectures for Communication

IEEE 802.11

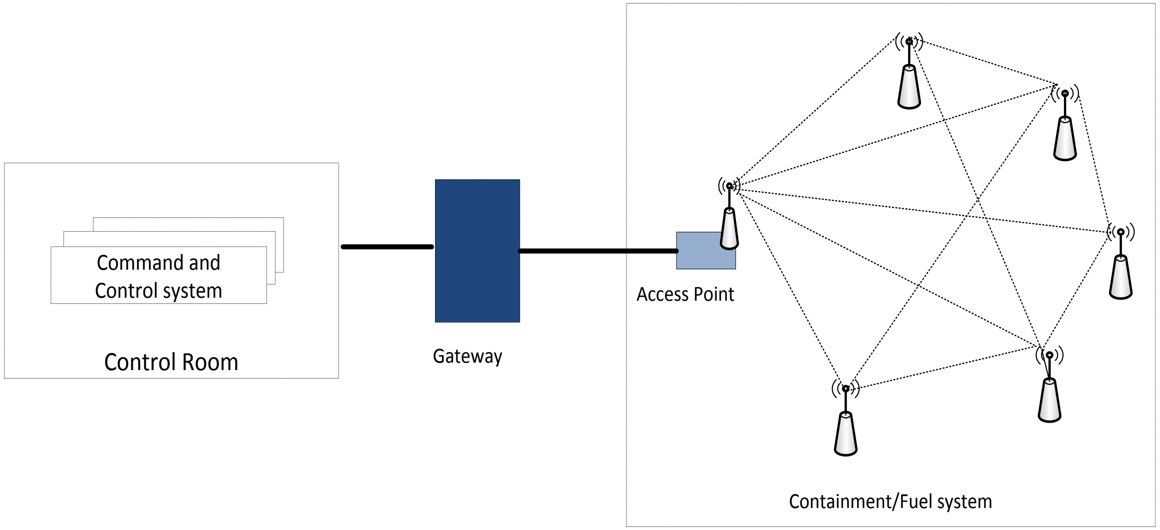
- Optimised for larger data-rate rather then low power consumption.
- Does not guarantee low latency.

IEEE 802.15.1

- Not scalable enough to be used in large control systems.
- Does not guarantee low latency.
- Short range communication.

