Research Supporting Regulatory Guidance for New Technologies and New Materials

Contents

Introduction

In support of ONR Contract ONR378, Wood RSD has undertaken research into publically available guidance which could support the development of regulatory guidance on the introduction of new technologies and new materials in the nuclear industry. This report is a collation of the information gained from available data from both the nuclear industry and also high consequence industries where new materials and technologies have been, or may be introduced. The report is intended to provide non-technology specific, high level guidance relating to the introduction of new materials or new technologies into the nuclear industry.

Examples of Operational Experience have been provided to illustrate the impact of the introduction of new technologies and new materials. Regulatory guidance derived from this research will support the development of a draft ONR Technical Assessment Guide on the introduction of new technologies or new materials into the nuclear industry.

Proposed regulatory guidance is presented in tabular form following each document reviewed, or specific section. Guidance has either been drawn directly from source RGP, or has been inferred from the information available. Links to extant SAPs are also provided for context.

Examination of extant ONR guidance has been undertaken for applicability to new technologies or new materials, and summaries of the applicability of ONR Safety Assessment Principles, Technical Inspection Guides, Technical Assessment Guides and selected IAEA Guidance are presented at Appendices A and B, respectively. This report does not seek to replicate the specific guidance available to ONR Inspectors, such as that available in TAG16, Integrity of Metal Structures, Systems and Components, which considers both existing and new metallic components for use in nuclear power plants. Similarly, the report does not attempt to replicate TAG5, Guidance on the Demonstration of ALARP.

Regulatory themes are summarised in concluding remarks, and form the basis for a draft ONR Technical Assessment Guide.

For the purposes of this report the terms ‘new’ and ‘novel’ are essentially synonymous. A new material or technology is considered to be of a kind never before existing i.e. previously unknown, or is markedly different from what was before. Materials or technologies which are minor evolutions from previously used materials or technologies or were manufactured using minor changes to processes could be considered modifications to existing materials, and thus not new.

Abbreviations

AA	Adaptive Automation
ALARP	As Low As Reasonably Practicable
ASME	American Society of Mechanical Engineers
ASR	Alkali Silica Reaction
AGR	Advanced Gas Cooled Reactor
BNL	Brooklyn National Laboratory
CANDU	Canada Deuterium Uranium
C & I	Control and Instrumentation
CNSC	Canada Nuclear Safety Regulator
COTS	Commercial Off The Shelf
CPS	Computerised Procedure System
DAC	Design Acceptance Certificate
DECC	Department for Economic and Climate Change
EB	Electron Beam (Welding)
EERA	European Energy Research Alliance
EPMA	European Powder Metallurgy Association
EPRI	Electric Power Research Institute
GDA	Generic Design Assessment
GFR	Gas Cooled Fast Reactor
GTAW	Gas Tungsten Arc Welding
HAZ	Heat Affected Zone
HEP	Human Error Probability
HFE	Human Factors Engineering
HIP	Hot Isostatic Pressing
HMI	Human Machine Interface
HPC	High Performance Concrete
HRA	Human Reliability Analysis
HRP	Halden Research Project
HIS	Human System Interface
HTSE	High Temperature Steam Electrolysis
HVFAC	High Volume Fly Ash Concrete
IAEA	International Atomic Energy Agency

IFE	Institutt fur Energiteknikk
ILW	Intermediate Level Waste
INES	International Nuclear Event Scale
INL	Idaho National Laboratory
ITER	International Thermonuclear Fast Reactor (as originally defined)
LB	Laser Beam (Welding)
LFE	Learning From Experience
LFR	Lead Fast Reactor
LMFR	Liquid Metal Fast Reactor
LOA	Level of Automation
LVFAC	Low Volume Fly Ash Concrete
LWRS	Light Water Reactor Sustainability
NESCC	Nuclear Energy Standards Collaboration
NG	Narrow Gap
NNUMAN	New Nuclear Manufacturing
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission (US)
OLM	On-Line Monitoring
ONR	Office for Nuclear Regulation
OPEX	Operational Experience
PHWR	Pressurised Heavy Water Reactor
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Assessment
PSF	Performance Shaping Factor
RAIN	Robotics and Artificial Intelligence in Nuclear
RBNK	Reaktor Bolshoy Moshchnosti Kanalnyy (High Power Channel-type Reactor)
RGP	Relevant Good Practice
RPV	Reactor Pressure Vessel
RSD	Regulatory Support Directorate
SAP	Safety Assessment Principle
SAW	Submerged Arc Welding
SCC	Stress Corrosion Cracking
SCC	Self Compacting Concrete
SCM	Supplementary Cementitious Materials

SETP	Strategic Energy Technology Plan
SFR	Sodium Fast Reactor
SIC	Silicon Carbide
SMR	Small Modular Reactor
SWCR	Supercritical Water Cooled Reactors
TIG	Tungsten Inert Gas
TAG	Technical Assessment Guide
TRISO	Tristructural-isotropic micro fuel
TRL	Technology Readiness Level
UNGG	Uranium Naturel Graphite Gaz
VHTR	Very High Temperature Reactor

Review of Selected IAEA Technical Papers

1. IAEA TECDOC-1654 Advanced Fuel Pellet Materials and Fuel Rod Design for Water Cooled Reactors

TECDOC-1654, Advanced Fuel Pellet Materials and Fuel Rod Design for Water Cooled Reactors (Reference 1) is the proceedings of a 2009 Conference on the subject of advanced fuel pellet materials and fuel rod design for water cooled reactors. The subject matter of the paper suggested that there could be information on the future implementation of novel materials and technologies pertinent to fuel rod design. The proceedings focussed on different approaches to studying different fuel designs, and discussed post manufacturing microstructural examinations, laboratory studies examining the thermal and corrosion properties of candidate fuel element materials, predictive modelling of proposed fuel designs, criticality analysis, both theoretical and experimental, and tests in both research and operating reactors.

A process was described for the development of a fuel irradiation experiment within the Halden research reactor for thorium based fuels, and provided a number of applicable principles which could be applied to a prototype or demonstration reactor containing a new fuel and/or core design. The described process covered objective setting, defining the fuel behaviours that require characterisation, establishing measurable parameters and test pellet properties, and finally developing an experiment execution plan.

Suggested Regulatory Guidance	Related SAP Clauses
A safety case for the introduction of new fuels, fuel manufacturing techniques or operating parameters should ideally combine a mixture of all of these methods outlined above to demonstrate their safety. In addition a safety case that indicates the safety of any experimental tests, an appropriate commissioning programme and an argument that failure of these elements would not lead to significant core damage and/or release of radioactivity or increased exposure to operators should also be produced.	ERC.1, ERC.3, ERC.4, EHT.1, EKP.1-5

2. IAEA TECDOC-1865 Reliability of Advanced High Power, Extended Burnup Pressurised Heavy Water Reactor Fuels

TECDOC-1865, Reliability of Advanced High Power, Extended Burnup Pressurised Heavy Water Reactor (PHWR) Fuels, (Reference 2) is a review of a coordinated research project undertaken to review the current level of understanding of the impact of extended fuel burnup in terms of safety and operational margins for pressurised heavy water reactors. The majority of research focussed on the predictive modelling of fuel concepts, different core configurations and differing burnup conditions. Experimental data from irradiation experiments were reported, with generated data used to support code development.

Whilst the research described was focussed on PHWR fuel concepts, there is considerable read across to other reactor designs in terms of the extent of experimental data available under representative conditions to support the fuel design, the fidelity of fuel modelling under varying neutron flux conditions through life, the quantification of code uncertainty and associated level of code validation.

Suggested Regulatory Guidance	Related SAP Clauses
A safety case should be made for any new fuel design or change of operating parameters to existing fuel. This safety case should draw upon (where applicable) modelling and testing in existing or prototype reactors. Computational models should be sufficiently validated against representative experimental data. Fuel irradiated for experimental purposes should be withdrawn early for PIE work to be conducted to forewarn of any incipient failure that could occur at an increased burn up.	ERC.1, ERC.3, ERC.4,EHT.1, AV.1-8, EMT.1-8, EKP.1-5

3. IAEA Nuclear Energy Series NF-T-4.9 Enhancing Benefits of Nuclear Energy Technology Innovation through Cooperation among Countries – Final Report of the INPRO Collaborative Project SYNERGIES

Nuclear Energy Series, NF-T-4.9, Enhancing Benefits of Nuclear Energy Technology Innovation through Cooperation among Countries, (Reference 3) is a summary of a collaborative project across Member States to examine the benefits of international collaboration. The report emphasises the potential benefits to be gained if commercial reactor vendors would be prepared to increase collaboration for mutual benefit. Any collaborative efforts in this arena would be subject to a level of regulatory scrutiny proportionate to the magnitude, complexity, and potential safety significance of the project. The report suggests that in such collaborative instances, it may be of benefit for national regulators to also collaborate.

The SYNERGIES final report also indicates the issues that may be involved through the introduction of new materials. Previous IAEA comments in this area have focussed upon the structural integrity aspects of new materials but this report highlights other aspects that may need to be considered (as well as novel degradation mechanisms primarily through irradiation) i.e. ease of manufacture, compatibility with other materials, effects of dimensional distortion that may occur (a classic example of this being graphite in AGR cores), and potential waste management issues.

Suggested Regulatory Guidance	Related SAP Clauses
In instances where the regulator feels the need to gain additional confirmation to obtain confidence in a safety case, e.g. by experiments on materials or by software verification it may be useful to consider collaborating with other regulators in undertaking this work.	ECS.2-5
The introduction of new materials may involve other issues than just a consideration of structural degradation properties. The performance of the material from initial component manufacture through to final waste management and disposal should to be considered.	ECS.2-5 EAD.1-5

4. IAEA-TECDOC-1852 Dissimilar Metal Weld Inspection, Monitoring and Repair Approaches

TECDOC-1852, Dissimilar Metal Weld Inspection, Monitoring and Repair Approaches, (Reference 4) is a summary of good practices aimed at NPP operators, and is based upon the operating experiences and case studies provided by study participants. The report focuses on the requirements for an in-service inspection programme, various inspection methods and techniques, and specific challenges for the ultrasonic inspection of dissimilar metal welds, and the detection of stress corrosion cracking.

Whilst focussed on a review of existing dissimilar weld materials, the report does highlight the necessity of understanding how ultrasonic waves propagate and interact with defects in materials in order to develop reliable ultrasonic testing techniques for the inspection of critical defects in inhomogeneous weld materials.

Suggested Regulatory Guidance	Related SAP Clauses
Novel materials should be shown to be compatible with other materials in the facility.	EQU.1, EHA.17, EMC.13-16, EMC.22
Operators should define the potential operating conditions that the novel material will be subjected to and will need to identify all potential degradation mechanisms of the novel materials.	EMC.21-23, EAD.1-5, EKP.2
Operators will also need to identify that suitable inspection/monitoring systems are available to detect any onset of degradation at a suitably early stage. Such inspection and monitoring systems should be shown to be suitable for the novel material. In many cases operators should consider a repair or replacement process in the event that the novel material does not behave as anticipated.	EMT.1-8, EMC.24-26

5. IAEA-TECDOC-1316 Effects of Radiation and Environmental Factors on the Durability of Materials in Spent Fuel Storage and Disposal

TECDOC-1316, Effects of Radiation and Environmental Factors on the Durability of Materials in Spent Fuel Storage and Disposal (Reference 5), is a review report considering the challenges surrounding extended storage of irradiated fuel assemblies, either under water, or in dry storage facilities. The combination of various fuel and cladding types, and facilities which are either ageing or approaching the end of design life, present challenges for both operators and regulators. The report highlights the necessity to understand the ageing and degradation for materials stored in wet or dry conditions. Understanding of the ageing and degradation of irradiated materials is hindered by the expense of conducting experiments, which hampers efforts to develop ageing models based upon quantitative data.

At the time of writing, dry storage techniques were in their infancy, with only a few examples of implementation. However, the report highlighted that the ageing properties of dry stored irradiated materials will be different to materials stored in pools, and as such direct read across between wet and dry stored materials is not necessarily possible.

Whilst not specifically focussed on new and novel materials and storage technologies, the report identified the key regulatory theme of ageing and degradation. Any use of any new or novel materials will require appropriate justification via the safety case, and attention should be drawn to the fact that post operational considerations i.e. storage and ease of disposal require thought. Additionally, the long time period associated with storage and disposal is likely to mean that only a limited data set will be available to support modelling and as such greater attention may be required in the areas of accelerated ageing, surveillance specimens, and appropriate inspection and monitoring.

Suggested Regulatory Guidance	Related SAP Clauses
Because of the long time periods associated with storage and disposal it is unlikely that novel materials will have the associated data to fully justify them for these periods. In such cases a range of approaches may be adopted to support the safety case.	RW.1-7, AV.1-8

6. IAEA Nuclear Energy Series NF-T-4.3 Structural Materials for Liquid Metal Cooled Fast Reactor Fuel Assemblies – Operational Behaviour

Nuclear Energy Series NF-T-4.3, Structural Materials for Liquid Metal Cooled Fast Reactor (LMFR) Fuel Assemblies – Operational Behaviour (Reference 6), is a review of the experiences from the development of fuel assembly cladding and structural materials during various national liquid metal cooled fast reactor programmes over the period 1950-1990. The report highlights that the lifetime of LMFR fuel assemblies was to a large degree limited by the structural changes of the assembly materials over time in the high temperature, high neutron flux environment, as well as the presence of a liquid metal coolant. The primary risk to fuel assemblies was determined to be failure of the fuel containment, which would release fuel or fission products into the coolant, with the primary potential cause of failure being changes to physical properties or dimensional changes of structural alloys resulting from prolonged exposure to the strenuous nuclear environment.

The report highlighted that lessons were learnt in structural materials choices after void swelling was discovered in UK fuel assembles, which resulted in a change of materials strategy by other nations researching LMFR technologies. This information highlights the difficulty in gaining experimental data in the absence of suitable research reactors. The report concluded that ion simulation procedures could provide some representative data (albeit under ion bombardment conditions, rather than neutron), but would also require the development of theoretical models to cover the expected range of materials changes under high burn-up conditions in the nuclear environment present in a LMFR.

Suggested Regulatory Guidance	Related SAP Clauses
Before introducing new materials and technologies it is important that the safety case identify the important safety parameters that the new material/technology must meet.	SC.3-7, ECS.2-5, EKP.1
Programmes for monitoring, inspection, sampling surveillance and testing of new materials and technologies, to detect and monitor ageing and degradation processes, should be used to verify assumptions and assess whether the safety margins will be adequate for the remaining life of the structure, system or component.	ECS.2-5, EMT.1-7, EAD.1-5

7. IAEA Nuclear Energy Series NP-T-2.11 Approaches for Overall Instrumentation and Control Architectures of Nuclear Power Plants

Nuclear Energy Series NP-T-2.11 Approaches for the Overall Instrumentation and Control Architectures of Nuclear Power Plants (Reference 7), is a review of how Control and Instrumentation (C&I) systems have developed over time, and the challenges arising from the advent of increasingly complex digital systems containing thousands, if not millions of lines of software, as well as programmable technologies. The report notes that previous analogue technologies were largely independent systems with human-system interfaces, and the concept of defence in depth was not fully defined, resulting in varying approaches. More modern systems are considered to have many advantages over older analogue systems, such as improved operational efficiency and improved equipment monitoring, as well as self-monitoring. However, challenges remain with digital C&I systems, such as uncertainties and differences in developing and licensing systems and equipment, the management of technical complexity which has arisen from enhancements in functionality, highly integrated architectures, widespread communications and flexible configurations.

The report raises the concern that there may come a time where the enhanced capabilities of digital systems may be compromised by the degree of complexity present within, which could undermine any safety function claimed.

Notwithstanding the above, the report describes the key features of a C&I system and how it should be designed and introduced. Design in depth, independence, categorisation of functions and classification of systems, security, integration and consistency with other plant systems, risks of overcomplexity, and protection from the environment were all considered key themes that should be considered.

Suggested Regulatory Guidance	Related SAP Clauses
For novel C&I systems there is an architecture of principles that should be adopted in designing the system.	ESR.1-10
For any novel technology, but especially for a novel C&I system, that is being introduced into an existing facility it is important that the novel technology be compatible with the existing technologies and systems on the facility.	EMT.3-4, ESR.1-10

8. IAEA TECDOC-1830 On-Line Monitoring of Instrumentation in Research Reactors

TECDOC-1830, On Line Monitoring of Instrumentation in Research Reactors (Reference 8) reports the outcomes of an IAEA coordinated research project on improved control and instrumentation maintenance techniques for research reactors with the intent of creating a baseline for the implementation of on-line monitoring (OLM) techniques and demonstrating their validity for improved maintenance practices in research reactors. The project highlighted that there are several advantages to OLM, e.g. instantaneous identification of problems and no need to obtain access to equipment. Despite the research reactor focus, the report highlighted the implementation of OLM in the Sizewell B nuclear power plant.

Two major problems have been identified for OLM, the need to address common mode drift, and the need to verify the system over the full range. Common mode drift was considered to be solvable either by the rotational use of redundant channels to verify system accuracy or the use of independent modelling. Full range system calibration verification was considered to be achievable if initial start-up, normal operating and shut down condition data were to be collected and used to identify calibration problems. Research reactors were felt to be more straightforward to verify due to the increased number of start-up and shut down cycles generally undertaken.

Suggested Regulatory Guidance	Related SAP Clauses
Novel methods of instrumentation need to ensure that there is no common mode fault and justified across the full operating range.	EDR.3, EMT.3, EMT.6-7, ECM.1
Structures, systems and components incorporating novel technologies should preferably be type tested before they are installed to conditions equal to, at least, the most onerous for which they are designed.	ECM.1, EMT.3, EKP.1
Where specific type testing is not possible or limited data available, enhanced commissioning testing and monitoring should be considered.	ECM.1, EMT.6-7

9. TECDOC-1622 Status and Trends of Nuclear Technologies

TECDOC-1622, Status and Trends of Nuclear Technologies (Reference 9) is a review of the broad state of the worldwide nuclear industry as of 2009, and provides commentary on some of the new technologies under consideration for future new nuclear reactors. The review discusses the Gen IV International Forum, who have reviewed a number of technologies such as the gas cooled fast reactor, sodium cooled fast reactor, lead cooled fast reactor, molten salt reactor, superheated water cooled reactor and very high temperature reactor. Advanced fuels such as DUPIC (Direct Use of Spent PWR fuel in CANDU reactors), thorium coated particles, reduced moderator light water reactors, the advanced fuel cycle initiative, prismatic uranium oxide fuel, and U and Pu nitrides as fuels were discussed. All were thought to have potential advantages, but all have drawbacks of one form or another when compared to fuels in use today.

Whilst a somewhat dated, high level review, the paper does allow for the derivation of regulatory themes along the lines of materials compatibility, ageing and degradation, generation of waste, physics properties, thermal properties, handling and storage.

Suggested Regulatory Guidance	Related SAP Clauses
Novel or new materials should be demonstrated to be compatible with existing materials under operational conditions through life.	EMT.3-4, EAD1-5
The safe working life of structures, systems and components containing new materials that are important to safety should be evaluated and defined at the design stage.	EAD.1
Adequate margins should exist throughout the life of a facility to allow for the effects of materials ageing and degradation processes on structures, systems and components containing new materials.	EAD.2
The generation of radioactive waste from new materials should be prevented or, where this is not reasonably practicable, minimised in terms of quantity and activity.	RW.1-7
Waste generated from the introduction of new materials should be compatible with existing waste treatment or disposal systems, or subject to a new waste treatment process justified in a safety case.	RW.5

Suggested Regulatory Guidance	Related SAP Clauses
The ageing and degradation properties of new materials should be understood throughout life. This should include physical, mechanical, chemical and thermal properties.	EAD.1-5

10. TECDOC–1851 Integrated Approach to Safety Classification of Mechanical Components for Fusion Applications

TECDOC 1851, Integrated Approach to Safety Classification of Mechanical Components for Fusion Applications (Reference 10) is a compilation of work conducted by experts in the field of fusion research to provide guidance on the safety classification of mechanical components. The report focusses on magnetic confinement fusion applications i.e. tokamaks, but considered that the underlying principles would also apply to inertial and magnetic fusions devices.

The document illustrates the differences in classifying mechanical components in fusion reactors, and highlights the issues relating to safety classification. The report concluded that the basic principles described in SSG-30 remain applicable, but that there are some important differences between fission and fusion applications, and additionally there are a number of areas for which data are lacking e.g. material properties for structural materials under fusion irradiation conditions (14MeV neutrons).

Suggested Regulatory Guidance	Related SAP Clauses
Novel materials should be demonstrated to be compatible with existing materials under operational conditions through life.	EMT.3-4, EAD.1-5
The safe working life of structures, systems and components containing new materials that are important to safety should be evaluated and defined at the design stage.	EAD.1
Adequate margins should exist throughout the life of a facility to allow for the effects of materials ageing and degradation processes on structures, systems and components containing new materials.	EAD.2
Novel materials should be characterised under representative operating conditions wherever possible.	EMT.3-4

11. IAEA TECDOC-1545 Characterisation and Testing of Materials for Nuclear Reactors

TECDOC 1545, Characterisation and Testing of Materials for Nuclear Reactors (Reference 11), is the proceedings of a Technical Meeting, and amongst other things, reviews how materials development programmes will play a major role in the design and development of new nuclear power plant, as well as life extension and development of fusion plants. The report notes that there have been advancements to materials over time, as well as characterisation techniques and technologies. Clearly of interest are new fuel types, which will require extensive characterisation before introduction into service.

The TECDOC gives quite a number of examples of technologies available to characterise nuclear materials, such as neutron beam experiments. However, it may not be possible to test new and novel materials in conditions completely representative of the final reactor design. Research reactors can provide near neighbour conditions, from which much data can be gained. The report also considers that there may be a requirement for a specialised facility to generate data. The report discusses the general suite of characterisation techniques available at the time of writing, and also considers some of the newer techniques under development, some of which can provide a degree of in-situ analysis. The report highlights that all techniques are limited by the quality of data gained. If poor data are gained, then only limited confidence can be derived from the technique, and therefore more data may/will be required to support the development and understanding of the material.

The effect of neutron flux on materials over time is considered to be of high importance. There are the possibilities of hydrogen embrittlement, swelling, irradiation induced creep, corrosion, changes to fracture toughness, void swelling, fatigue or microstructural changes. All these things can limit materials' lifetime, or suitability for use in a nuclear reactor.

The report contains a discussion on the fact that information gained on the use of graphite in historical reactors is actually of limited value for future designs because graphite sources have changed, as well as processing techniques, which highlights the dangers of reliance on historical data without understanding the conditions under which the data was gained.

Suggested Regulatory Guidance	Related SAP Clauses
New materials should be fully characterised under conditions representative to those which the materials will experience.	EMT.3-4, EKP.1
Novel technologies used to characterise materials should be verified and validated, and their limitations understood.	AV.1-8
Materials manufactured using alternative processes or using new sources of precursor materials should be fully characterised to ensure that materials properties are comparable to originally manufactured materials.	EQU.1, ERL.1, EMT.8
In the absence of research reactors being available it is likely that prototype reactors will need to carry out many of the functions that would normally be carried out by research reactors. This may involve: • More extensive commissioning programmes than will be required for later facilities, • More extensive instrumentation • The ability of the prototype reactor to demonstrate safety outside of its normal operating regime.	ECM.1, ESR.1-10, FA.1-25, SC.1-8
Parties who wish to introduce new materials and technologies (and regulators that assess them) should recognise the important role that PIE can play in providing additional safety justification and ensure that this is properly incorporated (where available) in novel material and technology safety cases.	EMC.1-34

12. TECDOC 1790 Processing of Irradiated Graphite to meet Acceptance Criteria for Waste Disposal

TECDOC 1790, Processing of Irradiated Graphite to meet Acceptance Criteria for Waste Disposal (Reference 12), is a review of a coordinated research project. The document reviews how to deal with irradiated-graphite from power and research reactors. The report also considers the formation of radionuclides such as ^{14}C in graphite, as well as other isotopes such as ^{36}Cl as side effects from the graphite manufacturing process and intercalated into the matrix. The report also considered that graphite essentially self assembles during the high temperature processing of mined graphite.

The review discusses the effects of fast and slow neutron irradiation. e.g. <250°C and the generation of Wigner Energy, release of which was responsible for the Windscale fire in 1957, and is linked to the generation of strain in the lattice, which if uncontrollably released results in rapid increases in temperature. Second order interactions with cooling gas and ionizing radiation are considered (beta, gamma), which can lead to the formation of species which can oxidise graphite to form CO and CO_2, with corresponding weight loss and the potential for the reduction of structural strength, and potential implications for the handling or disassembly of weakened irradiated graphite.

The report concludes that the actual characteristics of irradiated graphite will very much depend on the specific reactor type, as well as the through life operating conditions. For example, ^{14}C formation in Russian RBMK reactors from the He/N coolant via the $^{14}N(n,p)^{14}C$ reaction has been observed, as well as the unexpected formation for the new compound paracyanogen $(C_2N_2)_n$ with essentially all carbon atoms being ^{14}C. This has also been observed in CANDU reactors. It is noted that ^{14}C on the surface of irradiated graphite presents handling issues. Additionally, the composite nature of novel fuels such as tristructural-isotropic (TRISO) could be problematic in terms of handling post irradiation.

Future high temperature reactors are giving thought to the gas coolant. Helium would solve the problem of graphite oxidation, but consideration would have to be given to the fact that impurities in fuel material could still lead to graphitic oxidation.

There is also a choice of technologies for dismantlement. France chose to dismantle the Uranium Naturel Graphite Gaz (UNGG) reactors under water to provide radiological shielding, but this resulted in isotopic leeching into the water shield and greater ILW to deal with. The UK decided to disassemble Magnox designs in air, and is giving consideration to the future dismantlement of the AGR fleet in the same manner.

Suggested Regulatory Guidance	Related SAP Clauses
The behaviour of new or novel materials in a neutron flux should be sufficiently understood to accurately predict material response through life.	EMT.3-4, EKP.1
New and novel materials should be tested in conditions sufficiently close to operational conditions to provide accurate data.	EMT.3-4, EKP.1
Ageing and degradation mechanisms of new or novel materials should be fully understood over the projected operational lifetime of the material or facility.	EAD.1-5
Disassembly aspects of new material containing facilities should be considered before introduction, including long term environmental impact and waste management requirements.	DC.1

Suggested Regulatory Guidance	Related SAP Clauses
The risk of radionuclide leech into the environment during operation and long term post irradiation storage should be assessed and minimised.	RW.1-7, RL.1

13. TECDOC-1701 The Behaviours of Cementitious Materials in Long Term Storage and Disposal of Radioactive Waste

TECDOC 1701, the Behaviours of Cementitious Materials in Long Term Storage and Disposal of Radioactive Waste (Reference 13) is the final report of an IAEA coordinated research project between member states, and reviews the aspects of cement technology pertinent to the nuclear industry, particularly in the area of long term storage. The report highlights the extensive use of cementitious materials (concrete, mortar etc.) as a containment matrix for waste immobilisation due to their advantages including durability and low permeability when cured. Research into the field has considered a variety of forms and backfills, as well as the interactions between waste forms and containment materials over time, and thus is considered a relatively mature technology. However, given the timescales projected for the long term storage of radioactive waste there is a requirement to understand the ageing and degradation mechanisms of cementitious materials, as well as the potential for synergistic effects or unexpected consequences, and the long term storage environment.

Conventional cementitious systems are well known and are often used, (-with tailoring) for specific applications e.g. aggregates (particulate fillers) are added to bulk material and control rate of heating and shrinkage. Admixtures can be added (chemicals added to control properties of cementation fluid state), blending materials are available (inorganics added to contribute to matrix formation). Finally, radionuclide sorbers can be added to assist binding of selected nuclides e.g. zeolites, bentolite and vermiculite.

Cement waste products are complex, and their production is dependent on many variables such as form of waste, water to cement ratio, waste to cement ration, Admixtures (type, content), Admixture to cement ration, type of cement, order of mixing, emplacement and curing. Improvements to materials have been made, largely through sorbers to improve radionuclide uptake. There remain challenges, with contaminated organic waste an issue due to the general immiscibility of organic chemicals and water, which likely precludes direct cementation. There have been successes, however, on the absorption of organic waste onto polymer systems, which can then be immobilised into cement. Zeolites have also been used to reduce the levels of leeching from cements.

Conventional cements have limitations. High pH and intolerance to certain waste types has prompted research into novel cement formulations. Research continues, and some positive results have been forthcoming. However, a significant drawback to date is the lack of nuclear data relating to cements, and little if any long term data to support ageing and degradation models. Radiological release and environmental leech data are also lacking at present.

The report notes that short term characterisation results should only be used as a guideline for waste form development and durability predictions, with empirical extrapolation only suitable over short time frames in the absence of kinetic data. As such, there is a need to understand composition variables and exposure scenarios, as well as the changing conditions over time and potential changes to durability. Development of predictive models is of key importance, but requires a fundamental understanding of the various processes ongoing in ageing cements.

Suggested Regulatory Guidance	Related SAP Clauses
Development or process optimisation of new materials should be demonstrated at both laboratory and plant scale to demonstrate understanding of material properties.	ECS.5, EQU.1
The impact of additives on the performance of new materials should be understood through life.	ECS.5, EQU.1, EAD.1-5
Limitations in the deployment of new or novel materials should be understood prior to deployment.	SC.3-4, ECM.1, EKP.1
Ageing and degradation mechanisms of new or novel materials should be fully understood over the projected operational lifetime of the material or facility.	EAD.1-5
The long term storage properties of materials should be understood with regard to potential failure of encapsulation or containment.	EAD.1-5, RW.5
Shortfalls in data supporting the introduction of new materials may require corresponding enhancements to commissioning, monitoring and surveillance programmes to provide the required substantiation.	ECM.1, EMT.6-7

14. TECDOC 1869 Status of Research and Technology Development for Supercritical Water Cooled Reactors

TECDOC 1869, Status of Research and Technology Development for Supercritical Water Cooled Reactors (Reference 14) reviews the current interest in innovative water cooled reactors and supercritical water-cooled reactors, and the research focussing on three main areas, thermohydraulics, materials and chemistry.

Supercritical Water Cooled Reactors (SWCR) are designed to operate with high thermal efficiency and also exploit the physical properties of supercritical water, removing the problem of localised boiling at the fuel-coolant interface, eliminating voids under normal conditions. The technology can be utilised as a normal reactor, but can also be configured as a fast neutron reactor, or actinide burner.

Operating temperature and pressure is higher than conventional water cooled reactors through the requirement to keep the water in the supercritical state. Therefore accurate understanding of thermal hydraulics response, and its prediction is of high importance. Due to temperatures and pressures involved within SCWR designs, choice of materials is very important, as well as the water chemistry strategy.

Designs under consideration within Europe and Asia have slightly different safety philosophies e.g. a Japanese design wishes to employ proven mature technologies where possible e.g. negative void coefficient and Doppler Effect using established light water reactor technologies. A Russian design under consideration can be run as a single or double pass design without moderator present, but uses a burnable poison.

Thermal hydraulics becomes very important for SCWR as the properties of water change significantly from the sub-critical state to the supercritical state. These differences are of such importance that the international community have spent the last 15 years trying to characterise supercritical water and fuel systems but there remains a lack of thermal hydraulics data e.g. heat transfer data, so characterisation remains a significant challenge.

Materials selection and water chemistry are also important in SCWR designs. Materials selection for SCWR remains a challenge due to high temperatures, which in general rules out commonly used alloys e.g.

zirconium alloys as fuel cladding have insufficient strength at temps >500°C and low corrosion resistance >400°C.

Three strategies for SCWR materials are under consideration, use of existing materials, modify existing materials to mitigate known weaknesses, or develop new materials. Using existing materials is the low risk option as they are a known quantity, but the materials choice may not be suitable for the application. Modification of materials might involve changes to surfaces to improve characteristics. Modifications will generally be much quicker and straightforward than developing a new material, but may not meet the required mechanical or chemical characteristics. Finally, development of a new material is a possibility, but comes at the highest cost in terms of time and resource, with no guarantee of success, and also the least amount of understanding through the predicted lifetime. It may be possible to read across some data from PWR operations, but the differences in operating conditions means that such data should only form a subset of a wider data set, and not the sole source of evidence supporting SCWR operation.

Materials properties that need to be considered are corrosion, oxide thickness, stress corrosion cracking, irradiation assisted stress corrosion cracking, creep, void swelling, ductility and strength. However, testing of candidate materials in representative conditions including irradiation or high pressure remains a challenge. E.g. autoclaves generally can't support very high water flow rates.

Currently no candidate material has sufficient properties to resist general corrosion and SCC for fuel claddings of SCWRs. RPV materials are also proving challenging; even though temperatures are lower, data are not proven for SCC.

Irradiation levels are anticipated to be similar to existing water cooled reactors, and the elevated temperatures might actually help thermally induced annealing of radiation induced defects or voids. Many alloys of interest have been irradiated under similar temperatures in fast neutron reactors, which will provide a degree of data supporting future materials choices.

Modifications to materials are under consideration, with surface coatings or shot peening found to have been used to enhance oxidation resistance through cold working of the surface. Chemical Vapour Deposition and physical vapour deposition are also promising, with surfaces coated in a homogenous boundary layer. There have been promising results at high temperatures, but there are concerns over coating adhesion over time under cyclic temperature conditions.

Materials degradation modelling is undertaken to be able to extrapolate materials performance under SCW conditions for full fuel cycle which is approximately. 3.5 years. Models exist, but validation is necessary e.g. to determine the kinetics of oxide growth and layer restructuring. There has been a 10 year programme at VTT in Finland to develop such a model.

Water chemistry experience from fossil fuel supercritical water plants can be translated into the SCWR domain, but the aim for SCWR is slightly different in that corrosion minimisation in the primary circuit is key. Irradiation of water leads to the formation of hydrogen, oxygen and hydrogen peroxide, potentially oxidative conditions. The concern is the behaviour of chromium under oxidation, especially as passive films on all candidate alloys are chromium containing oxides.

Transport of corrosion products and impurities from and into the core is important and knowledge of such is a major gap in knowledge of SCWR technology. The magnitude of the problem of crud build up is not known under irradiation and therefore the deposition of radioactivity in the system over time remains uncertain.

Safety system R&D is based upon Water Cooled Reactor safety systems, but the two and three pass systems need attention, as refilling/reflooding of the core is potentially delayed. The feed water is also the cooling water, so loss of feed water is a problem. Integrated tests are required to validate system codes to confirm the effectiveness of safety devices and systems before a prototype can be built.

System start up processes and procedures need to be developed to bring the fluid to supercritical, and it is inevitable that the core will dry out during the process, the impact of which needs to be understood.

Suggested Regulatory Guidance	Related SAP Clauses
New and novel materials should be tested in conditions sufficiently close to operational conditions to provide accurate data.	EMT.3-4
The behaviour of new or novel materials in a neutron flux should be sufficiently understood to accurately predict material response through life.	EMT.3-4

15. IAEA Nuclear Engineering Series NW-T-2.10 Decommissioning after a Nuclear Accident: Approaches, Techniques, Practices and Implementation Considerations

IAEA Nuclear Engineering Series NW-T-2.10, Decommissioning after a Nuclear Accident: Approaches, Techniques, Practices and Implementation Considerations (Reference 15) is a review paper covering aspects of non-routine decommissioning required under such circumstances such as post-accident (INES Scale 4-7), as opposed to an incident, which may not result in decommissioning of the facility. The paper also discusses the policy and strategy aspects of such an accident scenario e.g. maintaining sub-criticality, decay heat removal and maintaining containment through the use of physical barriers. The review reflects the fact that post-accident decommissioning is demanding, will require significant extra resources to cover unexpected expenses, and the probability that the prioritisation of resources will be necessary.

Historically, no two nuclear accidents have been identical, and as such it is possible that technologies of many forms will be required to assist in decommissioning. Consideration should to be given to the value of adapting existing technologies, when compared to the time and cost of developing a new, bespoke technology to fulfil a specific decommissioning requirement. Recovery activities post Chernobyl and Three Mile Island adapted existing technologies, and these were reported as being highly effective in capturing on site data.

If adaptation is not effective or possible, specific research and development activities may be required. However, any new technologies developed should be sufficiently tested and commissioned, and operators trained in its use. LFE from other operators who have introduced similar technologies may also be beneficial, and should be considered where appropriate. Should unproven or innovative technologies be required to expedite progress in a particular scenario e.g. robotics for hazardous environments, then sufficient understanding and proof testing of the technology should be demonstrated prior to use in an operational capacity, and appropriate levels of caution applied.

The report posed the question as to whether worker/operator health and safety could be negatively impacted by the introduction of new technologies, but also positively, could new technologies actually help worker safety, examples including lead blankets to reduce worker dose and ice cooled garments for workers in hot working environments. It was recognised that technological solutions will be scenario dependant e.g. Chernobyl ‘sarcophagus’ followed by New Safe Containment, and the Underground Frozen Wall at Fukushima Daiichi

The review highlighted that new technologies may be required to provide protection from exposure to high dose rates, airborne radioactivity, noxious atmospheres, high temperature as well as other physical, chemical or environmental conditions which could limit or prevent human access. Additionally, human factors including accessibility, narrow spaces, underwater operations, lack of visibility and heavy loads were highlighted as elements which should be considered when new technologies are considered for post-accident recovery conditions.

Severe post-accident conditions may need substantially more technical solutions, and trade-offs in technology will depend on the specific situation and any adaptation required or possible, when compared to the generation of additional waste forms from the introduction of new technologies.

The potential danger of over complexity was noted with regard to new technologies, as this could result in lower than required reliability when compared to existing technologies. New technologies will require a user friendly man-machine interface, and comprehensive documentation to train operators. New technologies must be capable of being decontaminated, which will require careful consideration with regard to the physical design of any technology introduced into a contaminated area. For long term application of new technologies there will be a requirement for spare parts through life, which potentially could be tens of years.

Robotics have advanced massively in scope and ability since Windscale, Three Mile Island (TMI) and Chernobyl, and, and have taken information from high hazard or consequence industry e.g. chemical industry or aerospace.

Characterisation of new technologies is critical to successful deployment. Demonstration of reliable performance is needed as well as operator training, both generically and for specific tasks. Operators must understand the specific requirement for the technology under consideration, its role, and the environment it will experience.

Examples of utilisation of new and innovative technologies were described by the report, and give an indication of how technologies have been introduced over time in long term decommissioning projects e.g. Windscale and Three Mile Island. In the case of Windscale, improvements in scanning technologies has facilitated 3D reconstruction of the current condition of the Pile, and this alongside improvements in remote controlled cranes has allowed for the movement of fuel and rubble. Small submersibles have been developed to investigate the condition of flooded reactors post-accident, as well as 'swimming' submersibles and long arm grabbers which can be inserted via narrow ports. However, as mentioned previously, new technologies should be radiation tolerant to maximise operational life.

For long term fuel recovery and storage, High Integrity Containers – designed to be equivalent to encapsulation and to avoid the risks to personnel from solidification activities have been deployed at TMI and Fukushima, and are considered to be an alternative for long term disposal.