IEEE 802.15.4

- ZigBee
- WirelessHART



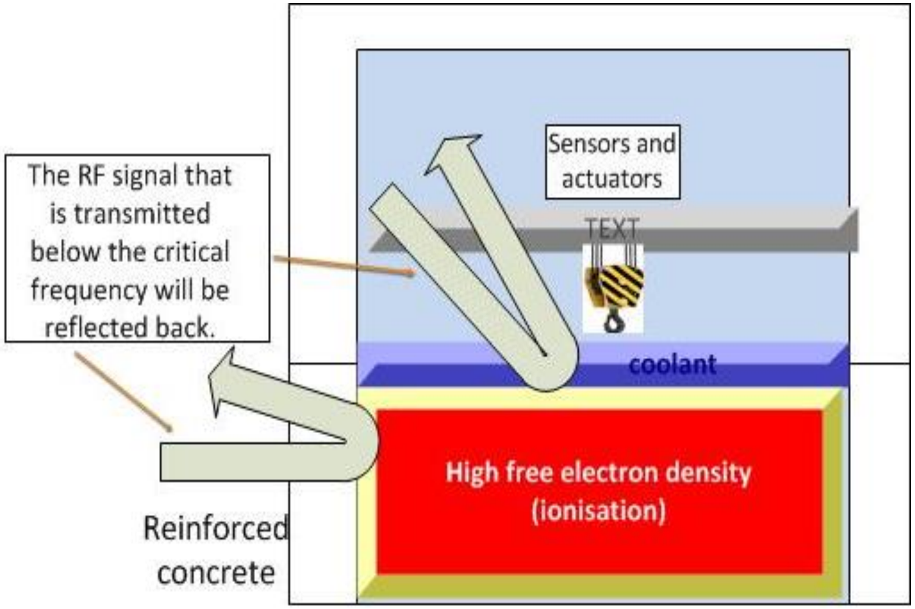
Wireless structure

IEEE 802.15.4e

- An improvement of IEEE 802.15.4
- Scalable
- Short delay
- Reliable
- Secure

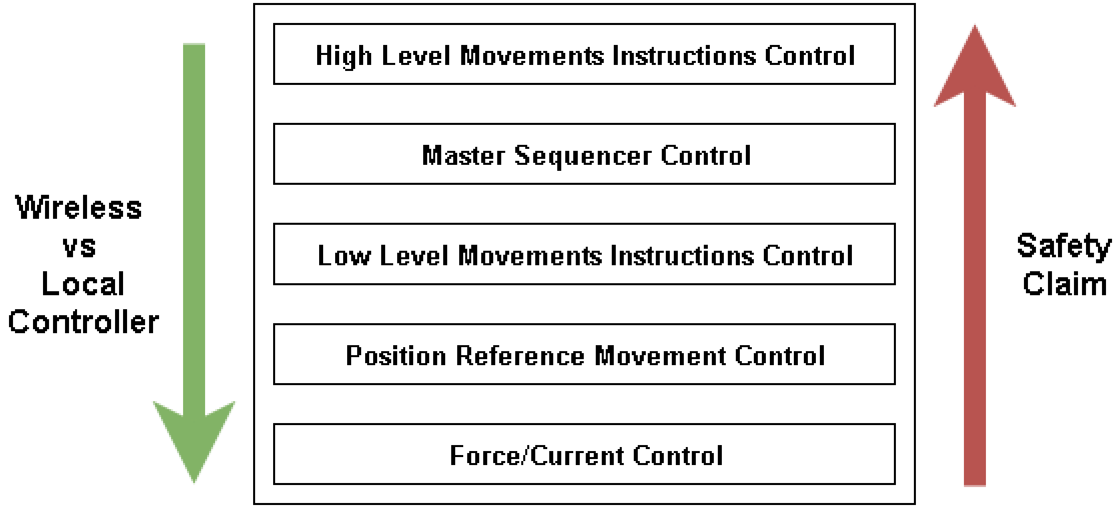
ICON – Architectures for Communication

- Gamma radiations carry sufficiently high energy to create ionisation of atoms/molecules.
- The free electron density impacts the RF signal propagation characteristics.
- Shielding effect (based on the freq. of the signal)



Ionisation

ICON – Control-Based Failure Analysis



- Specific control and coding can overcome communication failures
- As more parts of the control sub-systems become wireless, the harder it may be to provide a safety claim.
- Failsafe strategies can reduce the impact of communication failure
  - Local sequencer and self-supervising capabilities for state transition
  - Fault detection and limiters for control variables (e.g. position, force)

ICON – Resilient and Self-Powering Hardware

Radiation type	Energy range	Main types of interaction	Primary effects in Si and SiO_2	Secondary effects in Si and SiO_2
Photons	Low energy	Photoelectric effect	Ionising phenomena	Displacement damage
	Medium energy	Compton effect		
	High energy	Pair production		
Neutrons	Low energy	Capture and nuclear reaction	Displacement damage	Ionising phenomena
	High energy	Elastic scattering		

Mitigation:

- Shielding & small electronic devices,
- NASA or MIL standard devices (expensive)

Self-Powering Hardware: e.g. Gamma diamond detector

Related Project: ASPIRE: Advanced Self-Powered sensor units in Intense Radiation Environments (£875k, Prof. T. Scott, R. Piechocki et al.)

ICON – Safety through **ALTRAN** and partners

- Structured and systematic examination of a complex planned or existing process or operation in order to identify and evaluate problems
- Analysis and review of nuclear standards in the context of the SSR and general nuclear system
- Further detailed analysis ongoing

- Aim to have a review of results by ONR Office for Nuclear Regulation

Outlook

Wireless technology

advantages

over wired

for Digital Instrumentation & Control (I&C) purposes

- **cheaper in set-up**
- **easier maintained**
- **easier installed and upgraded**
- **much less dependent on infrastructure**

Our unique team will realize the unresolved step change from wireless networks to robust and dependable (nuclear) Wireless Sensor & Control Networks (WSCNs)