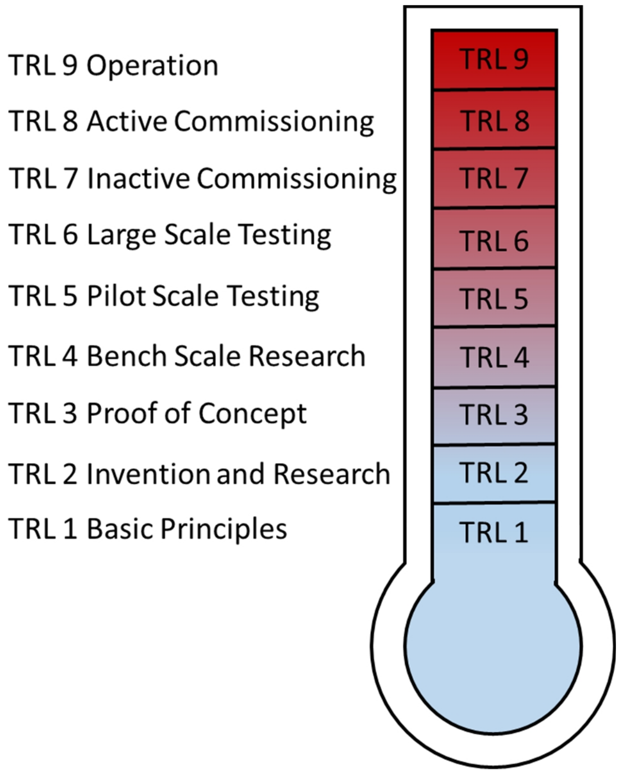
Suggested Regulatory Guidance	Related SAP Clauses
New technologies should be tolerant of the environment which they will see through life.	EQU.1, ECM.1, EMT.3-4, EKP.1
New technologies should be designed for decontamination if used in a contaminated environment.	DC.1, RP.4-5
The behaviour of new or novel materials in a neutron flux should be sufficiently understood to accurately predict material response through life.	EMT.3-4, EAD.1-5
Limitations in the deployment of new or novel materials should be understood prior to deployment.	ECM.1, EMT.3
The performance of a new material or technology under fault conditions should be understood.	EMT.3, EMT.8, RP.2, FA.1

Suggested Regulatory Guidance	Related SAP Clauses
New technologies should be designed with the user in mind, and should contain a workable user human machine interface, as well as allow for effective user training.	EHF.1-12
The risks and benefits of introducing new technologies should be considered against the risks and benefits of either using or adapting existing technologies.	FP.1-8, SC.1-8, EKP.1-5

Guidance on the use of Technology Readiness Levels

The concept of Technology Readiness Levels (TRLs) was proposed in the 1970s by NASA as a means of determining whether a technology was sufficiently mature to be used in space flight. The TRL scale was formally adopted for use in NASA projects in the late 1980s and the nine level scale of increasing demonstration of technical maturity has been adopted in many other industries, including the civil nuclear industry. The Nuclear Decommissioning Authority has published guidance on TRLs for use in civil nuclear decommissioning programmes (Reference 16).

The nine level scale begins at TRL1, in which the basic principles of a technology are proposed and observed. During TRL2 further research is conducted, which then may allow TRL3, proof of concept of key characteristics to be completed and demonstrated. Bench scale research at the component level in the laboratory is demonstrated during TRL4, with representative environment testing of components demonstrated at TRL5. System level demonstration is demonstrated at TRL6 in a representative environment. In the civil nuclear arena, inactive commissioning of a system would be demonstrated at TRL7, with active commissioning demonstrated at TRL8. Finally, at TRL9 the system is operational.



There are no fixed definitions for TRLs, with bespoke conditions for each TRL often required depending on the specific technology in question. Additionally, application of the TRL model does not necessarily guarantee that a technology will successfully be developed from initial concepts to operation. However, the staged nature of the TRL model does promote a systematic development programme, with technologies demonstrated in increasingly complex and representative environments.

General Guidance Relating to Nuclear Waste Packages

The transport of nuclear fuel and waste packages may involve movements from one country to another. The IAEA ensures that these packages are safe by specifying the methods by which these packages should be shown to be safe (in Requirements SSR-6 and through Guidance SSG-26). It is then up to the specific national regulators to ensure that these prescriptive requirements are met.

As a consequence of this approach it should be relatively straight forward for new technologies to be introduced as long as data can be produced to show that the package meets the overall requirements defined in SSR-6 (this is actually a gross simplification as the requirements do require more than just a "tick box" approach, e.g. potential degradation mechanisms need to be identified and the packages justified that these mechanisms do not affect safety).

How IAEA requirements, e.g. in terms of impact resistance, temperature resistance etc., are derived is less clear, but generally have been derived from the worst case scenarios relating to road/rail/aircraft accident and subsequent fuel fire. However this prescriptive approach differs significantly from the goal setting regulatory approach used more generally in nuclear safety in the UK.

There are matters of principle that can be derived for the introduction of new materials, technologies etc. to nuclear facilities from the transport package approach. Upon designing any new facilities the design should set out the parameters that need to be met, e.g. structural integrity requirements, reliability requirements, inspectability requirements, criticality requirements etc. Any new material, technology or system should then have very clear design requirements that it needs to satisfy and as a consequence the issues that the safety case needs to address and satisfy. In this respect the Design Authority should play a key role in ensuring that any new novel issues do not adversely affect the safety of the facility.

Suggested Regulatory Guidance	Related SAP Clauses
Facility or technology designs should set out the safety parameters that need to be met by any new novel aspects that wish to be introduced.	FP.1-8, SC.1-8, EKP.1-5
The Design Authority should play a key role in ensuring that any new novel approaches do not adversely affect the safety of the facility.	SC.1-8

Regulatory Guidance relating to New Technologies and New Materials from selected examples of Operational Experience

Flamanville RPV

The Flamanville Reactor Pressure Vessel closure head and lower head were manufactured in 2006-2007 for installation into the Flamanville 3 EPR reactor under construction. During qualification testing in 2014, AREVA observed that impact testing on samples representative of the domes to be installed produced lower than expected results, potentially indicating inhomogeneity within the steel.

Further testing by AREVA on representative dome material produced results which revealed carbon concentration gradients at the surface of the dome (measured by portable spectroscopy), and were assessed to be the result of significant positive carbon segregation, present over a diameter of approximately one metre. Further examination showed that the carbon segregation was present to a depth of greater than one quarter of the dome thickness.

AREVA concluded that the carbon segregation was from the ingot used for forging, and the cropping of the dome post forging had not eliminated the imperfections. The technique used to manufacture the ingots was not considered best practice by ASN, as similar RPV domes had been manufactured by other manufacturers for other EPR plants under construction without carbon segregation present.

Upon discussing the issue with ASN (Reference 17), the French Nuclear Regulator, AREVA were required to conduct additional testing to demonstrate that the mechanical toughness within the areas of high carbon segregation in the installed domes would meet the required specification. ASN assessed that best available techniques (BAT) had not been used during manufacture, and whilst additional testing could determine that sufficient mechanical toughness was present in the RPV dome material, the lack of BAT would preclude the demonstration of the highest quality of manufacture.

ONR has reviewed the Flamanville 3 RPV in light of the UK Hinkley Point C reactor design, and has issued a summary of the technical issues relating to the Flamanville 3 RPV as an Appendix to ONR Technical Assessment Guide 16, Integrity of Metal Structures, Systems and Components (Reference 18).

Suggested Regulatory Guidance	Related SAP Clauses
For any new material or technology the Licensee must have appropriate oversight and exercise the appropriate control to minimise the potential risk from the novel approach.	FP.1-8, SC.1-8
Where the new technology is being introduced by a contractor the Licensee should be fully aware and agree appropriate measures with the contractor to ensure that the new technology is justified.	SC.1-8
The Licensee should carry out a fault study to examine the potential risks involved in introducing a new technology and where possible carry out tests to justify that that these risks have not occurred.	FA.1-14, EKP.2
The commissioning process should be such that no new technology is installed upon the plant until after all tests to justify it have been evaluated.	ECM.1

Windscale Fire

Windscale was a graphite moderated reactor which had a fire in 1957 with a release of radioactivity to the environment. Although at the time of the accident the reactor had been operating for several years the reactor itself was novel. In addition, although the cause of the accident was attributed to human error there were a number of unexpected factors during the operation that necessitated different operations. Key amongst these observations were the discovery of Wigner energy which necessitated the reactor to be operated in such a way as to anneal out the potential damage caused by the build-up of this energy (especially the exacerbation of any fuel rod fire), a higher than anticipated critical mass due to the quality of the graphite, and the discovery of uranium oxide particles in the vicinity of a similar reactor in the USA. This latter observation prompted the addition of air filters as a late design change, these filters being termed

"Cockcroft's Follies" and were resisted by some as unnecessary. In the event these filters were the key preventative in significantly reducing the amount of radioactivity reduced to the environment.

The designers should have recognised the novelty of the reactor and therefore introduced safety measures to not only prevent an accident but to mitigate the effects of an accident should it occur. Although the risk of a fire was a major concern the air filters were only added as an afterthought. Although the reactor design was novel it was only through the observations in a similar reactor in the USA that prompted the design change.

Suggested Regulatory Guidance	Related SAP Clauses
Novel technologies and materials should be understood in the environment which they will see, especially in the presence of a neutron flux.	EQU.1, ECM.1, EMT.3-4, EKP.1
New materials and technologies should be fully characterised prior to introduction	EMT.3-4
Where uncertainty remains due to limitations in available data, additional safety measures should be considered to minimise risk.	EMT.3-4
All relevant OPEX, even if not from the same design of facility should be considered in the safety case and facility design.	MS.4

Chernobyl

A significant accident took place in 1986 at the Chernobyl NPP. This was one of a series of RBMK reactors and as such the technical issues were not novel and no novel material was being introduced. Hence many of the causes of the accident that have been identified are not relevant to this report. However the accident occurred during a novel safety test and thus is relevant to the concept of "novel materials, technologies, systems and procedures". Hence several of the causes are generically applicable to the introduction of new systems/procedures, namely

- Inadequate safety analysis
- Insufficient attention to independent safety review
- Inadequate operating procedures
- Inadequate liaison between designers and operators
- Operators did not follow the test procedures (and the test procedures did not account for actions in the event that the test did not go as planned)

Suggested Regulatory Guidance	Related SAP Clauses
When introducing any new technology or procedure the novel aspect must be subject to the same degree of safety analysis and scrutiny (depending upon its safety importance) as when the facility is first assessed licensed and this scrutiny should include discussions between operators and designers.	SC.1-8

Suggested Regulatory Guidance	Related SAP Clauses
When novel procedures are adopted, e.g. during commissioning, detailed operating procedures must be produced that have been subject to the same degree of scrutiny as routine operating procedures and these procedures should also provide information to the operator on what to do if things do not go as planned.	SC.1-8, EHF.3-5,9-10
No variation to planned operating procedures should be allowed without full safety analysis and scrutiny.	EHF.3, EHF.9, EHF.10
Operators carrying out the novel procedures should be fully trained and competent.	EHF.8

Castle Bravo

Castle Bravo was the first US atmospheric test of a 'dry-fuel' thermonuclear device. The magnitude of the explosion was of the order of 50% greater than expected, with the subsequent atmospheric radioactive contamination larger than anticipated. The novel aspect of this test was the use of solid lithium deuteride. The designers anticipated that only the ^{6}Li isotope would contribute to the explosion whereas in actual fact the ^{7}Li isotope comprising 60% of the lithium actually contributed via a decay mechanism not anticipated by the designers. It is a moot point whether further safety analysis would have revealed this deficiency in the safety case but clearly more safety analysis and scrutiny would probably have been beneficial. The further lesson from this incident is the requirement to incrementally increase risk when commissioning or trialling new materials. A smaller demonstration or prototypic test would undoubtedly have revealed the deficiency in the safety analysis.

Suggested Regulatory Guidance	Related SAP Clauses
The introduction of novel materials or technologies should be subject to the full rigour of safety analysis, justification and independent review.	SC.1-8, EMT.3-4, EKP.4-5
Any trial of new material or technology should wherever possible be such that the risk is gradually increased and where appropriate and proportionate, small scale laboratory, prototypes or demonstration tests should form part of the safety justification.	ECM.1, EMT.3-4

Paks Nuclear Power Plant Fuel Rod Cleaning Incident

On 10 April 2003, an INES Level 3 incident occurred at the Paks Nuclear Power Plant in Hungary, and involved significant fuel damage in a newly constructed fuel washing facility. Due to corrosion products from the steam generators being discovered in the primary coolant it was thought necessary to wash the fuel elements and to expedite this a new facility was purchased from Framatome. Unfortunately the facility had not undertaken a sufficient safety analysis, specifically an adequate thermal hydraulics assessment which would have identified the consequences of inadequate cooling. The facility was unable to control the temperature of the fuel assemblies leading to overheating followed by fuel damage and radiological release.

There were a number of contributory factors to this event, the absence of a properly analysed safety case probably being the main contributor but the plant was said to be deficient in a number of usual regulatory requirements, in particular the reliance on a single pump for cooling (no diversity or redundancy) and hence susceptibility to the single failure criterion, and appropriate instrumentation to inform the operators of the correct condition of the facility.

Other contributory factors that were cited were an over-reliance of the operator on the sub-contractor (Framatome), undue time pressure such that the facility was not properly commissioned (which should have shown up the cooling fault had adequate instrumentation been available) and shortage of regulatory resource.

Suggested Regulatory Guidance	Related SAP Clauses
Any new technology should be subject to the same degree of rigour to justify its operation as any other nuclear technology. This should include a fully developed safety case and appropriate commissioning programme.	SC.1-8, ECM.1, EMT.3-4, EKP.1
A new facility with new technology should have comprehensive instrumentation to inform the operators that the facility is operating as planned and for the facility to have adequate shutdown instructions in the event that it does not.	EHF.6, ESR.1-10
The operator is always responsible for the safety of its facility and in situations where it sub-contracts its work it must maintain an independent review and act as intelligent customer for the work or services being procured. Where this work is novel in nature and of high safety significance then the highest degree of external scrutiny must be applied.	FP.1-2
New or novel materials or technologies that deliver a safety function should be identified and classified according to their significance to safety. The level of regulatory scrutiny applied should be proportional to the nuclear safety risk and appropriate time should be planned for the regulatory assessment of new or novel materials or technologies, especially if the facility is novel in nature.	MS.1-4, SC.1-8, ECS.2

Papers Reviewed from the Canadian Nuclear Safety Regulator

Presentations from the Canadian Nuclear Safety Regulator (CNSC) have been sampled and are summarised below, with pertinent regulatory themes highlighted. In the presentation titled "Regulating innovative Nuclear Technologies" (Reference 19), the CNSC chief regulatory operations officer highlighted that new technologies require an "objective setting" approach, rather than a prescriptive approach. It was emphasised that the regulator needs to be flexible to technological developments, and be responsive to evolving expectations and trends. Specific reactor design improvements such as strong negative reactivity coefficients and better fission product retention were highlighted.

CNSC presented at the 2016 Technical and Regulatory Issues Facing Nuclear Power Plants Conference on the subject of CNSC Activities in Support of Regulation of Activities Involving New Reactor Technologies (Reference 20). One of the key themes presented was that there should be no relaxation in safety standards or requirements in relation to the introduction of new technologies, and that weaker safety cases should be avoided. The presentation noted that the introduction of new technologies may be cost and time intensive which may prove challenging in a resource constrained environment, but early engagement with the regulator should be undertaken to facilitate regulatory understanding.

At the IAEA Technical Meeting on Technology Assessment of Small Modular Reactors for Near Term Deployment, CNSC presented on Regulatory Challenges Presented by SMR Technologies (Reference 21). The paper inferred that a different level of proof (of safety) would be required for a prototype reactor, a first of kind and a reactor that is part of a series. Whilst not stated explicitly, it could be inferred that the successful operation of a prototype reactor would provide a significant part of the safety case for a first of kind and following class of reactors. The presentation also highlighted the risk of increased uncertainty in relation to the level of data available for new technologies, and that it is important that uncertainties or limitations in data are understood before introduction into service.

CNSC issued a discussion paper on Small Modular Reactors: Regulatory Strategy, Approaches and Challenges in 2016 (Reference 22). The paper summarises the broad regulatory considerations relating to the development of SMRs, and the process in Canada required for the licensing of such a reactor design. Of note, the paper highlighted the challenges of safety cases containing deterministic and probabilistic data when the level of experimental data supporting such technologies may well be limited. The paper also discusses the need for coherent research and development programmes aligned with suitable commissioning activities.

Suggested Regulatory Guidance	Related SAP Clauses
Any new material, technology or process should clearly demonstrate the benefits anticipated to result, especially to safety.	FP.1-8, SC.1-8, EKP.1-5
If a Licensee wishes to introduce a novel technology onto its facility then it should enter into early engagement with the regulator.	MS.1-4
There should be no relaxation in safety standards or requirements in relation to the introduction of new technologies, and that weaker safety cases should be avoided.	SC.1-8, ECS.2-5
The introduction of new technologies may be resource intensive, but early and continued engagement with the regulator should be supported by the operator or Licensee.	MS.1-4
New technologies should be subject to appropriate verification and validation in conditions representative of operation.	ECM.1, EMT.3-4
Uncertainties relating to new technologies or new materials should be understood before introduction into service.	EMT.3-4
Safety cases for new technologies or new materials should be underpinned by an extensive research and development programme and a suitable commissioning programme.	SC.1-8, EMT.3-4, ECM.1

US Nuclear Regulatory Commission Views on Advanced Fuels

Project Plan to Prepare the USNRC for Efficient and Effective Licensing of Accident Tolerant Fuel

As the title suggests, this paper (Reference 23) is a plan for how the regulator might deal with new fuel concepts and designs. The US Nuclear Regulatory Commission (NRC) is a prescriptive regulator and provides guides for its Licensees on how to justify their facilities. In essence, this paper describes the use of expert elicitation to prioritise the areas where guides should first be produced. However the overall current justification process is identified. This comprises a 5 stage process:

- Unirradiated material testing,

- Test reactor irradiation and testing
- Lead test assembly irradiation and testing
- Transient Irradiation and testing
- Updating of analyses taking place concurrently with all the 4 previous stages and validation of models

The USNRC justification process currently requires test reactor and lead test assembly testing. Whilst this approach may be applicable for new fuels in existing reactor types, this may not be possible for new designs of reactors and their fuels without building specific test reactors.

The programme plan did highlight that associated activities also need to be considered, especially in the reactor operator concept, transport packages and storage casks.

Suggested Regulatory Guidance	Related SAP Clauses
Current approaches to justifying novel fuels of using test reactors may not be feasible and the first of kind reactor may need to become the "test/demonstration reactor".	EMT.1-8, SC.1-8, ERC.1-4
When considering new fuels the justification should not only cover in reactor performance but all associated activities, i.e. manufacture, transport, handling, storage, any intended reprocessing and ultimate disposal.	ERC.1-4, EHT.5, ECR.1-2

Regulatory Guidance on the Introduction of SMART Devices

A potentially significant change in technology is in the area of control and instrumentation, in particular the use of digital and Smart devices. ONR TAGs 028 (C&I) and 042 (Validation of Codes) highlight that it is practically impossible to fully validate software and in particular "Commercial Off the Shelf (COTS) devices", the confidence in the safety of such devices coming from ensuring quality of design, development and manufacture. There are specific papers on this subject that are useful;

Safety Demonstration of a Class 1 Smart Device

These components are of necessity purchased from sub-contractors and it is the Licensee's responsibility to act as an intelligent customer in procuring these devices. This paper (Reference 24) describes how Horizon Nuclear power addressed this issue. As stated in the TAG 028, Horizon sought to ensure demonstration of best practice for these Smart devices in design, development and manufacture through all processes following a suitable quality management system. To aid Horizon in ensuring that this was the case it developed bespoke questionnaires for its suppliers to demonstrate that good practice had been followed in producing the devices and in some cases it required evidence to support the responses to these questions.

- The assurance process comprised 3 types of assessment of the design, its development and its manufacture:
    - Assurance that the device complied with relevant standards
    - Assurance that the properties of the device meet those specified,, and
    - A vulnerability assessment

Justification of Commercial Industrial Instrumentation and Control Equipment for Nuclear Power Plant Applications

This paper (Reference 25) reiterates the 3 component assurance process as described in Reference 24. It also states that the COTS safety function (and any digital requirements to the overall COTS justification. It cites the main challenges to the use of COTS as being:

- Challenges in their use, e.g. ensuring redundancy and diversity to prevent common cause failure
- Hardware and Software vulnerabilities, e.g. change control of design etc., counterfeiting and security issues
- Organisational Challenges, e.g. difficulties with achieving information due to intellectual property rights

In order to overcome these issues the paper recommends the following justification process for any new COTS:

- Define requirements and prerequisites for the device
- Select candidate device
- Establish contractual relationship with manufacturer (for access to information)
- Plan the assessment
- Carry out the Assessment
- Identification of Lifetime issues
- Produce summary justification document

Security Informed Safety: Integrating Security within the Safety Demonstration of a Smart Device

This paper (Reference 26) is by the same set of authors as the References 24 and 25 discussed above. In effect it is pointing out that especially for Smart and COTS devices safety and security should be considered together in an integrated fashion. These devices are unlikely to accommodate security requirements as a "backfit".

Suggested Regulatory Guidance	Related SAP Clauses
Operators should undertake a staged approach to justify any proposed Smart/COTS devices and regulatory assessment could comprise of an assurance that all these stages have been undertaken and carried out properly.	SC.1-8, ESS.1-27, ESR.1-10
A staged approach is equally applicable for other safety related components purchased from sub-contractors and the assessment process should ensure that these steps have been carried out by the operator.	SC.1-8, ESS.1-27, ESR.1-10

Suggested Regulatory Guidance	Related SAP Clauses
Smart and COTS devices should consider safety and security requirements in an integrated fashion. Similarly for any novel safety innovation that is to be introduced, its impact not only to safety needs to be considered but also its potential impact on security (and the environment).	MS.2

Robotics and Artificial Intelligence in Nuclear (RAIN)

A technology hub (Reference 27) has been created to describe the current work being carried out in this area (largely academic departments, but also a few industrial organisations) which is cited as being in 3 main areas, remote handling, remote inspection and safety. It would appear obvious that the main driver behind this work is the reduction of radiation doses to workers who currently need to carry out these tasks.

In the safety area a number of research challenges are mentioned:

- Designed to be verifiable,
- The reasoning behind AI decisions
- Long term autonomy, i.e. ability to self-monitor, diagnose and reconfigure,
- Need for comprehensive verification across the full component including sub components, systems and multi systems, and
- Existing standards are inappropriate and need to evolve with technology.

The above are commendable wishes but are probably not all regulatory requirements. The RAIN website explains how components will be verified by both white and red testing, i.e. non-radioactive and in radiation fields. Whilst all of this is also commendable there are broader implicit issues:

- Operators need to define the operating limits for which the components need to be verified, e.g. temperature, environment (e.g. aqueous), radiation field (flux etc.) and the components need to be verified for all these parameters, i.e. radiation field at temperature and not temperature and radiation separately.
- In addition to testing the regulator will require documentary evidence of why the component is safe for use in the nuclear industry although clearly the results of the testing programme will probably play a large part in this.
- Once in operation the components will become irradiated and add to the radioactive waste burden, hence regulators must be assured that they will both work and be compatible with any waste management plan.

Suggested Regulatory Guidance	Related SAP Clauses
Any robotics or AI that is to be used in the nuclear industry for safety related purposes should be verified for the operating conditions that it is planned to operate in.	ECM.1, EMT.3-4
This verification should include written documentation stating the reasons why this component is deemed to be safe for its intended use in the nuclear industry.	SC.1-8

Suggested Regulatory Guidance	Related SAP Clauses
Any component involving robotics or AI should have all aspects of that component verified, i.e. sub-components, systems and multi-systems.	EMT.3-4
Such components should be shown to be compatible with the site's radioactive waste management plan.	DC.2

Regulatory Guidance Relating to Small Modular Reactors

The Department for Environment and Climate Change (DECC) commissioned a "Techno-Economic Assessment of SMRs" in 2016, as part of the UK Government target of reducing UK carbon emissions by 80% by 2050. The assessment comprises 4 parts, and three were reviewed as possible sources of regulatory guidance.

Project 1 - Comprehensive Analysis and Assessment (Reference 28).Although most of this Project deals with the economic arguments for SMRs it also sets out what are considered to be the licensing challenges (in the view of the authors, i.e. Atkins):

- One versus multiple modules
- Lack of OPEX
- Specific design aspects
- Operations and site boundary issues
- Waste disposal

This list could be questioned, e.g. there is no mention of fuel manufacturing facility, fuel transport or waste management (as opposed to waste disposal) with some proposed SMR fuels requiring decades longer to cool than current reactor fuels. Irrespective of the potential challenges though, Project 1 gives no indication to either operators or regulators of how these may be overcome.

Project 3, Emerging technologies and Literature Review (Reference 29), is a two-part paper which identifies the new technologies likely to arise from new SMRs and the safety issues that may arise. However, as with the previous projects it gives no guidance upon how these technologies should be justified for use.

The final Project 4, Pre-GDA Review (Reference 30) is the most useful of the 4 projects as it outlines the challenges that SMR designers and operators will face in obtaining a License from ONR, and in the first instance a DAC (Design Acceptance Certificate) as part of ONR's GDA (Generic Design Assessment) process. The report helpfully identifies many ONR principles that need to be met by SMR's and ways in which the designers/operators may need to meet these (as well as some of the difficulties, e.g. validation of thermal hydraulic codes for nuclear materials in reactor). However at no point does the report examine what the regulator could do differently. Clearly it should be a pre-requisite that there is no degradation in safety requirements however the report emphasises that to enter the GDA process a "frozen" reference design is required. This may be an area where change could take place. Currently designers are faced with the difficulty of:

- Needing a DAC to achieve funding but,
- Needing funding to carry out the requisite research outlined in Project 4 to "freeze" the design.

It is recognised that the existing GDA process is a staged one which incrementally goes into more detail of the proposed safety case, nevertheless it is a pre-requisite that a "frozen" reference design exists which therefore makes it more difficult for the design to evolve as more R&D and modelling work is carried out.

New Reactor Control Rooms

The US NRC presented a poster paper at the 2019 Regulatory Information Conference (Reference 31) of its assessment of 2 different "novel" reactor control rooms, one at an AP1000 and the other at NuScale. The approaches made by these operators were entirely different. The AP1000 was designed on the basis of meeting laid down prescriptive USNRC Design Acceptance Criteria (DAC) and USNRC was involved during the design process. The NuScale control room on the other hand did not use the DAC until the design was nearly complete. In both instances USNRC carried out validation tests of the control rooms especially examining the human interface issues but both have (so far) proved satisfactory.

The NuScale approach is clearly more risky in terms of getting regulatory acceptance but the AP1000 approach could also be questioned in that compliance alone does not always provide the best solution.

Suggested Regulatory Guidance	Related SAP Clauses
Operators and/or Design Authorities should define human interface requirements for new designs of control room that need to be met and these should be tested.	ESS.1-27, ESR.1-10

Sample Based Review of Concrete Technologies

Background

It has been reported (Reference 32) that each new civil nuclear power plant (NPP) constructed requires, on average 100,000m^3 of concrete. Recent experience at Hinkley Point C illustrates the scale of the operation (Reference 33), with the first pour of the raft comprising 2000 cubic metres of the eventual 9000 cubic metre total (Reference 34), a new record for the UK construction industry.

It should also be remembered that, in those quantities, concrete is the only material that has to be manufactured on the site (Reference 35) without the benefits of factory controlled quality assurance, quality control, inspection and testing. The requirement to meet the design specification in accordance with SAP ECE.25 becomes more challenging as a result.

Suggested Regulatory Guidance	Related SAP Clauses
The properties of new materials for civil engineering purposes should be characterised, in order so that they can be used for construction purposes.	ECE.25

Irrespective of the challenges of scale and location, NPP concrete has to fulfil a number of functions, most of which are of importance to nuclear safety, for example:

- Structural support
- Shielding
- Secondary containment

- Seismic resistance
- Resistance to normal and abnormal operating loads
- Resistance to environmental loads
- Resistance to impact loads

In the newer generations of reactor system these functions are expected to be required for operating periods in excess of 60 years with many of the concrete components being inaccessible for inspection or repair once the plant becomes operational. In addition waste and spent fuel storage and disposal facilities may require structural integrity for even longer periods. For a material with generally poor tensile properties that can be prone to cracking via several mechanisms including swelling due to the alkali-silica reaction (ASR), this poses a number of challenges that the industry has been working to meet for some time.

Developments

Since construction of NPP began in the 1950's there have been a number of innovations in the development of concrete as an engineering material (Reference 36). Notable among these are:

- High performance concrete (HPC): the addition of chemical admixtures such as plasticisers and viscosity modifiers, and mineral admixtures such as fly ash and silica fume, modifies the microstructure of the concrete, particularly at the aggregate to binder interface. This modification allows improved tailoring of the bulk mechanical properties of the concrete. The ability to control bulk mechanical properties is a key factor in meeting the requirements of SAP ECE.16.
- Self-compacting concrete (SCC): SCC is a HPC that utilises a superplasticiser and a low water-to-powder ratio. This concrete compacts under self-weight without the need for external energy input.
- High and low volume fly ash concrete (HVFAC/LVFAC): Siliceous fly ash is used as a cement replacement. Use of HVFAC is exemplified by Sizewell B where the cement replacement level was 40%, resulting in significant cost savings. General property improvements were realised and the concrete proved to be very workable and could be pumped over distances and heights. An added benefit is that the use of less cement reduces the carbon footprint of the overall construction project because cement manufacture has a significant environmental impact via energy demand and CO_2 emissions (Reference 37).

HPC, SCC and HVFAC/LVFAC are considered mature materials technologies but remain the subject of ongoing research aimed at making further improvements.

Suggested Regulatory Guidance	Related SAP Clauses
New materials under consideration for construction should meet the design methodologies, and should be suitable to enable the design to be constructed.	ECE.16

Self-Healing Concrete

In 1994, Dry (Reference 38) published the first paper on self-healing cement matrices. Between 2001 and 2013 research in the area of self-healing materials, as measured by the number of published papers on the subject, increased by more than an order of magnitude (Reference 39). As the name suggests, these materials are not designed to be resistant to cracking, but are designed to self-repair thereby automatically mitigating the risk of crack-like defects, a major example of risk being creation of a pathway for water to reach embedded steel reinforcing bars. Failure of steel reinforcement in concrete by corrosion can result in significant loss of bulk properties.

SAP ECE.3 requires civil engineering structures to be tolerant of identified defects. Self-healing concrete structures could be seen as meeting that requirement, not in a conventional manner by virtue of bulk mechanical properties, but by the ability to remove defects once they occur.

Suggested Regulatory Guidance	Related SAP Clauses
New materials which incorporate self-healing properties should be demonstrated to meet required safety functions.	ECE.3, EKP.5

There are three primary methods by which self-healing concrete may be produced:

- Intrinsic self-healing: the presence of components within the cement matrix that will, in the event of matrix cracking, act to effectively heal the crack and prevent its progression. Also known as autogeneous healing, cracks are filled by one of two mechanisms:
    - Hydration of unhydrated cement particles: This is particularly important in young concrete structures where a volume of such particles exists, but cannot be relied upon in older concrete components
    - Hydration of embedded reagents that promote the deposition of crystals in the open crack. This mechanism was found to be the source of the longevity of Roman concrete (Reference 40) and is one effect of fly ash addition in HVFAC/LVFAC
- Capsule based self-healing: healing agents are contained within capsules distributed in the concrete matrix. When ruptured by a crack the capsules release the agents and a pre-designed reaction takes place to close the crack. The advantage of capsule based self-healing is that, unlike autogenous healing, it does not necessarily depend on the presence of water. The reaction between the healing agent and the concrete can be designed such that it is activated by water, air or contact between the agent and a specific component of the concrete matrix.
- Vascular based self-healing: healing agents are introduced to the interior of the structure through a network of hollow tubes or lined holes. This method is therefore not self-limiting because additional agents can be added from the exterior. However it is also not a true passive method because it depends on detection of defects in order to initiate flow of healing agents.

Self-healing concretes are not considered mature materials technologies. These materials have significant potential and are likely to remain the subject of ongoing research.

Standards Development

In 2011 the Nuclear Energy Standards Coordination Collaboration (NESCC) in the USA reviewed concrete codes and standards for nuclear power plants (Reference 41). The review highlighted a number of issues of note with respect to materials:

- The interaction of cement with supplementary cementitious materials (SCM), such as fly ash or silica fume, should be quantitatively taken into account. This appears to be a caution that the bulk properties of concrete may be sensitive to absolute quantities of additions and that, while cliff edge effects have not been noted, it does not mean they are not there.

- The use of SCM should be encouraged to realise the benefits available in performance. However, full characterisation of effects is required. Nuclear codes should not introduce arbitrary barriers to SCM use.
- All measures to avoid ASR should be taken. Applicable codes may require strengthening in this regard.
- Higher density aggregates used for radiation shielding also require full characterisation in terms of ASR and structural performance level.
- The behaviour of irradiated concrete should be investigated further. The performance of new types of concrete has not been established in this regard.

The NESCC review does not consider self-healing concrete. However, it would be prudent to apply all the issues the NESCC report identifies to any concrete formulation proposed for an application with nuclear safety implications.

Summary and Regulatory Themes

There are some mature materials technologies, developed from standard concrete, that produce reliable concrete that has been successfully used in NPP build. Although work continues to quantify the effects of composition changes and improve materials performance, use of these materials should be regarded as Relevant Good Practice (RGP) which largely meets the requirements of SAP ECE.16.

Suggested Regulatory Guidance	Related SAP Clauses
New materials under consideration should demonstrate that development conforms to extant RGP.	ECE.16

The precise composition of mature concrete material designs remains the subject of research in order to realise further improvement. Developments to the materials that arise from such research are incremental and as such should be regarded as an evolution of a code approved material. This is directly comparable to development of new pressure vessel steels where 'new' materials achieve codification via normal entry processes.

Nuclear codes should require full characterisation of the effects of changes in composition of concrete, but should not put in place unnecessary barriers to innovation. This is entirely consistent with the requirements of SAP Paragraph 333.

Suggested Regulatory Guidance	Related SAP Clauses
New materials should conform to extant codes, and any limits described in codes considered	ECE.1

Examples of Selected New Materials Research

Background

In recent years research into new materials has been given new emphasis as a result of the drive to consolidate the current generation of nuclear power generation designs as a safe, reliable, clean energy source, and to prepare for the next generation.

One example of a relevant initiative is the European Energy Research Alliance (EERA) European Strategic Energy Technology Plan (SETP) with four objectives aimed specifically at materials technology (Reference 42):

- Qualification of materials for codification and licensing of structural elements of prototype and demonstration reactors
- Lifetime assessment of components for long-term operation
- Development of materials of superior performance, especially fuel cladding
- Qualification of fuel materials for codification and licensing

There are three challenges that face the industry that can be seen in the above objectives:

- How to streamline codification and licensing of materials without compromising the quality of the existing processes for gaining acceptance within codes and standards
- How to improve materials to eliminate or mitigate known material degradation risks
- How to assess lifetime performance for new materials

These challenges are not exclusive to the European programme and can be seen in efforts worldwide to develop improved materials and get them to a point where design engineers can select them for use.

Selected Examples of Progress

There is a very large volume of published material on materials research in nuclear and non-nuclear applications. A number of examples have been selected and summarised to illustrate how materials research programmes are addressing the challenges listed above.

Fuel Cladding

There has been significant progress in the development of alternative fuel cladding materials as part of a general interest in accident tolerant fuel assemblies (Reference 43).

One of the alternative technologies to have advanced is the use of silicon carbide (SiC) for fuel cladding. Silicon carbide matrix composites, i.e. SiC fibres in a SiC matrix, are thermally stable and retain their strength and toughness up to very high temperatures. These materials have the essential prerequisite of neutronic compatibility with a fast neutron spectrum and should meet the requirements in terms of irradiation and oxidation resistance in reactor environments. SiC matrix composites have been developed within the fusion materials programmes in Europe and worldwide. In 2013 these composites had been fabricated and investigated as simple flat panels or plates, optimising microstructure to achieve state-of-the-art thermo-mechanical properties. By 2014 the challenge to engineer the materials into prototype components was well underway with Westinghouse reporting progress on tubes comprising both monolithic SiC and composite SiC.

At the same time as advances in materials are made, these must be matched by advances in engineering techniques in order to produce useful components. For SiC components, in addition to established advanced composite techniques such as vapour deposition, a new manufacturing method based on liquid phase sintering has been developed in Japan. This method is reported to produce dense components with improved properties with all the added benefits of a near nett shape manufacturing route.

Both the Westinghouse programme and that underway in Japan were on the verge of beginning irradiation testing in 2014, with the Japanese project scheduled to complete at the end of 2019.

High Temperature Materials

European materials research is currently focused on three next generation reactor designs:

- Sodium fast reactor (SFR)
- Lead cooled fast reactor (LFR)
- Gas cooled fast reactor (GFR).

All of these reactor designs require high temperature materials.

The requirement for high temperature performance is particularly challenging in the fuel assembly and the heat exchangers of the LFR (Reference 44). A requirement for stable, thin oxide films that do not adversely affect heat transfer has been identified to mitigate the risk of dissolution of component alloy constituents in to the liquid lead coolant. Work continues to identify methods by which this might be achieved with parallel work streams aimed at identification of alternative compatible materials.

In Korea, an initiative to combine a Very High Temperature Reactor (VHTR) with a High Temperature Steam Electrolysis (HTSE) process to economically produce bulk hydrogen as a clean energy source has required an assessment of nickel alloys exposed to long term high temperature operation in steam (Reference 45). A range of mechanical properties were studied and while it was not concluded that the alloys were unsuitable for the application, general degradation of structural performance was noted indicating strongly that alternative materials should probably be sought.

Modelling Irradiation Damage in Pressure Vessel Steels

With current and future generation reactors having life expectations in excess of 60 years, an improved understanding of how irradiation affects pressure vessel steels has become a necessity. It is reported that physically reliable computer models have been developed that model the behaviour of carbon atoms on a nano-scale to understand how point-defect clusters form during irradiation up to 1dpa.

The objective is to extend this modelling capability to develop an understanding of how the Fe-C system responds to long term irradiation and eventually to adapt that fundamental understanding to model pressure vessel steels.

General Observations and Regulatory Themes

Work underway to consolidate materials performance in current reactor designs is at an advanced stage. This is exemplified by the latest generation of pressure vessel material, SA508 Grade 4N, which has improved properties (Reference 46) over previous grades and enables current designs to be constructed. These materials and the technologies that engineer them are mature and should be considered RGP. Use of such materials is highly likely to contribute to meeting the requirements of SAP EMC.1.

There is a large volume of work ongoing on materials for future generations of reactor. This is at various stages of maturity but mostly remains at a fundamental research level. A reasonable conclusion is that very few of these initiatives are reaching technical maturity. The requirement for stable core materials is captured within SAP ERC.3.

The ability to model through-life behaviour of materials continues to deliver new solutions. However, validation of model outputs remains challenging, especially given the periods predictions are required for. All models that affect safety performance at any level should be appropriately validated. This is a recurring theme in the SAPs as exemplified by Paragraph 680 concerning fault analysis and SAP ECE.15 concerning civil engineering.

Codification and licensing of materials receives almost no coverage in the literature. It appears that little progress has been made and this remains a barrier to the introduction of new materials and associated technologies preventing them from meeting the requirements of SAP ECS.3.