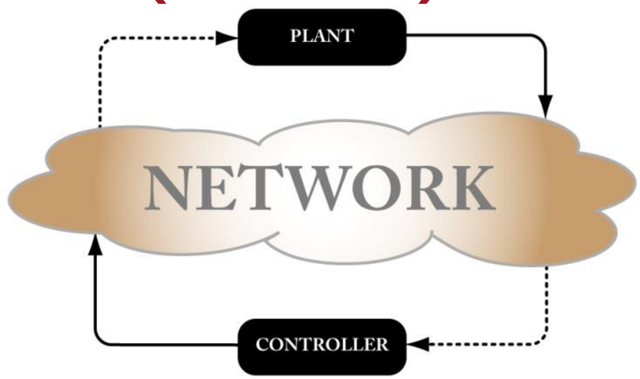
WSCNS considerations for Nuclear

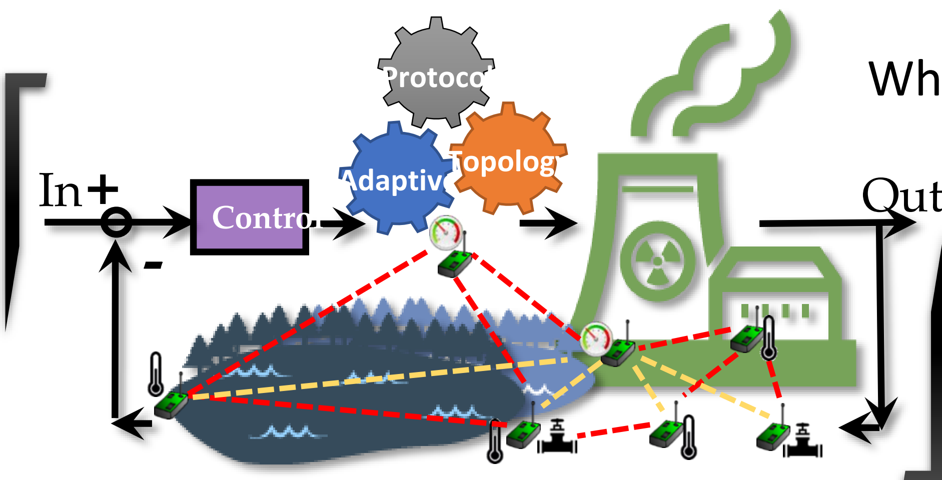
- **Security & Safety Requirements**
- **Robust to radiation (ionization)**
- **Energy constrained (EMI)**
- **Topology constrained and fast adaptive**
- **Easy extension, fault-tolerance, redundancy and retrofitting**
- **Optimized for control: coding and timing**

Networked Control Systems(NCSs)

- Limited communication
- Various ways to model the network

    Delays, Scheduling





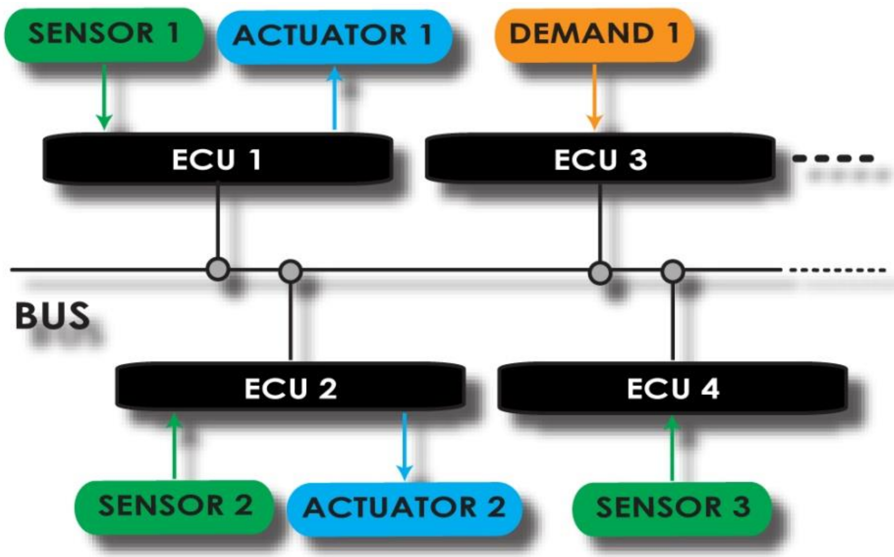
What is the ideal topology of the network ?

NETWORK STRUCTURE ?