Suggested Regulatory Guidance	Related SAP Clauses
New materials should demonstrate sufficient research and development to demonstrate engineering maturity.	EMC.1, ECE.3
New core materials should demonstrate an appropriate level of technical maturity prior to consideration for operational use.	ERC.3, ECE.3
Validation of models supporting the development of new materials should be against experiments which closely match the expected plant condition.	ECE.15

Welding Technologies

Background

From a metallurgical viewpoint, welding is a disruptive manufacturing process that induces significant mechanical and thermal cycles. These result in local mechanical, thermal and phase transformation strains that manifest as residual stress in the joint and adjacent material. The presence of residual stress in a structure is important because it adds to the overall stress state in the component during operations. Since these stresses can be tensile and high, often assumed to be of yield magnitude, they can be a significant factor in driving defects, e.g. fatigue crack growth, stress corrosion cracking.

Current and future generations of nuclear reactor will be required to operate for periods in excess of 60 years. As such there is an emergent requirement to:

- Minimise adverse welding residual stresses
- Understand residual stress in terms of nature and magnitude and be able to model it for a range of relevant geometries
- Link the selection of a welding process to the through-life structural integrity arguments for a component such that a robust safety case can be made in line with UK regulatory expectations as expressed in SAP EMC.1

Suggested Regulatory Guidance	Related SAP Clauses
Safety justifications for new metallic materials should be comprehensive and suitably robust, and consider the effects of defects as well as defect tolerance.	EMC.1, EKP.1-2
Manufacturing methods for new metallic materials should be designed to minimise adverse effects which could have an impact on safety.	EMC.5-6

Developments in Welding Technologies

In the UK, the New Nuclear Manufacturing (NNUMAN) programme continues to conduct research activity focused on welding and, in particular, on modelling residual stress.

NNUMAN has conducted extensive trials on thick section pressure vessel steels using six welding processes (Reference 47):

- Conventional Submerged Arc Welding (SAW)
- Conventional Gas Tungsten Arc Welding (GTAW)
- Narrow Gap SAW (NG-SAW)
- Narrow Gap GTAW (NG-GTAW)
- Laser Beam Welding (LB)
- Electron Beam Welding (EB)

A progress update (Reference 48) in 2017 noted the following:

- It is feasible to make 100 mm thick welds with a laser
- Vacuum laser welding offers much more promise than multipass narrow-gap approaches
- There is a potential issue with the toughness of electron beam welds
- Electron beam welding produces a wider heat affected zone (HAZ) than arc-based processes
- The peak residual stresses do not vary significantly in magnitude from one process to the next, but the distribution and extent of the tensile regions do vary significantly
- Submerged arc welding was found to be more robust than GTAW (or tungsten inert gas (TIG)) welding

The work appears to confirm that SAW continues to be good practice for joining thick section steels. It should be noted that the programme has found that vacuum LB welding may offer advantages over the narrow gap techniques that are currently favoured for thick section pressure vessel welds.

The work also highlights a potential concern with fracture toughness in EB welds. Further research has been conducted (Reference 49) that does not highlight any concern, including with SA 508 Grade 4N (not included in the NNUMAN programme), but instead supports the use of EB welding for primary circuit safety-critical components, highlighting the need for further work to support a future ASME III code case.

An important observation is that the peak residual stresses appear to be independent of the welding technique used. Variation occurs in the distribution and size of the tensile stress regions and this continues to be the subject of modelling efforts. In terms of defect tolerance assessment as part of a safety case, the implication of this observation is that peak residual stress should continue to be accounted for appropriately and any claims of reduction by use of advanced welding technique will require separate substantiation.

Summary and Regulatory Themes

The following general observations can be drawn from the review:

- The structural performance of welds continues to be pivotal in substantiating safety claims and meeting the requirements of SAP EMC.1

- Longer life expectancy for current and future reactor designs has placed new emphasis on control and predictive capability for welding residual stress. SAP EMC.7 requires that a detailed schedule of loadings should be used for component design but does not apply to residual stress because it is regarded as a secondary stress. However, it has an important part to play in defect tolerance and stress corrosion cracking so should be taken into account when demonstrating that SAP EMC.1 has been met. Additionally, with all new techniques for modelling residual stress, appropriate validation is required.
- Progress has been made on welding techniques and residual stress modelling but the need for further research remains
- Codification of advanced welding techniques applied to thick section pressure vessel steels appears to be at an early stage which prevents compliance with SAP ECS.3.

Suggested Regulatory Guidance	Related SAP Clauses
Safety justifications for new metallic materials should be comprehensive and suitably robust, and consider the effects of defects as well as defect tolerance.	EMC.1, EKP.1-2
New materials which require welding should consider the effect of loading through life.	EMC.7

Hot Isostatic Pressing (HIP)

Although relatively new to the nuclear industry, Hot Isostatic Pressing (HIP) is not a new technology, nor does it produce new materials. It is an established and refined technology that produces materials that exhibit the behaviours that are expected of them, generally free from effects related to the manufacturing route, e.g. anisotropy in materials properties from forging, porosity in castings, residual stress in welding etc.

The HIP process is best described as three dimensional forging (Reference 50) of an object. It is essentially the controlled application of pressure in all directions at a suitable temperature.

Applications of HIP

There are two practical applications of the HIP process that find commercial use:

- Densification of castings: castings often contain porosity which, for many functions of a component, is not of particular detriment provided bulk strength is not affected. However, for components with a safety function or a critical economic function, densification is often needed in order to reduce uncertainty in through life structural integrity performance. In these cases the HIP process, correctly applied, can densify an existing casting such that 100% or near 100% densification results.
- Component manufacture: components are manufactured by filling a near nett shape carbon steel canister with metal powder. The canister is evacuated and sealed and then subject to a period at temperature and pressure in an autoclave. During this treatment the powder particles yield and grain boundary creep and diffusion occurs, consolidating the component into a single piece. The resultant component is then machined to remove the canister material and achieve finished dimensions.

Benefits of the HIP Process

The main benefits of the HIP process, as summarised from the European Powder Metallurgy Association (Reference 51) (EPMA) are:

- Improvements in quality and performance as a result of fine isotropic microstructures
- Reduction in the number of welded joints
- Densification without any segregation effects
- Near nett shape process delivering reduced environmental impact
- Flexibility in component and alloy design
- Ease of inspection

Although the power generation industry did not initially embrace the HIP process for component manufacture, attention has turned to it over the past few years in response to reports of benefits coming from other high hazard industries, mainly aerospace and oil & gas. An Electric Power Research Institute (EPRI) presentation (Reference 52) from 2016 confirms the expectation that HIP components will perform well in nuclear applications, noting the additional benefit of using HIP in hard-facing applications.

Lessons from the Development of the HIP Process

As a mature process outside the nuclear industry, HIP has benefitted from a number of lessons learned as it developed. Possibly the most significant lesson was that the powdered metal used in the process needs to have carefully controlled dimensions and morphology.

Originally, milled powders were used in the HIP process. Quality problems, particularly with oxide particles in the finished components, were solved by using gas atomised powders that are spherical and have a fine particle size. It is understood that in the EPRI programme and in all critical applications the use of milled powder has been discontinued.

Certification of HIP Manufactured Components

The integration of HIP into design codes and standards is not straightforward. Although the materials used in HIP are identical to those already listed in many codes and standards, the material in the form presented by a HIP component is not. This is because many design codes have evolved against a background of traditionally applied manufacturing routes. It is interesting to note that if design codes recognised isotropic materials properties there would be more flexibility in design, e.g. possible reduction in requirements for piping branch reinforcement.

ASME has a number of code cases for HIP materials which continues to expand. In due course the expectation is that HIP components will be commonplace in the nuclear industry.

Limitations of the HIP Process

HIP appears to only be limited by one factor, that is the size of autoclave that can hold the component during the process. As part of HIP development, autoclaves have become larger and it is understood that components up to 15 tonnes and over 3m in length can now be produced using this method.

Summary and Regulatory Themes

A number of summary points have been drawn from the review:

- HIP has not been widely adopted in the nuclear industry, possibly because of the initial absence of inclusion in relevant design codes and standards and the subsequent time required to achieve certification. This position is changing, for example via code cases in ASME. Consequently HIP components in a small range of materials are able to meet the requirements of SAP ECS.3 and the performance and safety benefits associated with the requirements of SAP EMC.9 are available to plant designers.
- Other high hazard industries have benefitted from the use of HIP components. Lessons learned have resulted in a mature and expanding technology.
- The benefits of using HIP components are numerous and provide the potential to deliver improvements in safety by the elimination of weaknesses introduced by conventional manufacturing techniques. Successful application of HIP to radioactive components could also provide safety improvements, but has yet to be demonstrated.

Suggested Regulatory Guidance	Related SAP Clauses
New materials which have undergone HIP should demonstrate compliance with extant codes, or demonstrate an approach derived from existing codes or standards.	ECS.3-4
New materials should demonstrate that any reduction in welds etc. is commensurate with an improvement in safety.	EMC.9, EKP.1

General Observations

The review has highlighted that work is continuing to develop and apply new materials and new technologies in the nuclear industry. A number of general observations have been made:

- The demand for clean energy and promotion of nuclear power as an available solution has generated interest in new nuclear power and hence in new technology and materials.
- Incremental development of technologies and materials from those previously used has generally been successful. This builds on RGP and is highly likely to meet UK safety case expectations.
- Development of genuinely new technology and materials is progressing but has generally not reached maturity at this stage.
- One of the major hurdles to the introduction of new technology and materials is codification. Without it no claim of meeting codes and standards can be made. This is a common theme within this review.
- It is very difficult to recognise any new technology or material as RGP, and hence an ALARP measure, until such time as codification has been achieved (where required). Consequently it may be some time before potential safety benefits can be realised within the design of new nuclear systems.

Regulatory Lessons from the Aerospace Industry

Airworthiness of Aircraft

For an aircraft to be introduced into service, it must receive an airworthiness certificate, and must undergo a large series of tests prescribed by the regulator. These tests are specified in the relevant regulations, issued by the European Union Aviation Space Agency (EASA) in Europe, and the Federal Aviation Administration (FAA) in the USA. Under an International convention there is a large degree of compatibility between the two sets of regulations. Interestingly the EASA Regulations are divided into "hard law" and "soft law" with "hard law" being mandatory in terms of how regulations should be met, and "soft law" being non-mandatory guidance upon how the regulations may be met. There is therefore a mixture of prescriptive and non-prescriptive regulations. These regulations deal with all types of aeroplanes with large passenger planes being dealt with, for example in Section 25 of the US Federal Aviation Regulations. This Section is divided into six sub-sections, covering general characteristics, flight characteristics, structure, design and construction, power plant and equipment.

The Sections not only deal with the areas that need to be covered by the designers, manufacturers and operators but also where regulators should be involved. Of note are the requirements for regulators to conduct a detailed review of the design, review the laboratory tests that have been conducted, review the results from flight tests and interact with aircraft operators on the proposed process for the introduction of the aircraft into service.

There are interesting aspects to the prescribed tests. Firstly the tests require full scale testing of the aeroplane structure (in addition to model tests and supporting analysis) requiring large scale testing facilities. Secondly the tests not only examine susceptibility to extremes of weathers, i.e. temperatures, hail, turbulence but also potential accident conditions such as low speed take offs, engine failures and bird strikes.

There are significant similarities between the ways in which aeroplanes are regulated and nuclear regulation but there are some lessons to be learnt.

- Regulators are involved from the beginning of the design process (earlier than in the nuclear industry) and can therefore influence the way in which the design develops.
- Regulators specify how aircraft are brought into service (this is similar to nuclear commissioning),
- Full scale structural tests are required – this is impractical for many larger nuclear components but where possible large scale tests should be performed, e.g. RPV hydrotests,
- Tests of aircraft cover the extreme of conditions that may be experienced, including postulated accident conditions.

The Comet Disasters

The de Havilland Comet, the first jet powered commercial passenger aircraft, is sadly equally well known for the three fatal crashes which occurred over a 12 month period, in May 1953 near Calcutta, Naples in January 1954 and Clampino in April 1954. All three planes experienced explosive decompression and mid-air structural failure. The investigation into the cause of the loss of Comets G-ALYP and G-ALYY in January 1954 and April 1954 (Reference 53) determined that the cause of the disasters was a result of an aesthetic design change to the window frames from a conventional oval design to a more rectangular one, exacerbated by a change from gluing the window supports to riveting. Unfortunately the jagged edges of the rivet holes were a source for crack initiation. At the time there was little knowledge of the stress concentration effect of sharp corners from which cracks initiated and then propagated rapidly causing gross failure of the fuselage in mid-air. The full scale cyclical tests carried out at the Royal Aircraft Establishment Farnborough confirmed the root cause of the disasters.

Suggested Regulatory Guidance	Related SAP Clauses
All changes to safety related components should be fully evaluated for their potential safety impact.	FP.3, SC.1-8
Where possible full scale testing should be carried out in addition to laboratory tests.	EMT.6-7
The potential effects of any changes in manufacturing techniques should be evaluated to ensure there is no adverse effect on safety.	ECM.1, EAD.3-5, EKP.1

Boeing 737 Max 8 Crashes

There have been two crashes of the Boeing 737 Max 8 aircraft, the first being a Lion Air Flight at Jakarta in October 2018 and a later crash in Ethiopia in March 2019. Due to ongoing investigations there is little formal information on these accidents and the following discussion relies on press reports and industry analysis.

The design of the Boeing 737 family of aircraft has iterated over time since its introduction into service in 1968, with the most recent variant, the 737-Max 8, introduced as a result of commercial pressures from Airbus. The new larger LEAP-1B engines that were to be fitted presented ground clearance issues and so it was proposed to move them further forward on the wing and higher than previously fitted engines. However, this significant modification changed the flight characteristics of the aircraft and an anti-stall system known as Manoeuvring Characteristics Augmentation System (MCAS) was introduced.

The aim of this system was to enhance the pitch stability of the aircraft, and force the nose of the aircraft down if the detected angle of attack (AoA) was too high. However, this system relied on a single sensor to activate and bring the nose of the aircraft down, thus increasing airspeed and preventing a stall. In the case of the two 737 Max 8 crashes, it is believed that the MCAS activated because of a false reading from the AoA sensor, forcing the nose of the aircraft down despite the best efforts of the pilots to counter the resultant dive.

A CNN report of 1 May 2019 (Reference 54) stated that AoA sensor failures or repairs had been reported over 200 times to the FAA since 2004, and that former Boeing engineers had criticised the software design for relying on data from a single AoA sensor. The CNN article also reported that Boeing did nor flight test AoA sensor malfunctions and how the MCAS software would respond.

Suggested Regulatory Guidance	Related SAP Clauses
Any design changes to safety related equipment should be checked to ensure that their importance has been properly categorised and as a consequence appropriately justified.	ECS.1-5
All design changes that impact on operator behaviour should involve proper operator training and operating instructions that are assessed. Where possible this training should as a minimum occur on simulators and preferably on the plant itself (under appropriate supervision).	EHF.8-9

Suggested Regulatory Guidance	Related SAP Clauses
Operating instructions that are developed for new equipment/facilities should be checked for their clarity and appropriateness using both experienced and inexperienced operators.	EHF.9
All design changes should be protected from inadvertent adverse impact upon the safety of the facility by appropriate safety measures.	FP.3-6, MS.2

Human Factors Research relating to the Introduction of New Technologies and New Materials

Research on Human Factors in New Nuclear Technology

The organisations that have been most heavily involved in research on human factors in new nuclear technologies are the Brooklyn National Laboratory (BNL) and Idaho National Laboratory (INL) in the U.S, the Halden Research Project (HRP) at the Institutt for Energiteknikk (IFE) in Norway, nuclear regulators (e.g. ONR, NRC) and various universities with research teams mainly located in China and South Korea.

Some of the most recent research in the domain of human factors and new technology was presented by Andreas Bye of the HRP, IFE at the NRC's 30th Annual Regulatory Information Conference, March 13-15, 2018 (Reference 55). The following questions were posed:

(1) Are the challenges to human performance the same in a computerised control room as in a panel based one?

(2) Does more automated C&I introduce new vulnerabilities?

(3) Does new technology impact teamwork and conduct of operations?

(4) Is human performance with respect to safety impact similar in analogue and computerised control rooms?

Bye's presentation described a series of studies conducted at the HRP to try and answer these questions. Questions 1 and 2 were combined and investigated in an exploratory study on operator response to failures of a computerised procedure system (CPS). Using an AP1000-style CPS, the researchers evaluated whether the participants (3 operators) would detect a failure in the automatic evaluation function of the CPS. Improper evaluation of parameters resulting in a failed input to the CPS, would either result in the display of a red cross for a procedure step, indicating that the required parameter is not met, when in fact it is met (false negative) or display a green checkmark for a procedure step, indicating that the required parameter is met, when in fact it is not met (false positive). The results showed that false negatives were identified whereas false positives were not identified. It was acknowledged that this study was based on a very small sample size, but may indicate that there are different challenges to human performance using new technologies for 'false positives' and 'false negatives'.

Bye suggests that for design, there needs to be consideration of how feedback from automatic evaluation systems in CPS should be presented. With regard to training, operators should be trained to be more critical of all types of feedback and regarding Human Reliability Analysis. The question was also raised as to whether automatic systems are dominated by positive feedback and how is training checked?

Suggested Regulatory Guidance	Related SAP Clauses
For new technologies, consideration should be given to how feedback from automatic evaluation systems in computerised procedure systems should be presented.	EHF.1-7
Operators should be trained to be appropriately critical of all types of feedback received from computerised procedure systems.	EHF.8
The training of operators should be checked prior to the operation of new technologies, and periodically throughout life.	EHF.8
Licensees should provide evidence that automatic systems are not dominated by positive feedback.	ESR.9-10

Issues surrounding question 2 were further reported in a summary of 20 years of automation work at Halden (Skraaning & Jamieson, 2017. HRP-387). Regarding automation transparency it was reported that operators had insufficient capacity to simultaneously monitor automation and detect deviating system states and that they paid extra attention to the process state when working with the non-transparent interface. The question was raised as to which type of models and guiding principles should be used as the basis for design of human-automation collaboration? One problem appears to be that Level of Automation (LOA) is considered by some academics as a misguiding concept.

Suggested Regulatory Guidance	Related SAP Clauses
The limitations of current knowledge regarding Automation transparency should be articulated in cases where new technologies are under consideration. Appropriate validated research should be presented.	ESS.27

In response to question 3: Does new technology impact teamwork and conduct of operations? Bye described a study on handheld overview displays for ex-control room use, which brought the Shift Supervisor up-to-date before entering the control room (Karstadd et al, HWR-996, Kaarstad, HPR-384). It was found that in difficult scenarios, team engineering expertise was critical for performance and the quality of teamwork decreased with complexity and fatigue. The new technology led to less structured meetings, poor quality of briefings/discussions and communication errors. The conclusion from another study (Massaiu, HWR-1121) is that new technology must be developed to support crews, not add to complexity. Adaptive Automation (AA) may be the answer.

From the evidence presented it would appear that a new technology led to less structured meetings, poorer quality of briefings/discussions and communication errors. It may be the case that these issues would be resolved from adequate training and adaptation to new technologies by various teams.

Suggested Regulatory Guidance	Related SAP Clauses
New technologies should be designed to support teams of operators and not to add to complexity.	EHF.1-7
Training of operators in the use of new technology should be technology specific and sufficiently thorough.	EHF.8

Finally in response to question 4: Is human performance with regard to safety impact, similar in analogue and computerised control rooms, Bye reported the results of a series of studies using micro-tasks (HWR-1130, HWR-1169). This method uses decontextualized tasks, typically identification or verification tasks, with a frozen state of the plant or mini-scenarios. Data collections are short in duration and measure accuracy and speed (response time). The micro-task questions relate to indications available on the panels/display in front of the participant which are part of real control room tasks. The questions are easy to understand and quickly answered (< 20 sec) with a single choice between options or a numerical entry. Some results indicate the valve and pump questions show an advantage for conventional boards whereas questions about levels, pressures and differences show an advantage for digital displays.

A second strand to question 4 considered whether the cognitive task type mattered? Results were compared from two micro-task studies with task types in HRA methods. These were identification/verification tasks, i.e. check/reading versus calculation. The results showed a big difference in error rates in simple checks and calculation tasks and such empirical data should be used to update the HRA methods.

More data is required to consolidate these findings but it would appear that the type of cognitive task is as important a factor in human performance as the presentation mode, i.e. analogue or digital. For example, comparisons and calculations may be better in new digital solutions. One question is how to use modified HRA techniques for digital control rooms and on the design side, what are the best ways to present information.

Suggested Regulatory Guidance	Related SAP Clauses
Licensees should demonstrate that appropriate consideration has been given to the optimal way of presenting information to operators.	EHF.7

John O'Hara (BNL) and Stephen Fleger (NRC) also presented at the 2018 RIC meeting (Reference 57). They considered whether Adaptive Automation (AA) has the potential to improve human-automation team performance. They note that while automation technology has advanced, the technology for human-automation interaction has not and furthermore, there is limited Human Factors Engineering (HFE) guidance available for safety designers, regulators and safety reviewers. To address this gap, the NRC has been conducting research on general human-automation interaction and AA. So far, the research suggests that AA may help to keep operators 'in the loop' and maintain situation awareness; support vigilance by reducing complacency and boredom; maintain workload at an acceptable level and maintain skills by providing the opportunity for manual performance.

From the evidence presented it would appear that AA has a number of advantages, however there are still issues to be resolved. These issues mainly revolve around configuration changes, for example, the workload imposed by interacting with automation to achieve configuration changes; unexpected configuration changes; communication of roles and responsibilities associated with configuration changes; invoking thresholds and operators being interrupted by automation.

Suggested Regulatory Guidance	Related SAP Clauses
For new technologies, an appropriate assessment should be undertaken to understand the effects of interacting with automation to achieve configuration changes.	EHF.1-7

Impact of New Technologies on Human Reliability Analysis

ONR (Hickling & Bowie, 2013, Reference 58) have conducted a review of the HRAs submitted as part of the PSAs for two nuclear power station designs for construction in the UK (GDA). Both reactor designs have Human Systems Integration (HSI) driven by digital technology. The objective was to establish whether existing HRA methods are applicable to modern HSIs by conducting an extensive literature review and identifying or deriving relevant Human Error Probabilities (HEPs). Based on the data reviewed, it was concluded that existing HRA methods are probably optimistic in estimates of HEPs where diagnosis is involved or where process control is dependent on human-computer interaction.

Boring (2014, Reference 59) notes that none of the existing HRA methods, e.g. THERP, ASEP, SPAR-H, ATHEANA adequately addresses digital human machine interfaces (HMI), nor do they provide supplemental guidance to explain how to use these methods to evaluate operator performance with digital systems. Boring refers to U.S. NRC sponsored work at INL to look at HRA as related to computerised procedures (CPs) and small modularised reactors (SMRs) and recommends the following research in order to address HRA in digital HMIs:

- Conduct a systematic operating experience review of human errors in interacting with digital HMIs as documented by non-nuclear industries with significant digital HMI experience, e.g. the aviation industry and software firms. Note that Hickling and Bowie (2013, Reference 58) have already conducted a literature review on HRA in digital HMIs.
- Identify human failure events (HFEs) specific to nuclear power plant control room operations using digital HMIs. Boring reports that informal discussions with the PRA groups at an SMR vendor has suggested that the risk significant HFEs identified to date as part of the PRA licensing submittal have all centred on operation interaction with digital HMIs. The vendor has adopted conservative screening values as part of their HRA, however, this choice reflects the lack of ready HRA methods to conduct valid, detailed analysis on HFEs related to digital HMIs.
- Establish performance shaping factors (PSFs) that are unique to digital HMIs. These PSFs will need to be identified and the empirical basis for quantification established. Boring notes that in the HMI context, it is important to distinguish between internal and external PSFs. This distinction is generally not observed in most current HRA methods, however, when generalising PSFs to new interface technologies this distinction becomes important. Internal PSF are usually invariant across technologies and domains, since they arise within the individual. For example, regardless of whether high workload is caused by analogue instruments or multiple digital screens, the effect is the same on the operator's psychological experience. External PSFs reflect the external world that the operator interacts with, which can vary significantly from one domain to another and from one technology to another. It is therefore recommended that research should focus on documenting external PSFs in digital HMIs.
- Perform a validation study using a research simulator on the effects of digital HMIs on reactor operator performance. One approach could be to 'piggyback' small validation components on existing human factors studies, e.g. research on control room interfaces developed through the Light Water Reactors Sustainability (LWRS) project at INL. ONR (who have already conducted a literature review on this topic) should maintain a watching brief on the NRC research in order to identify and develop the necessary guidance to evaluate operator performance with digital systems. It should be noted, for example, that any guidance surrounding HRA should focus on the impact of external PSFs, which may vary according to the technology used.

Suggested Regulatory Guidance	Related SAP Clauses
Proposals for the introduction of digital systems should demonstrate the effect of such systems on operator performance via an appropriate human reliability assessment.	EHF.10

Training and competency requirements

There appeared to be a lack of literature on the training and competency requirements associated with the adoption of new technologies. Any material identified was incorporated into the findings of HSI/HAI/HMI research.

Bye (Reference 55) considered that operators should be trained to be more critical of all types of feedback. With regard to HRA, the question was raised as to whether automatic systems are dominated by positive feedback and how is training checked? Bye also reported that new technology led to less structured meetings, poorer quality of briefings/discussions and communication errors. It may be the case that these issues would be resolved from adequate training and adaptation to new technologies by various teams.

Strauch (Reference 56) discusses limitations in time and resources dedicated to training programs, which affect operators' expertise to effectively operate these automated systems. He concludes that automation-related operator errors can be reduced when automation is mapped to operator expertise levels and that automation training programs need to provide operators with the necessary contextual experiences.

Guidance relating to Human Factors

The lack of guidance for human factors and new nuclear technologies is an underlying theme throughout the review and it can be questioned as to whether existing human factors recognised good practice (RGP) and regulatory requirements are fit for purpose in the design, operation, maintenance and decommissioning of modern NPPs (although see Boring's, 2014 proposals above).

Hugo, Gertman & Tawfik (2013, Reference 60) report from their extended literature review that '...there remains a large gap in the availability of human factors guidance for the selection and deployment of HSI technologies for specific work domains in new NPPs as well as upgraded workplaces (that is control rooms, local control stations, workshops, laboratories, etc.)'.

Boring et al., (2015, Reference 61) developed the Guideline for Operational Nuclear Usability and Knowledge Elicitation (GONUKE) in order to fill gaps in guidance and create a step-by-step process for control room modernisation. GONUKE builds on best practice in the software industry by recommending an 'iterative user-centred approach with multiple cycles of design and evaluation'. Currently, nuclear regulatory guidance for control room design focuses on summative evaluation after the design is complete but GONUKE also conducts evaluation early in the design cycle by using mock-ups and prototypes for usability testing. At the summative phase, it is proposed that GONUKE involves expert review, e.g. design verification against human factors standards such as NUREG-0711 (Reference 62) and user-testing through integrated system validation. GONUKE also includes knowledge elicitation, in order to capture operator insights into the system.

A recent Safety Guide issued by the IAEA (June 2019, Reference 63), notes in paragraph 1.12, p. 3 that 'This Safety Guide applies to the application of HFE in the design, operation and maintenance of HMIs for new plants as well as for modifications of HMIs of existing plants'. This guidance follows RGP for human factors engineering in design, but offers no specific guidance for new technologies or new materials.

Since the ultimate objective of GONUKE is to provide nuclear industry guidance for the steps to be taken in support of design and evaluation of new human-machine interfaces in control rooms, it may be advisable to monitor developments in this area to determine how it can be applied to ONR guidance.

Suggested Regulatory Guidance	Related SAP Clauses
Control rooms which will employ new or novel technologies should demonstrate that the design and evaluation has been undertaken in accordance with last relevant good practice.	EHF.6, ESS.1-27, ESR.1-10

Human Factors Research at Idaho National Laboratory

Joe, Hanes and Kovesdi (2018, Reference 64) have produced a report for the U.S. Department of Energy (DoE) on Developing a Human Factors Engineering Program Plan and End State Vision to Support Full Nuclear Power Modernization. These authors have also presented conference papers outlining details of the programme (Joe, 2017, Reference 65; Kovesdi, Joe and Boring, 2017 Reference 66).

The DoE reports on the LWRS Research and Development (R&D) activity and milestones achieved. The report provides guidance for operating commercial NPPs to support the development and evaluation of an HFE programme management plan (PMP) and an end state vision for plant modernisation.

It also provides of examples of best practice and lessons learned in relation to HFE PMPs based on Main Control Room (MCR) modifications from analogue to digital C&I systems. This includes a summary of the rationale for full digital I&C integration but highlights a number of factors that need to be considered and describes how HFE should merge with full C&I integration.

Finally, the report considers the economic issues associated with the cost-justification of HFE involvement in plant modernisation.

The INL programme represents an excellent opportunity for ONR to consider how best to develop UK guidance that supports HFE programme management in modernised NPPs and full C&I integration into MCRs.

Suggested Regulatory Guidance	Related SAP Clauses
Cases for the introduction of new or novel technologies should be based upon RGP and the latest peer reviewed thinking.	SC.1-8, ESR.1-10, EHF.1-10

Levels of Automation (LOA) – Academic Critiques

Two recent journal Special Issues have considered the advantages and disadvantages of LOA in a range of safety-critical industries. Human Factors (2017), 59 (2) included a Special Section on Measuring Safety and Performance in Human-Automation Systems: Theories, Metrics, and Practice. The Journal of Cognitive Engineering and Decision Making (2018), 12 (1) included a Special Issue on Advancing Models of Human-Automation Interaction.

In the Human Factors Special Section, Marquez and Gore (2017, Reference 67), who work for NASA Ames, discussed the benefits of automation for time-critical tasks when it is not humanly possible for operators to respond quickly e.g. in fault management and the automatic landing sequence that allows Mars rovers to land safely on the surface of the planet. It was reported that as automation becomes ubiquitous in aerospace and other sectors, it is important for systems to be designed to take into consideration the known and documented disadvantages of human-automation. For example, skills degradation and the trade-off between performance, workload and situation awareness with the inclusion of degrees of automation.

Burns (2018, Reference 68) notes that a serious challenge for cognitive engineers and human factors engineers is keeping up with the rapid ongoing changes in technology and automation. She points out that modern automated systems are complex and operate in dynamic, multi-agent environments and can be upgraded and changed overnight, sometimes with significant changes to their functioning and LOA. [Note the recent aviation disasters involving the Boeing 737 Max, where the issue has been traced to a data-processing problem with the flight computer and FAA pilots in simulator studies discovering an issue that affected their ability to perform the procedure to counteract runaway stabiliser trim.]

Notwithstanding the considerable work done by the INL, BNL and NRC on HSI/HMI/HAI and modern nuclear technology, the academic community highlight a number of issues concerning current assumptions, models and frameworks for integrating humans and technologies, irrespective of the industry concerned. The ONR should consider implementing a watching brief on how human information processing and performance issues are being modelled in new technologies from a range of industries and how this could impact on guidance for the UK nuclear industry.

Suggested Regulatory Guidance	Related SAP Clauses
Licensees should demonstrate a clear assessment of the effect of new technologies on human information processing and performance.	EHF.1-10

Conclusions relating to Human Factors

This literature review has identified a number of research papers and reports that tackle the adoption of new technologies with a focus on Human Factors, including:

- Human-System Interface (HSI) implementation, e.g. digitalisation of nuclear power plant control rooms; integration of Control and Instrumentation; computerised procedures (CPs); automated work packages
- Impact of new technological designs on Human Reliability Analysis (HRA)
- Training and competency requirements for nuclear personnel in new designs
- Guidance for ensuring that chosen technologies support situation awareness, contribute to reduction of workload and support balanced task allocation
- Lessons learned from other industries, e.g. large, high-resolution displays, handheld and wearable devices and augmented reality systems
- The conclusions are that despite extensive research programmes on HSI/HMI/HAI implementation and the impact of new design on HRA, there are still many issues that remain unresolved. There is limited research on the training and competency requirements for nuclear personnel and new technologies and a lack of guidance on how new technologies will impact on human performance and safety. Finally, there may be more opportunities to learn lessons from other safety-critical industries, e.g. aviation, air traffic control, offshore oil and gas operations.

Summary of Regulatory Themes

The regulatory guidance described in this report has been collated into broad themes for incorporation in to a draft ONR Technical Assessment Guide on the introduction of new technologies and new materials. Whilst not exhaustive, the themes should provide significant guidance relating to the introduction of new technologies and new materials into the nuclear industry.

Theme 1: ALARP

Suggested Regulatory Guidance	Related SAP Clauses
A safety case for the introduction of new fuels, fuel manufacturing techniques or operating parameters should ideally combine a mixture of all of these methods outlined above to demonstrate their safety. In addition a safety case that indicates the safety of any experimental tests, an appropriate commissioning programme and an argument that failure of these elements would not lead to significant core damage and/or release of radioactivity or increased exposure to operators should also be produced.	ERC.1, ERC.3, ERC.4, EHT.1, EKP.1-5
A safety case should be made for any new fuel design or change of operating parameters to existing fuel. This safety case should draw upon (where applicable) modelling and testing in existing or prototype reactors. Computational models should be sufficiently validated against representative experimental data. Fuel irradiated for experimental purposes should be withdrawn early for PIE work to be conducted to forewarn of any incipient failure that could occur at an increased burn up.	ERC.1, ERC.3, ERC.4, EHT.1, AV.1-8, EMT.1-8
Because of the long time periods associated with storage and disposal it is unlikely that novel materials will have the associated data to fully justify them for these periods. In such cases a range of approaches may be adopted to support the safety case.	RW.1-7, AV.1-8
Before introducing new materials and technologies it is important that the safety case identify the important parameters that the new material/technology must meet.	SC.3-7, ECS.2-5, EKP.1
Facility or technology designs should set out the safety parameters that need to be met by any new novel aspects that wish to be introduced.	FP.1-8, SC.1-8, EKP.1-5
The Design Authority should play a key role in ensuring that any new novel approaches do not adversely affect the safety of the facility.	SC.1-8
When introducing any new technology or procedure the novel aspect must be subject to the same degree of safety analysis and scrutiny (depending upon its safety importance) as when the facility is first assessed licensed and this scrutiny should include discussions between operators and designers.	SC.1-8

Suggested Regulatory Guidance	Related SAP Clauses
New technologies should be tolerant of the environment that they will see through life.	EQU.1, ECM.1, EMT.3-4
New materials should demonstrate that any reduction in welds etc. is commensurate with an improvement in safety.	EMC.9, EKP.1
The performance of a new material or technology under fault conditions should be understood.	EMT.3, EMT.8, RP.2, FA.1
Any trial of new material or technology should wherever possible be such that the risk is gradually increased and where appropriate and proportionate, small scale laboratory, prototypes or demonstration tests should form part of the safety justification.	ECM.1, EMT.3-4
The risks and benefits of introducing new technologies should be considered against the risks and benefits of either using or adapting existing technologies.	FP.1-8, SC.1-8, EKP.1-5
For any new material or technology the Licensee should have appropriate oversight and exercise the appropriate control to minimise the potential risk from the novel approach.	FP.1-8, SC.1-8
The introduction of novel materials or technologies should be subject to the full rigour of safety analysis, justification and independent review.	SC.1-8, EMT.3-4, EKP.4-5
When considering new fuels the justification should not only cover in reactor performance but all associated activities, i.e. manufacture, transport, handling, storage, any intended reprocessing and ultimate disposal.	ERC.1-4, EHT.5, ECR.1-2
Any new technology should be subject to the same degree of rigour to justify its operation as any other nuclear technology. This should include a fully developed safety case and appropriate commissioning programme.	SC.1-8, ECM.1, EMT.3-4, EKP.1
New or novel materials or technologies that deliver a safety function should be identified and classified according to their significance to safety. The level of regulatory scrutiny applied should be proportional to the nuclear safety risk and appropriate time should be planned for the regulatory assessment of new or novel materials or technologies, especially if the facility is novel in nature.	MS.1-4, SC.1-8, ECS.2
There should be no relaxation in safety standards or requirements in relation to the introduction of new technologies, and that weaker safety cases should be avoided.	
The Licensee should carry out a fault study to examine the potential risks involved in introducing a new technology and where possible carry out tests to justify that that these risks have not occurred.	FA.1-14, EKP.2

Theme 2: Research and Development

Suggested Regulatory Guidance	Related SAP Clauses
In the absence of research reactors being available it is likely that prototype reactors will need to carry out many of the functions that would normally be carried out by research reactors. This may involve: • More extensive commissioning programmes than will be required for later facilities, • More extensive instrumentation • The ability of the prototype reactor to demonstrate safety outside of its normal operating regime	ECM.1, ESR.1-10, FA.1-25, SC.1-8
Development or process optimisation of new materials should be demonstrated at both laboratory and plant scale to demonstrate understanding of material properties.	ECS.5, EQU.1
The impact of additives on the performance of new materials should be understood through life.	ECS.5, EQU.1, EAD.1-5
Limitations in the deployment of new or novel materials should be understood prior to deployment.	SC.3-4, ECM.1, EKP.1
Safety cases for new technologies or new materials should be underpinned by an extensive research and development programme and a suitable commissioning programme.	SC.1-8, EMT.3-4, ECM.1
Current approaches to justifying novel fuels of using test reactors may not be feasible and the first of kind reactor may need to become the "test/demonstration reactor".	EMT.1-8, SC.1-8, ERC.1-4
New materials should demonstrate sufficient research and development to demonstrate engineering maturity.	EMC.1, ECE.3
New core materials should demonstrate an appropriate level of technical maturity prior to consideration for operational use.	ERC.3, ECE.3
In the absence of comprehensive experimental data supporting new technologies or materials, Licensees should consider incorporating further safety measures to reduce risks.	