Kempton, L., Herrmann, G., & Di Bernardo, M. (2017). Self-organization of weighted networks for optimal synchronizability. IEEE Transactions on Control of Network Systems. DOI: 10.1109/TCNS.2014.2301653

Limited Communication

- Distributed sensors, actuators and controllers (nodes)
- Limited communication over network
- Only some signals can be updated at any time tick, other signals stay the same
- What is the optimal communication sequence between nodes?
- This can be an integration problem

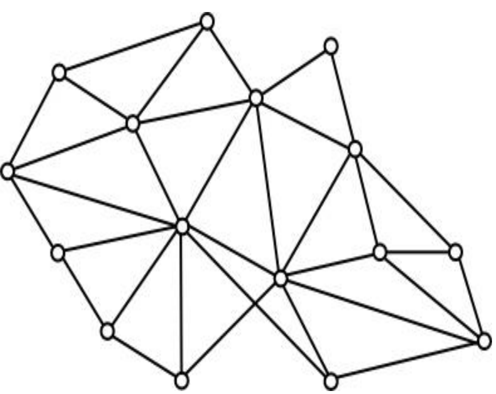


COMMUNICATION FOR CONTROL ?

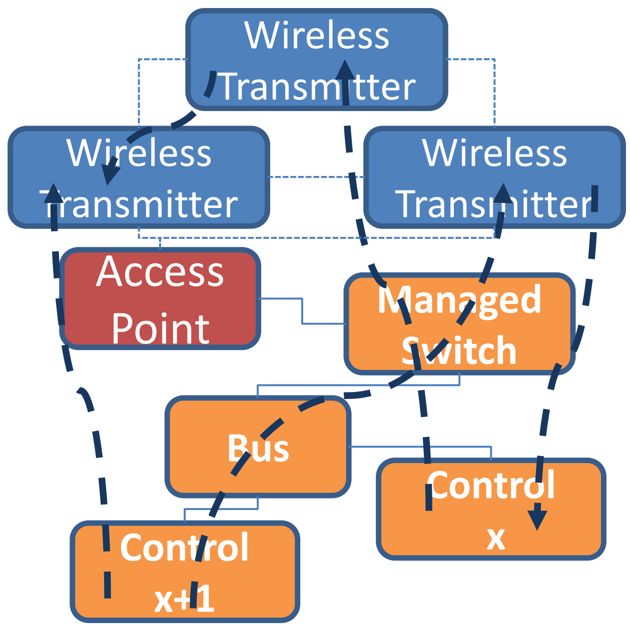
Longo, S., Herrmann, G., & Barber, P. (2012). Robust Scheduling of Sampled-data Networked Control Systems. IEEE Transactions on Control Systems Technology, 20(6), 1613-1621. DOI: 10.1109/TCST.2011.2170172

NETWORKED CONTROL SYSTEMS (NCSs)

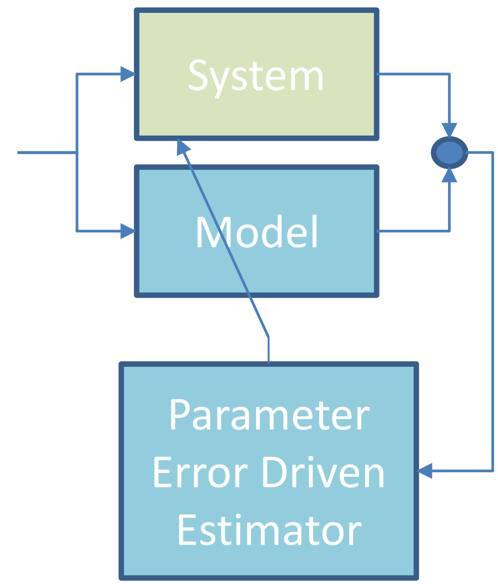
NETWORK STRUCTURE



COMMUNICATION FOR CONTROL



ESTIMATION for Fault Tolerance



Hardened Algorithms, Safety & Security through Redundancy, Encoding, Encryption, Adaptivity and Rigorous Analysis

Wragge-Morley, R. T., Herrmann, G., Barber, P., & Burgess, S. C. (2015). Gradient and Mass Estimation from CAN Based Data for a Light Passenger Car. SAE International Journal of Passenger Cars, 8(1), 137-145. DOI: 10.4271/2015-01-0201

South West Nuclear Hub at the University of Bristol

Overview

- Nuclear energy research at the University of Bristol
- Strategic growth – South West Nuclear Hub
- Innovation – NUCLEATE
- Nuclear Skills and Education

SOUTH WEST NUCLEAR HUB

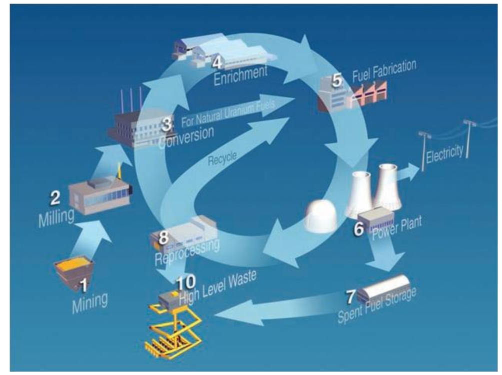
Current Team and Portfolio

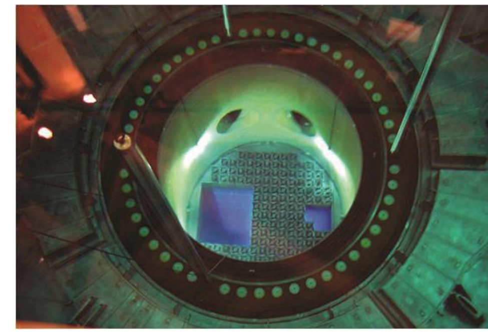
Nuclear Research Centre

University of BRISTOL | UNIVERSITY OF OXFORD

- Resident experience
  ~45 academics
- Combined Portfolio
  ~£20M
- Total number of researchers
  ~90

Portfolio includes: EPSRC, EU and industrial funding, with new joint projects developed since launch





Name	Publications	FWCI	in global top 1%	in global top 10%
University of Bristol	60	2.75	6 (10.0%)	17 (28.3%)
University of Nottingham	59	2.46	1 (1.7%)	18 (30.5%)
University of Manchester	204	2.29	6 (2.9%)	45 (22.1%)
University of Oxford	153	2.19	10 (6.5%)	44 (28.8%)
University of Cambridge	127	2.18	5 (3.9%)	41 (32.3%)
University of Edinburgh	78	1.89	4 (5.1%)	23 (29.5%)
University of Warwick	81	1.79	2 (2.5%)	18 (22.2%)
Imperial College London	357	1.66	10 (2.8%)	79 (22.1%)
University of Southampton	65	1.54	1 (1.5%)	12 (18.5%)
University of Leeds	67	1.51	0 (0.0%)	13 (19.4%)
University College London	242	1.49	5 (2.1%)	50 (20.7%)
University of Plymouth	61	1.46	1 (1.6%)	10 (16.4%)
Health Protection Agency London	57	1.45	0 (0.0%)	9 (15.8%)
University of Birmingham	68	1.36	0 (0.0%)	13 (19.1%)
University of Sheffield	138	1.27	1 (0.7%)	10 (7.2%)
Culham Science Centre	118	1.26	1 (0.8%)	18 (15.3%)
Rutherford Appleton Laboratory	114	1.24	1 (0.9%)	22 (19.3%)
University of Glasgow	69	1.13	4 (5.8%)	10 (14.5%)
University of Leicester	138	1.02	1 (0.7%)	19 (13.8%)
Lancaster University	77	0.95	0 (0.0%)	10 (13.0%)

Sir Andrew Witty's Review of Universities & Growth - Nuclear

Nuclear in the South West

Nuclear Licensed Sites
Hinkley Point, Berkeley, Oldbury, Harwell, Winfrith, Aldermaston, Devonport Dockyard

Nuclear Industry EDF Energy and Horizon Nuclear Power (Gloucester), Magnox (Berkeley), Babcock (Devonport)

Supply Chain Amec FW, Atkins, Altran UK, Fraser-Nash, Jacobs and EA (Bristol)

Government Office for Nuclear Regulation (Cheltenham), National Nuclear Lab (Stonehouse), CCFE and NNUF (Culham), Radioactive Waste Management Ltd (Harwell), Nuclear Defence Academy (HMS Sultan)