Theme 3: Material Properties

Suggested Regulatory Guidance	Related SAP Clauses
Novel materials should be shown to be compatible with other materials in the facility.	EQU.1, EHA.17, EMC.13-16, EMC.22
Operators should define the potential operating conditions that the novel material will be subjected to and will need to identify all potential degradation mechanisms of the novel materials.	EMC.21-23, EAD.1-5, EKP.1-2
Novel materials should be characterised under representative operating conditions wherever possible.	EMT.3-4, EKP.1-2
New materials should be fully characterised under conditions representative to those which the materials will experience.	EMT.3-4, EKP.1
Materials manufactured using alternative processes or using new sources of precursor materials should be fully characterised to ensure that materials properties are comparable to originally manufactured materials.	EQU.1, ERL.1, EMT.8
The behaviour of new or novel materials in a neutron flux should be sufficiently understood to accurately predict material response through life.	EMT.3-4, EKP.1
The properties of new materials for civil engineering purposes should be characterised to understand safety performance through life.	ECE.25
New materials under consideration for construction should meet the design methodologies, and should be suitable to enable the design to be constructed.	ECE.16
New materials which incorporate self-healing properties should be demonstrated to meet required safety functions.	ECE.3, EKP.5
Safety justifications for new metallic materials should be comprehensive and suitably robust, and consider the effects of defects as well as defect tolerance.	EMC.1, EKP.1-2
New materials should consider the effect of mechanical loading through life.	EMC.7
Safety justifications for new metallic materials should be comprehensive and suitably robust, and consider the effects of defects as well as defect tolerance.	EMC.1

Theme 4: Use of Standards

Suggested Regulatory Guidance	Related SAP Clauses
New materials under consideration should demonstrate that development conforms to extant RGP.	ECE.16
New materials should conform to extant codes where codes exist, and any limits described in codes considered.	ECE.1
Cases for the introduction of new or novel technologies should be based upon RGP and the latest peer reviewed thinking.	SC.1-8, ESR.1-10, EHF.1-10

Theme 5: Verification and Validation

Suggested Regulatory Guidance	Related SAP Clauses
In instances where the regulator feels the need to gain additional confirmation to obtain confidence in a safety case, e.g. by experiments on materials or by software verification it may be useful to consider collaborating with other regulators in undertaking this work.	ECS.2-5
Novel technologies used to characterise materials should be verified and validated, and their limitations understood.	AV.1-8
Parties who wish to introduce new materials and technologies (and regulators that assess them) should recognise the important role that PIE can play in providing additional safety justification and ensure that this is properly incorporated (where available) in novel material and technology safety cases.	EMC.1-34
The commissioning process should be such that no new technology is installed upon the plant until after all tests to justify it have been evaluated.	ECM.1
New technologies should be subject to appropriate verification and validation in conditions representative of operation.	ECM.1, EMT.3-4
Validation of models supporting the development of new materials should be against experiments which closely match the expected plant condition.	ECE.15

Theme 6: Ageing and Degradation

Suggested Regulatory Guidance	Related SAP Clauses
The introduction of new materials may involve other issues than just a consideration of structural degradation properties. The performance of the material from initial component manufacture through to final waste management and disposal should to be considered.	ECS.2-5 EAD.1-5
Novel or new materials should be demonstrated to be compatible with existing materials under operational conditions through life.	EMT.3-4, EAD1-5
The safe working life of structures, systems and components containing new materials that are important to safety should be evaluated and defined at the design stage.	EAD.1
Adequate margins should exist throughout the life of a facility to allow for the effects of materials ageing and degradation processes on structures, systems and components containing new materials.	EAD.2
The ageing and degradation properties of new materials should be understood throughout life. This should include physical, mechanical, chemical and thermal properties.	EAD.1-5
New technologies should be tolerant of the environment that they will see through life.	EQU.1, ECM.1, EMT.3-4

Theme 7: Monitoring

Suggested Regulatory Guidance	Related SAP Clauses
Operators will also need to identify that suitable inspection/monitoring systems are available to detect any onset of degradation at a suitably early stage. Such inspection and monitoring systems should be shown to be suitable for the novel material. In many cases operators should consider a repair or replacement process in the event that the novel material does not behave as anticipated.	EMT.1-8, EMC.24-26
Programmes for monitoring, inspection, sampling surveillance and testing of new materials and technologies, to detect and monitor ageing and degradation processes, should be used to verify assumptions and assess whether the margins will be adequate for the remaining life of the structure, system or component.	ECS.2-5, EMT.1-7, EAD.1-5

Theme 8: Supply Chain

Suggested Regulatory Guidance	Related SAP Clauses
Where the new technology is being introduced by a contractor the Licensee should be fully aware and agree appropriate measures with the contractor to ensure that the new technology is justified.	SC.1-8
The operator is always responsible for the safety of its facility and in situations where it sub-contracts its work it must maintain an independent review and act as intelligent customer for the work or services being procured. Where this work is novel in nature and of high safety significance then the highest degree of external scrutiny must be applied.	FP.1-2
The introduction of new technologies may be resource intensive, but early and continued engagement with the regulator should be supported by the operator or Licensee.	MS.1-4

Theme 9: E, C& I

Suggested Regulatory Guidance	Related SAP Clauses
For novel C&I systems there is an architecture of principles that should be adopted in designing the system.	ESR.1-10
For any novel technology, but especially for a novel C&I system, that is being introduced into an existing facility it is important that the novel technology be compatible with the existing technologies and systems on the facility.	EMT.3-4, ESR.1-10
Novel methods of instrumentation need to ensure that there is no common mode fault and justified across the full operating range.	EDR.3, EMT.3, EMT.6-7, ECM.1
Structures, systems and components incorporating novel technologies should be type tested before they are installed to conditions equal to, at least, the most onerous for which they are designed.	ECM.1, EMT.3, EKP.1
A new facility with new technology should have comprehensive instrumentation to inform the operators that the facility is operating as planned and for the facility to have adequate shutdown instructions in the event that it does not.	EHF.6, ESR.1-10
Operators should undertake a staged approach for to justify any proposed SMART/COTS devices and regulatory assessment could comprise of an assurance that all these stages have been undertaken and carried out properly.	SC.1-8, ESS.1-27, ESR.1-10
A staged approach is equally applicable for other safety related components purchased from sub-contractors and the assessment	SC.1-8, ESS.1-27, ESR.1-10

Suggested Regulatory Guidance	Related SAP Clauses
process should ensure that these steps have been carried out by the operator.	
SMART and COTS devices should consider safety and security requirements in an integrated fashion. Similarly for any novel safety innovation that is to be introduced, its impact not only to safety needs to be considered but also its potential impact on security (and the environment).	MS.2

Theme 10: Autonomous Systems

Suggested Regulatory Guidance	Related SAP Clauses
Any robotics or AI that is to be used in the nuclear industry for safety related purposes should be verified for the operating conditions that it is planned to operate in.	ECM.1, EMT.3-4
This verification should include written documentation stating the reasons why this component is deemed to be safe for its intended use in the nuclear industry.	SC.1-8
Any component involving robotics or AI should have all aspects of that component verified, i.e. sub-components, systems and multi-systems.	EMT.3-4
Such components should be shown to be compatible with the site's radioactive waste management plan.	DC.2
The limitations of current knowledge regarding Automation transparency should be articulated in cases where new technologies are under consideration. Appropriate validated research should be presented.	

Theme 11: Human Factors

Suggested Regulatory Guidance	Related SAP Clauses
New technologies should be designed with the user in mind, and should contain a workable user human machine interface, as well as allow for effective user training.	EHF.1-12
When novel procedures are adopted, e.g. during commissioning detailed operating procedures must be produced that have been subject to the same degree of scrutiny as routine operating procedures and these procedures should also provide information to the operator on what to do if things do not go as planned.	SC.1-8, EHF.3-5,9-10
No variation to planned operating procedures should be allowed without full safety analysis and scrutiny.	EHF.3, EHF.9, EHF.10
Operators carrying out the novel procedures should be fully trained and competent.	EHF.8
New designs of control room should set standards for the human interface requirements that need to be met and these should be tested.	ESS.1-27, ESR.1-10
For new technologies, consideration should be given to how feedback from automatic evaluation systems in computerised procedure systems should be presented.	EHF.1-7
Operators should be trained to be appropriately critical of all types of feedback received from computerised procedure systems.	EHF.8
The training of operators should be checked prior to the operation of new technologies, and periodically throughout life.	EHF.8
Licensees should provide evidence that automatic systems are not dominated by positive feedback.	ESR.9-10
New technologies should be designed to support teams of operators and not to add to complexity.	EHF.1-7
Training of operators in the use of new technology should be technology specific and sufficiently thorough.	EHF.8
Licensees should demonstrate that appropriate consideration has been given to the optimal way of presenting information to operators.	EHF.7
For new technologies, an appropriate assessment should be undertaken to understand the effects of interacting with automation to achieve configuration changes.	EHF.1-7
Proposals for the introduction of digital systems should demonstrate the effect of such systems on operator performance via an appropriate human reliability assessment.	EHF.10

Suggested Regulatory Guidance	Related SAP Clauses
Control rooms which will employ new or novel technologies should demonstrate that the design and evaluation has been undertaken in accordance with last relevant good practice.	EHF.6, ESS.1-27, ESR.1-10
Licensees should demonstrate a clear assessment of the effect of new technologies on human information processing and performance.	EHF.1-10

Theme 12: Leadership and Management for Safety

Suggested Regulatory Guidance	Related SAP Clauses
All relevant OPEX, even if not from the same design of facility should be considered in the safety case and facility design.	MS.4
Any new material, technology or process should clearly demonstrate the benefits anticipated to result, especially to safety.	FP.1-8, SC.1-8
If a Licensee wishes to introduce a novel technology onto its facility then it should enter into early engagement with the regulator.	MS.1-4

Theme 13: Radioactive Waste and Decommissioning

Suggested Regulatory Guidance	Related SAP Clauses
The generation of radioactive waste from new materials should be prevented or, where this is not reasonably practicable, minimised in terms of quantity and activity.	RW.1-7
Disassembly aspects of new material containing facilities should be considered before introduction, including long term environmental impact and waste management requirements.	DC.1
The risk of radionuclide leech into the environment during operation and long term post irradiation storage should be assessed and minimised.	RW.1-7, RL.1
The long term storage properties of materials should be understood with regard to potential failure of encapsulation or containment.	EAD.1-5, RW.5
New technologies should be designed for decontamination if used in a contaminated environment.	DC.1, RP.4-5

Appendix 1: Review of ONR SAPs for Applicability to New Materials or Technologies

SAPs applicability to the introduction of New Technologies and Materials

The Table below is a high level review of the ONR Safety Assessment Principles, 2014 Edition, Revision 0. The review considers whether the identified guidance within the SAPs is applicable to situations where novel technologies or new materials have been, or are to be introduced into a facility, system or site.

The table is not a detailed review of each piece of guidance, and only indicates whether the guidance appears to be applicable. It is intended to direct further attention, or where to apply effort to understand the implications of novel technologies or new materials.

Ref. No	SAP.	Page/Para	Applicability	Comment
1	Introduction/Regulatory Background	P8, para 7 and 8	Yes	New materials will be required to comply with legislation relating to chemicals etc. such as REACH.
2	Introduction/SFAIRP, ALARP and ALARA	P9, para 14	Yes	Introduction of new materials or technologies will have to meet the fundamental requirement to reduce risks ALARP through the application of good engineering practice. In doing to, it is anticipated that comprehensive risk assessments will have been undertaken to identify limitations, weaknesses or constraints in new materials or technologies, as well as identifying where improvements could be made and demonstrating that safety is not predicated on a small subset of material or technological characteristics.
3	Introduction/ Application of the SAPs	P11, para 26	No	Outwith the scope of this work.

Ref. No	SAP.	Page/Para	Applicability	Comment
4	Introduction/proportionality	P11, para 29	Yes	The magnitude of the risk posed through the introduction of new materials or technologies will determine the extent of the safety analysis, and the requirement for defence in depth, a lower hazard technology or material requiring a more limited analysis than a higher hazard (or less well characterised) technology or material.
5	Introduction/safety and security assessments	P13, para 41	Yes	Where the introduction of new technologies or materials have both safety and security elements, consideration may have to be given to how to sufficiently demonstrate the safety of the material or technology whilst also considering any security contribution. In these circumstances, further guidance on security related matters may be required.
Fundamental principles guidance, below, has been assessed as generally applicable to the introduction of novel technologies or new materials, and should therefore be considered during assessment.				
6	FP.1 Responsibility for Safety	Page 16	Yes	High-level organisational or personal responsibility for safety is also applicable for new materials or technologies introduced with potential nuclear safety risks.
7	FP.2 Leadership and Management for Safety	Page 16	Yes	Whilst specifically targeted at facilities and activities that give rise to radiation risks, the SAP is also equally applicable to the introduction of new materials or technologies that could also give rise to radiation risks.
8	FP3. Optimisation of protection	Page 16	Yes	Equally applicable to extant materials and technologies as well as new materials and technologies.
9	FP.4 Safety Assessment	Page 16	Yes	Applicable in that hazards posed by the introduction of new materials or technologies that form part of a site or facility will need to be understood and controlled.
10	FP.5 Limitation of risks to Individuals	Page 17	Yes	Introduction of new materials or technologies must not pose an unacceptable risk of harm to an individual through radiation risk.

Ref. No	SAP.	Page/Para	Applicability	Comment
11	FP.6 Prevention of accidents	Page 17	No	Not specifically applicable to new technologies or materials. However, general theme of accident prevention is still valid from the use of any material or technology.
12	FP.7 Emergency preparedness and response	Page 17	No	Not specifically applicable to new technologies or materials. However, general theme of emergency preparedness is still valid from the use of any material or technology.
13	FP.8 Protection of present and future generations	Page 17	Yes	The introduction of new technologies or materials may well have a bearing on the protection of present and future generations.
Leadership and management for safety guidance, below, has been assessed as largely not applicable to novel technologies or new materials, with the exception of lessons learned, which should be considered.				
14	MS.1 Leadership	Page 18	No	Not specifically applicable to new technologies or materials.
15	MS.2 Capable organisation	Page 20	No	Not specifically applicable to new technologies or materials.
16	MS.3 Decision making	Page 21	No	Not specifically applicable to new technologies or materials.
17	MS.4 Learning	Page 22	Yes	Lessons should be learned from the previous introduction of new technologies or materials.
Safety case guidance, below, has been assessed as applicable to the introduction of novel technologies or new materials.				
18	SC.1 Safety case production process	Page 26	Yes	Where new technologies or materials are to be introduced, an appropriate safety case should be developed.
19	SC.2 Safety case process outputs	Page 27	Yes	Outputs of a safety case should consider safety implications of introducing new technologies or new materials.
20	SC.3 Lifecycle aspects	Page 27	Yes	Safety cases should consider through life implications of introducing new technologies or materials.
21	SC.4 Safety case characteristics	Page 28	Yes	Hazards associated with the introduction of new technologies or new materials

Ref. No	SAP.	Page/Para	Applicability	Comment
				should be identified and risks minimised.
22	SC.5 Optimism, uncertainty and conservatism	Page 29	Yes	Safety cases relating to the introduction of new technologies or new materials should address uncertainties associated with limitations in data or understanding.
23	SC.6 Safety case content and implementation	Page 30	Yes	Safety cases relating to the introduction of new technologies or new materials should describe the necessary processes for safe operation.
24	SC.7 Safety case maintenance	Page 30	Yes	Safety cases relating to the introduction of new technologies or new materials should be formally reviewed through life at appropriate intervals.
25	SC.8 Safety case ownership	Page 31	Yes	The Licensee or dutyholder responsible for safety should demonstrably own safety cases relating to the introduction of new technologies or new materials.
Siting guidance, below, has been assessed as not applicable to the introduction of novel technologies or new materials.				
26	ST.1 Development control planning advice	Page 34	No	Not specifically applicable to new technologies or materials.
27	ST.3 Local physical aspects	Page 35	No	Not specifically applicable to new technologies or materials.
28	ST.4 Suitability of the site	Page 36	No	Not specifically applicable to new technologies or materials.
29	ST.5 Effect on other hazardous installations	Page 35	No	Not specifically applicable to new technologies or materials.
30	ST.6 Multi-facility sites	Page 35	No	Not specifically applicable to new technologies or materials.
Key engineering principles guidance, below, has been assessed as fully applicable to novel technologies and new materials and as such requires full consideration.				
31	EKP.1 Inherent safety	Page 37	Yes	Any new technologies or materials should not diminish existing claims on the inherent safety of a nuclear facility.
32	EKP.2 Fault tolerance	Page 38	Yes	The introduction of new materials or technologies should not increase the

Ref. No	SAP.	Page/Para	Applicability	Comment
				sensitivity of the facility to potential faults.
33	EKP.3 Defence in depth	Page 38	Yes	New technologies or materials must not reduce or degrade independent barriers to fault progression.
34	EKP.4 Safety function	Page 39	Yes	New technologies or materials which contribute to a facility safety function should be characterised.
35	EKP.5 Safety measures	Page 39	Yes	New technologies or materials which contribute to, or constitute safety measures should be understood and characterised.
Safety classification guidance, below, has been assessed as fully applicable to novel technologies and new materials and as such requires full consideration.				
36	ECS.1 Safety characterisation	Page 41	Yes	New technologies or materials which contribute to a facility safety function should be characterised.
37	ECS.2 Safety classification of structures, systems and components	Page 41	Yes	New technologies or materials which contribute to a facility safety function should be characterised.
38	ECS.3 Codes and Standards	Page 42	Yes	Where codes and standards exist which could apply to new technologies and materials, they should be applied. However, this may not always be possible for novel technologies and materials for which codes and standards have not yet been developed.
39	ECS.4 Absence of established codes and standards	Page 43	Yes	See No. 38 above. Near neighbour codes and standards may have to be employed for new technologies and materials in the absence of specific guidance, but should be utilised where appropriate.
40	ECS.5 Use of experience, test or analysis	Page 43	Yes	In the probable absence of established codes and standards, the use of experience, tests or analysis will take on additional significance, and should be applied to the introduction of novel technologies or materials.
Equipment qualification guidance, below, has been assessed to be applicable to the introduction of new materials and novel technologies.				

Ref. No	SAP.	Page/Para	Applicability	Comment
41	EQU.1 Qualification procedures	Page 43	Yes	Novel technologies or materials should be qualified to demonstrate that they will perform their safety function(s) in all normal, fault and accident conditions identified in the safety case and for the duration of their operational lives.
Design for reliability guidance, below, has been assessed as largely applicable to the introduction of novel technologies and new materials and as such should be fully considered in assessments.				
42	EDR.1 Failure to safety	Page 44	Yes	Novel technologies and new materials should be designed to be inherently safe, or to fail in a safe manner. Potential safety modes should be identified, using a formal analysis where appropriate.
43	EDR.2 Redundancy, diversity and segregation	Page 44	Yes	Redundancy, diversity and segregation should be considered during the design and commissioning phases where novel technologies and materials are to be used.
44	EDR.3 Common cause failure	Page 45	Yes	Where new technologies or new materials provide high reliability, common cause failure should be addressed.
45	EDR.4 Single failure criterion	Page 45	Yes	Applicable to novel technologies which are designed to fulfil a Category A safety function and also where uncertainty in fundamental understanding exists.
Reliability guidance, below, has been assessed as fully applicable to novel technologies and new materials and as such requires full consideration.				
46	ERL.1 Form of claims	Page 45	Yes	Reliability claims assigned to novel technologies or materials should take into account novelty, experience relevant to the proposed environment, and uncertainties in operating and fault conditions, physical data and design methods.
47	ERL.2 Measures to achieve reliability	Page 46	Yes	The measures proposed to demonstrate the required reliability of novel technologies or materials should be stated.
48	ERL.3 Engineered safety measures	Page 46	Yes	It is possible that novel technologies or materials may be proposed as engineered safety measures, subject to appropriate qualification etc.
49	ERL.4 Margins of conservatism	Page 46	Yes	Not directly applicable, but safety cases involving novel technologies or materials may require additional conservatism to account for increased uncertainties from

Ref. No	SAP.	Page/Para	Applicability	Comment
				reduced levels of knowledge.
Commissioning guidance, below, has been assessed as applicable to novel technologies and new materials and as such requires consideration.				
50	ECM.1 Commission testing	Page 47	Yes	Facilities or processes which incorporate novel technologies or new materials should be subject to appropriate commissioning tests defined in the safety case.
Maintenance, inspection and testing guidance, below, has been assessed as fully applicable to novel technologies and new materials and as such requires full consideration.				
51	EMT.1 Identification of requirements	Page 48	Yes	The requirements for the in-service testing of new technologies or materials should be defined in the safety case.
52	EMT.2 Frequency	Page 48	Yes	Structures, systems and components which contain novel technologies or materials should receive regular and systematic EIMT as defined in the safety case.
53	EMT.3 Type-testing	Page 48	Yes	Structures, systems and components which contain novel technologies or materials should be tested prior to installation to conditions equal to, at least, the most onerous for which they are designed.
54	EMT.4 Validity of equipment qualification	Page 49	Yes	Structures, systems or components which contain novel technologies or new materials should not be degraded by any modification or by the carrying out of EIMT.
55	EMT.5 procedures	Page 49	Yes	Commissioning and in-service inspection procedures should be adopted for structures, systems and components which contain novel technologies or materials.
56	EMT.6 Reliability claims	Page 49	Yes	Provision should be made for the testing, maintaining, monitoring and inspecting structures, systems and components which contain novel technologies or new materials in service or at intervals throughout their life, commensurate with the reliability required of each item.
57	EMT.7 Functional testing	Page 50	Yes	In-service functional testing of structures, systems and components containing novel technologies or new materials should prove the complete system and the

Ref. No	SAP.	Page/Para	Applicability	Comment
				safety function of each functional group.
58	EMT.8 Continuing reliability following events	Page 50	Yes	Structures, systems or components containing novel technologies or new materials should be inspected and/or re-validated after any event that might have challenged their continuing reliability.
Ageing and degradation guidance, below, has been assessed as completely applicable to novel technologies and new materials and as such requires full consideration.				
59	EAD.1 Safe working life	Page 50	Yes	The safe working lifetime of structures, systems and components which contain novel technologies or materials important to safety should be evaluated at the design stage.
60	EAD.2 Lifetime margins	Page 50	Yes	Adequate margin should exist throughout the life of the facility to allow for the effects of materials ageing and degradation processes on structures, systems and components containing novel technologies or materials.
61	EAD.3 Periodic measurement of material properties	Page 51	Yes	Where material properties could change with time and affect safety, provision should be made for periodic measurement of the properties. This is applicable for new materials.
62	EAD.4 Periodic measurement of parameters	Page 51	Yes	Where parameters relevant to the design of plant could change with time and affect safety, provision should be made for their periodic measurement. This is applicable to novel technologies or materials.
63	EAD.5 Obsolescence	Page 51	Yes	A process for reviewing the obsolescence of structures, systems and components containing novel technologies or materials important to safety should be in place.
Layout guidance, below, has been assessed as mostly inapplicable to novel technologies or new materials. However, access systems may employ novel technologies, and as such should be assessed.				
64	ELO.1 Access	Page 52	No/ Maybe	Not directly relevant. However, novel technologies may be employed within access systems.