Academia Universities of Bristol, Oxford, UWE, Birmingham, Cardiff, Bath, Southampton, Exeter, NCfN Southern Hub (Bridgwater College), EDF Campus (Cannington Court)

Strategic Need for a Nuclear Hub

Government: Nuclear Industrial Strategy

- “**joined up approach to nuclear R&D** across government, industry and academia”
- “research base is underpinned by world-leading facilities which are **fully utilised by both national and international customers**”.

edf

NATIONAL NUCLEAR LABORATORY

Industry Demand

- “the Hub, housing both members of academia and industry, facilitating cross-fertilisation of ideas, will deliver results **with the highest industrial impact**”
- “the provision of new Nuclear Masters and PhD courses partnered with industry will provide a much needed contribution towards providing a solution to the **aging UK nuclear workforce**”.

2011	2012	2014	2016	2016	2017
NRC	GOV.UK	hefce	SOUTH WEST NUCLEAR HUB	NUCLEAR SouthWest	NATIONAL NUCLEAR LABORATORY
Bristol-Oxford Nuclear Research Centre launched	Witty Review ranks Bristol #1 for nuclear research impact	£2.4m Catalyst Award – physical Hub for nuclear R&D in the SW	SW Nuclear Hub launched	Cluster linking local government, academia and business	NNL join NUCLEATE as a partner

Research…

University of Oxford, UWE Bristol, National Nuclear Laboratory

Industry…

EDF, Sellafield Ltd, Hitachi, GE, Areva

Enterprise…

Nuclear SouthWest, SETsquared Partnership (Universities of Bath, Bristol, Exeter, Southampton & Surrey), Somerset Chamber of Commerce, HPC, SWMAS, BusinessWest

Managing the Hinkley Point C local supply chain on behalf of EDF Energy

Skills…

National College for Nuclear

HPC, Hinkley Point Training Agency

Building better energy together

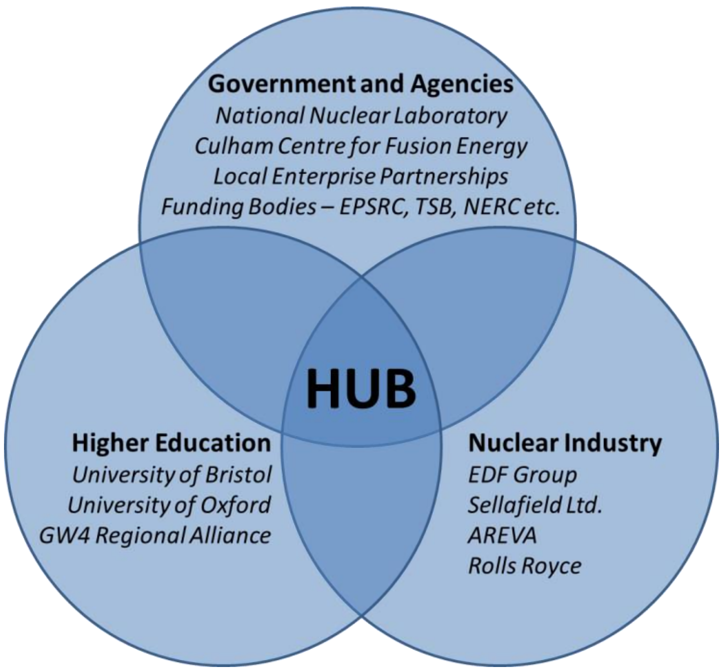
SOUTH WEST NUCLEAR HUB

HEFCE Catalyst Fund Award

Nuclear Research Centre

University of Bristol

University of Oxford



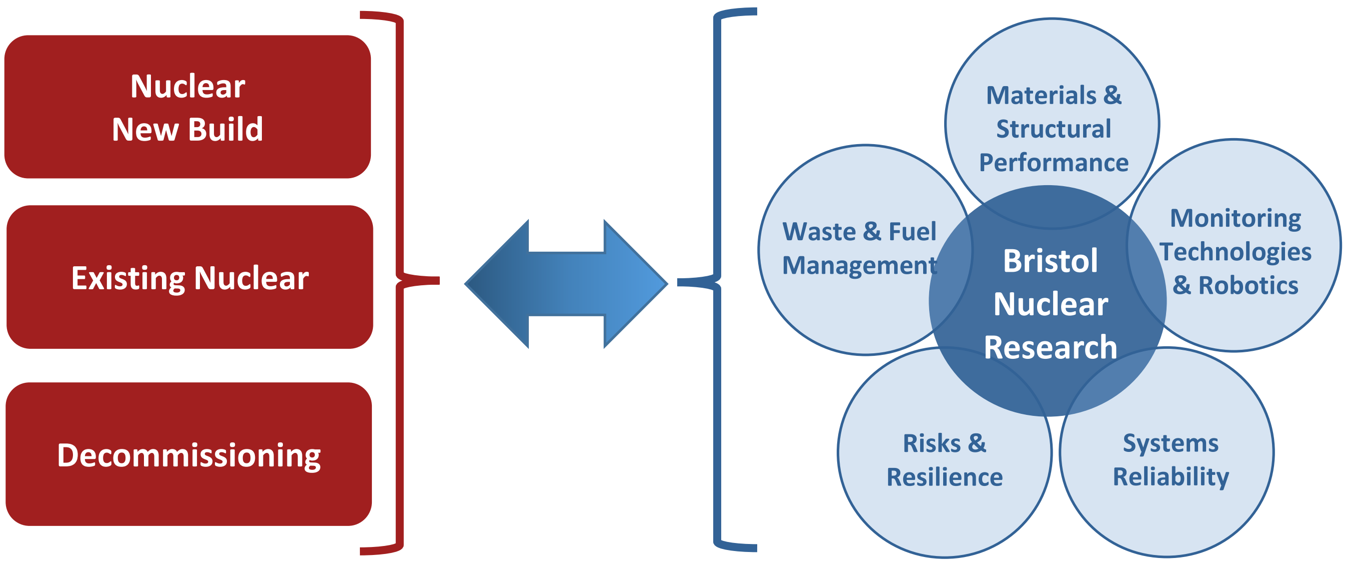
Hub Objectives:

- Establish a research and education Hub
- Integrate industrial participation with the Hub's research and teaching
- Expand nuclear energy related research activity
- Provide a Hub for nuclear energy related higher education, housing a cohort of nuclear students (MSc and PhD)

South West Nuclear Hub

Challenges

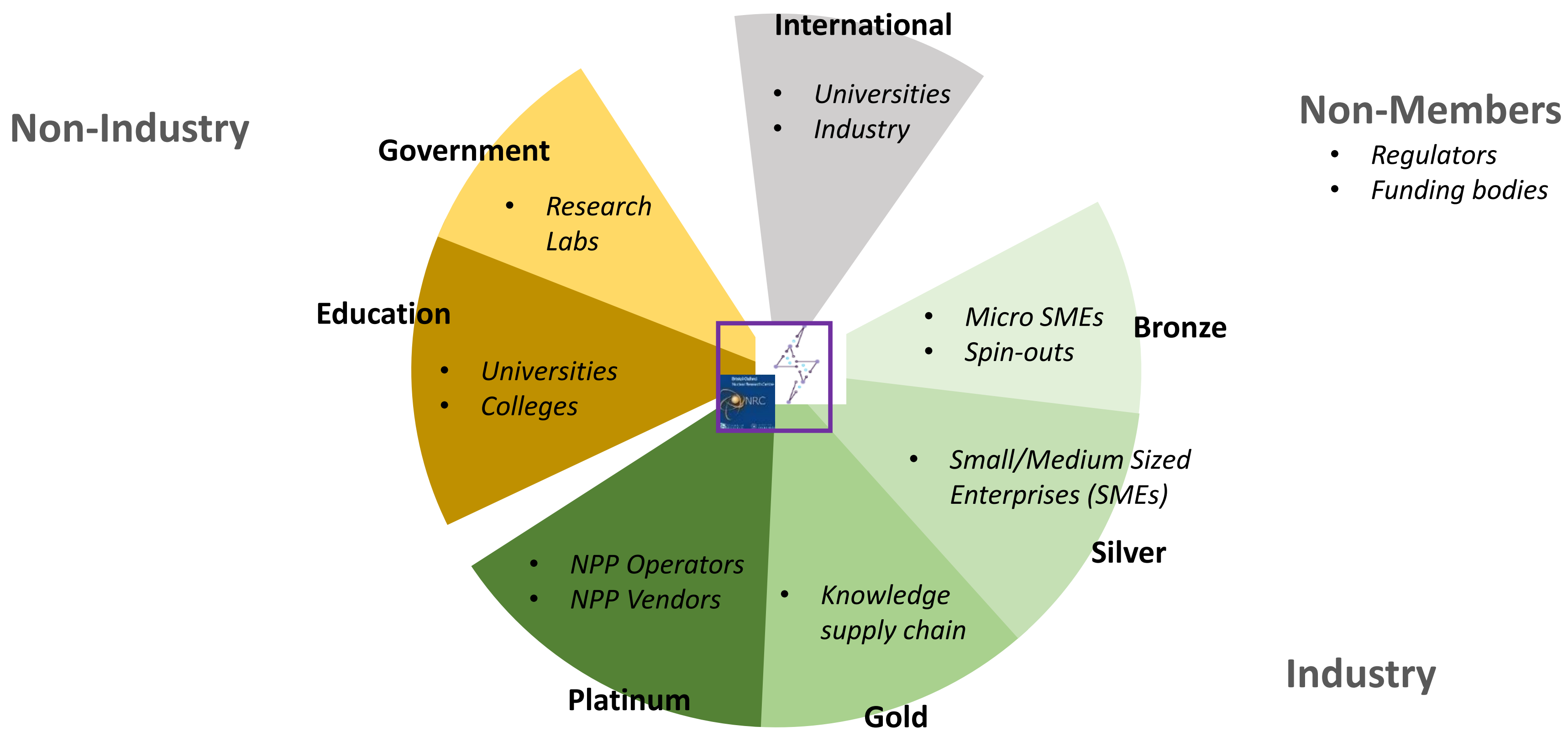
Bristol Research Themes



Nuclear Activities at Bristol

Bristol-Oxford Nuclear Research Centre	Cabot Institute	Safety Systems Research Centre
Earthquake Engineering Research Centre	**Umbrella Initiatives**	Advanced Computing Research Centre
Bristol Environmental Risk Research Centre	UK Research Centre in Non-Destructive-Evaluation	Bristol Robotics Laboratory

Membership and Network



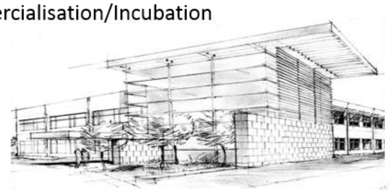
Locations

EDF, Horizon
Oldbury B
ONR, EA

<u>'NUCLEATE' Open Innovation and Technology Centre</u>

- Bigger space, large facilities and components
- Upscaling through the TRLs
- Commercialisation/Incubation

Bristol & Bath Science Park



M5

M4

University of Oxford
NNUF and CCFE, Culham
Hitachi

University of Cardiff

Bristol

<u>Interdisciplinary Nuclear Laboratories</u>

- Nationally leading facilities and expertise
- Fundamental Science and Engineering
- Long term, visionary research

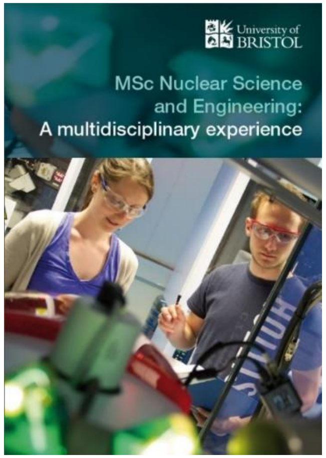
University of Bristol

NRC Bristol-Oxford Nuclear Research Centre

BristolTempleQuarter Enterprise Zone

- Digital and hi-tech sectors
- Commercial enterprise and creativity

Hinkley Point C
EDF Campus
NCfN – Bridgwater College



MSc Nuclear Science and Engineering

MSc cohort: 50/50 Science + Engineering;

- 2015: 4
- 2016: 8
- 2017: 20

Projects: industrially focussed, science and engineering academics provide supervision

Dr **Ross Springell**
(Physics)
- Specialist in actinide physics

Dr **Mahmoud Mostafavi**
(Engineering)
- Specialist in structural integrity

Next Steps

Discuss opportunities for collaboration:

- Science and Engineering Research
- Innovation
- Skills and Education

Membership of South West Nuclear Hub