Ref. No	SAP.	Page/Para	Applicability	Comment
65	ELO.2 Unauthorised access	Page 52	No/ Maybe	Unauthorised access to, or interference with, structures, systems and components containing novel technologies or materials, or reference data (including Building Information Modelling (BIM) should be prevented.
66	ELO.3 Movement of nuclear matter	Page 52	No	Site or facility layout not relevant to novel technologies or materials.
67	ELO.4 Minimisation of the effects of incidents	Page 53	No	Site or facility layout not relevant to novel technologies or materials.
External and internal hazards guidance, below, has been assessed as largely not applicable to the introduction of novel technologies or new materials. However, consideration should be given to specific guidance as necessary.				
68	EHA.1 Identification and characterisation	Page 54	No	Characterisation of internal and external hazards not directly relevant to novel technologies or materials.
69	EHA.19 Screening	Page 54	No	Screening of hazards with no significant contribution to overall risks is not directly applicable to novel technologies or materials.
70	EHA.2 Data sources	Page 55	No	Not specifically applicable to the introduction of novel technologies or materials.
71	EHA.3 Design basis events	Page 55	No	Not directly relevant to the introduction of novel technologies or materials.
72	EHA.4 Frequency of initiating event	Page 55	No	Not directly relevant to the introduction of novel technologies or materials.
73	EHA.6 Analysis	Page 56	No	Not directly relevant to the introduction of novel technologies or materials.
74	EHA.5 Design basis event operating states	Page 56	No	Not directly relevant to the introduction of novel technologies or materials.
75	EHA.18 Beyond design basis events	Page 57	No	Not directly relevant to the introduction of novel technologies or materials.
76	EHA.7 'Cliff-edge' effects	Page 57	No	Not directly relevant to the introduction of novel technologies or materials.

Ref. No	SAP.	Page/Para	Applicability	Comment
77	EHA.8 Aircraft crash	Page 58	No	Not directly relevant to the introduction of novel technologies or materials.
78	EHA.9 Earthquakes	Page 58	No	Not directly relevant to the introduction of novel technologies or materials.
79	EHA.10 Electromagnetic interference	Page 59	Yes	The facility design should include preventative and/or protective measures against the effects of electromagnetic interference. This may impact the introduction of novel technologies or materials.
80	EHA.11 Weather conditions	Page 59	No	Not directly relevant to the introduction of novel technologies or materials.
81	EHA.12 Flooding	Page 59	No	Not directly relevant to the introduction of novel technologies or materials.
82	EHA.13 Use, storage and generation of hazardous materials	Page 61	Yes	Relevant where new technologies or materials are proposed to store hazardous materials.
83	EHA.14 Fire, explosion, missiles, toxic etc. – sources of harm	Page 61	No	Not directly relevant to the introduction of novel technologies or materials.
84	EHA.15 Hazards due to water	Page 61	No	Not directly relevant to the introduction of novel technologies or materials.
85	EHA.17 Appropriate materials in case of fires	Page 61	Yes	Non-combustible or fire-retardant and heat-resistant materials should be used throughout the facility (see Principle EKP.1). This applies to new materials.
86	EHA.16 Fire detection and fighting	Page 62	Yes	Fire detection and fire-fighting systems of a capacity and capability commensurate with the worst-case design basis scenarios should be provided. This is applicable to systems containing novel technologies.
Pressure systems guidance, below, has been assessed as almost completely applicable to novel technologies and new materials and as such requires full consideration.				
87	EPS.1 Removable enclosures	Page 62	Yes	The failure of a removable enclosure to a pressurised component or system that could lead to a significant release of radioactivity should be prevented. This is applicable to both new materials and novel technologies.

Ref. No	SAP.	Page/Para	Applicability	Comment
88	EPS.2 Flow limitation	Page 62	Yes	Flow limiting devices which contain novel technologies or materials should be qualified before fitment to piping systems.
89	EPS.3 Pressure relief	Page 63	Yes	Pressure relief systems containing novel technologies should be qualified before installation.
90	EPS.5 Discharge routes	Page 63	No	Not directly relevant to the introduction of novel technologies or materials.
Integrity of metallic components and structures guidance, below, has been assessed as almost completely applicable to novel technologies and new materials and as such requires full consideration.				
91	EMC.1 Safety case and assessment	Page 66	Yes	More specifically relevant to new or novel materials than technologies (unless novel technologies have been used to generate materials). New materials should be demonstrated to be as defect-free as possible, and also tolerant to defects.
92	EMC.2 Use of scientific and technical issues	Page 66	Yes	Scientific and technical issues should be assessed within the safety case if new materials or novel technologies are to be employed.
93	EMC.3 Evidence	Page 66	Yes	Evidence supporting the necessary level of integrity of new materials or novel technologies should be presented as part of the safety case.
94	EMC.4 Procedural Control	Page 68	Yes	Procedural control should be applied to the manufacture or development of new materials or novel technologies.
95	EMC.5 Defects	Page 68	Yes	New materials important to safety should be demonstrated to be free from significant defects and tolerant of defects.
96	EMC.6 Defects	Page 68	Yes	It should be possible to establish the existence of defects of concern throughout the lifetime of the facility.
97	EMC.7 Loadings	Page 68	Yes	The loading on new materials through life should be understood over the lifetime of the facility.
98	EMC.8 Providing for	Page 69	Yes	Important for new materials where performance through life is uncertain.

Ref. No	SAP.	Page/Para	Applicability	Comment
	examination			
99	EMC.9 Product form	Page 69	Yes	The form of new metallic materials should consider ease of examination and to minimising the number and length of welds in the component.
100	EMC.10 Weld positions	Page 69	Yes	For metallic components containing new materials the positioning of welds should have regard to high-stress locations and adverse environments.
101	EMC.11 Failure modes	Page 69	Yes	For metallic components containing new materials failure modes should be gradual and predictable.
102	EMC.12 Brittle behaviour	Page 69	Yes	For metallic components containing new materials, designs in which components of a metal pressure boundary could exhibit brittle behaviour should be avoided.
103	EMC.13 Materials	Page 70	Yes	New materials employed in manufacture and installation should be shown to be suitable for the purpose of enabling adequate design to be manufactured, operated, examined and maintained throughout the life of the facility.
104	EMC.14 Techniques and procedures	Page 70	Yes	Manufacture and installation should use proven techniques and approved procedures to minimise the occurrence of defects that might affect the integrity of components or structures.
105	EMC.15 Control of materials	Page 70	Yes	For new or novel materials, identification, storage and issue should be closely controlled.
106	EMC.16 Contamination	Page 70	Yes	The potential for contamination of new materials during manufacture and installation should be controlled to ensure the integrity of components and structures is not compromised.
107	EMC.18 Third party inspection	Page 70	Yes	Manufacture and installation of new materials or components should be subject to appropriate third-party independent inspection to confirm that processes and procedures are being followed.

Ref. No	SAP.	Page/Para	Applicability	Comment
108	EMC.19 Non-conformities	Page 71	Yes	Where non-conformities with procedures are judged to have a detrimental effect on integrity or significant defects are found and remedial work is necessary, the remedial work should be carried out to an approved procedure and should apply the same standards as originally intended.
109	EMC.20 Records	Page 71	Yes	Detailed records of manufacturing, installation and testing activities should be made and be retained in such a way as to allow review at any time during subsequent operation.
110	EMC.27 Examination	Page 71	Yes	Provision should be made for examination that is capable of demonstrating with suitable reliability that the component or structure has been manufactured to an appropriate standard and will be fit for purpose at all times during future operations.
111	EMC.28 Margins	Page 71	Yes	An adequate margin should exist between the nature of defects of concern and the capability of the examination to detect and characterise a defect.
112	EMC.29 Redundancy and diversity	Page 72	Yes	Methods of examination of components and structures should be sufficiently redundant and diverse where new materials or components have been introduced.
113	EMC.30 Qualification	Page 72	Yes	Personnel, equipment and procedures should be qualified to an extent consistent with the overall safety case and the contribution of examination to structural integrity aspects of the safety case.
114	EMC.21 Safe operating envelope	Page 72	Yes	Throughout their operating life, components and structures containing new materials should be operated and controlled within defined limits and conditions (operating rules) derived from the safety case.
115	EMC.22 Material compatibility	Page 72	Yes	Materials compatibility for components containing new or novel materials should be considered for any operational or maintenance activity.

Ref. No	SAP.	Page/Para	Applicability	Comment
116	EMC.23 Ductile behaviour	Page 72	Yes	For metal pressure vessels and circuits which contain new materials or novel technologies, particularly ferritic steel items, the operating regime should ensure that they display ductile behaviour when significantly stressed.
117	EMC.24 Operation	Page 73	No	Not directly relevant to the introduction of novel technologies or materials.
118	EMC.25 Leakage	Page 73	Yes	Should novel technologies be employed to detect leakages, they should be appropriately qualified for use.
119	EMC.26 Forewarning of failure	Page 73	No	Not directly relevant to the introduction of novel technologies or materials.
120	EMC.31 Repairs and modifications	Page 74	Yes	Should new materials or technologies be used in repairs or modifications they should be understood and justified for use.
121	EMC.32 Stress analysis	Page 74	Yes	Applicable to new materials which should undergo stress analysis to support substantiation of the design through life.
122	EMC.33 Use of data	Page 74	Yes	Conservatism should be applied to data from new materials. This is of additional significance if limited data are available.
123	EMC.24 Defect sizes	Page 74	Yes	Where new materials have been incorporated into high reliability components and structures, the sizes of crack-like defects of structural concern should be calculated using verified and validated fracture mechanics methods with verified application.
Integrity of non-metallic components guidance, below, has been assessed as fully applicable to novel technologies and new materials and as such requires full consideration.				
124	ENC.1 Limits of application	Page 76	Yes	Where a non-metallic component or structure is chosen in preference to a metallic equivalent, the safety case should identify and then justify any limitations arising from this choice compared to using a metallic item. Additional justification may also be required for the use of new non-metallic materials in this circumstance.

Ref. No	SAP.	Page/Para	Applicability	Comment
125	ENC.2 Examination through life	Page 76	Yes	The design of non-metallic components or structures should include the ability to examine the item through life for signs of degradation. This will include new materials.
Civil engineering guidance, below, has been assessed to be partially applicable to novel technologies and new materials and thus will require consideration on a case-by-case basis against specific guidance.				
126	ECE.1 Functional performance	Page 77	No	Not directly relevant to the introduction of novel technologies or materials.
127	ECE.2 Independent arguments	Page 78	No	Not directly relevant to the introduction of novel technologies or materials.
128	ECE.3 Defects	Page 79	Yes	It should be demonstrated that structures important to safety are sufficiently free of defects so that their safety functions are not compromised, that identified defects can be tolerated, and that the existence of defects that could compromise safety functions can be established through their lifecycle. This applies to structures containing new materials.
129	ECE.4 Natural site materials	Page 79	No	Not directly relevant to the introduction of novel technologies or materials.
130	ECE.5 Geotechnical investigation	Page 79	No	Not directly relevant to the introduction of novel technologies or materials.
131	ECE.6 Loadings	Page 79	No	Not directly relevant to the introduction of novel technologies or materials.
132	ECE.7 Foundations	Page 80	No	Not directly relevant to the introduction of novel technologies or materials, unless new materials or novel technologies are to be used in foundation construction.
133	ECE.8 Inspectability	Page 80	No	Not directly relevant to the introduction of novel technologies or materials.
134	ECE.9 Earthworks	Page 80	No	Not directly relevant to the introduction of novel technologies or materials.
135	ECE.10 Groundwater	Page 81	No	Not directly relevant to the introduction of novel technologies or materials.
136	ECE.11 Naturally occurring explosive gases	Page 81	No	Not directly relevant to the introduction of novel technologies or materials.

Ref. No	SAP.	Page/Para	Applicability	Comment
137	ECE.25 Provision for construction	Page 81	No	Not directly relevant to the introduction of novel technologies or materials.
138	ECE.26 Provision for decommissioning	Page 81	No	Not directly relevant to the introduction of novel technologies or materials.
139	ECE.12 Structural analysis and model testing	Page 81	Yes	Structural analysis and/or model testing should be carried out to support the design and should demonstrate that the structure can fulfil its safety functional requirements over the full range of loading for the lifetime of the facility. This will be applicable to designs containing new materials or novel technologies.
140	ECE.13 Use of data	Page 82	Yes	Should new materials be used in structures, the data used in structural analysis should be selected or applied so that the analysis is demonstrably conservative.
141	ECE.14 Sensitivity studies	Page 82	Yes	There may be uncertainties associated with new or novel material, the sensitivity of which should be understood.
142	ECE.15 Validation of methods	Page 82	No	Not directly relevant to the introduction of novel technologies or materials.
143	ECE.16 Materials	Page 82	Yes	If new materials are used in construction, the construction materials used should comply with the design methodologies employed, and be shown to be suitable for enabling the design to be constructed and then operated, inspected and maintained throughout the life of the facility.
144	ECE.17 Prevention of defects	Page 83	Yes	If new materials are used in construction, the construction should use appropriate materials, proven techniques and a quality management system to minimise defects that might affect the required integrity of structures.
145	ECE.18 Inspection during construction	Page 83	No	Not directly relevant to the introduction of novel technologies or materials.
146	ECE.19 Non-conformities	Page 83	No	Not directly relevant to the introduction of novel technologies or materials.
147	ECE.20 Inspection, testing and	Page 83	Yes	Use of new or novel materials during construction should attract an enhanced

Ref. No	SAP.	Page/Para	Applicability	Comment
	monitoring			inspection programme.
148	ECE.21 Proof pressure tests	Page 84	Yes	Pre-stressed concrete pressure vessels and containment structures should be subjected to a proof pressure test, which may be repeated during the life of the facility. This is applicable if new materials or technologies have been involved in the construction of the pressure vessel.
149	ECE.22 Leak tightness	Page 84	No	Not directly relevant to the introduction of novel technologies or materials.
150	ECE.23 Inspection of sea and river flood defences	Page 84	No	Not directly relevant to the introduction of novel technologies or materials.
151	ECE.24 Settlement	Page 84	No	Not directly relevant to the introduction of novel technologies or materials.
Graphite reactor guidance, below, has been assessed as almost completely applicable to novel technologies and new materials and as such requires full consideration.				
152	EGR.1 Safety cases	Page 85	Yes	If novel technologies or materials are employed in graphite reactor cores, then the safety case should demonstrate that either (a) the graphite reactor core is free from defects that could impair its safety functions; or (b) the safety functions of the graphite reactor core are tolerant of those defects that might be present.
153	EGR.2 Demonstration of tolerance	Page 86	Yes	Should the graphite reactor core design employ novel technologies or materials, the design should demonstrate tolerance of graphite reactor core safety functions to: (a) ageing processes; (b) the schedule of design loadings (including combinations of loadings); and (c) potential mechanisms of formation of, and defects caused by, design specification loadings.

Ref. No	SAP.	Page/Para	Applicability	Comment
154	EGR.3 Monitoring	Page 87	Yes	Should the graphite reactor core design employ novel technologies or materials, there should be appropriate monitoring systems to confirm the graphite structures are within their safe operating envelope (operating rules) and will remain so for the duration of the life of the facility.
155	EGR.4 Inspection and surveillance	Page 87	Yes	Should the graphite reactor core design employ novel technologies or materials, features should be provided to: (a) facilitate inspection during manufacture and service; and (b) permit the inclusion of surveillance samples for monitoring of materials behaviour.
156	EGR.5 Manufacturing records	Page 87	Yes	Manufacturing case histories should be recorded where new materials have been employed in manufacturing.
157	EGR.6 Location records	Page 87	No	Not directly relevant to the introduction of novel technologies or materials.
158	EGR.7 Materials properties	Page 88	Yes	Should the graphite reactor core design employ novel technologies or materials, analytical models should be developed to enable the prediction of graphite reactor core material properties, displacements, stresses, loads and condition.
159	EGR.8 predictive models	Page 88	Yes	Should the graphite reactor core design employ novel technologies or materials, predictive models should be shown to be valid for the particular application and circumstances by reference to established physical data, experiment or other means.
160	EGR.9 Materials property data	Page 88	Yes	Should the graphite reactor core design employ novel technologies or materials, extrapolation and interpolation from available materials properties data should be undertaken with care, and data and model validity beyond the limits of current knowledge should be robustly justified.

Ref. No	SAP.	Page/Para	Applicability	Comment
161	EGR.10 Effect of defects	Page 88	Yes	Should the graphite reactor core design employ novel technologies or materials, an assessment of the effects of defects in graphite reactor cores should be undertaken to establish the tolerance of their safety functions during normal operation, faults and accidents. The assessment should include plant transients and tests, together with internal and external hazards.
162	EGR.11 Safe working life	Page 89	Yes	The safe working life of graphite reactor cores should be evaluated if new materials or novel technologies have been incorporated.
163	EGR.12 Operational limits	Page 89	Yes	Should the graphite reactor core design employ novel technologies or materials, operational limits (operating rules) should be established on the degree of graphite brick ageing, including the amounts of cracking, dimensional change and weight loss. To take account of uncertainties in measurement and analysis, there should be an adequate margin between these operational limits and the maximum tolerable amount of any calculated brick ageing.
164	EGR.13 Use of data	Page 89	Yes	Should the graphite reactor core design employ novel technologies or materials, data used in the analysis should be soundly based and demonstrably conservative. Studies should be undertaken to establish the sensitivity to analysis parameters.
165	EGR.14 Monitoring systems	Page 89	Yes	Should the graphite reactor core design employ novel technologies or materials, the design, manufacture, operation, maintenance, inspection and testing of monitoring systems should be commensurate with the duties and reliabilities claimed in the safety case.
166	EGR.15 Extent and frequency	Page 90	Yes	Should the graphite reactor core design employ novel technologies or materials, in-service examination, inspection, surveillance and sampling should be of sufficient extent and frequency to give confidence that degradation of graphite reactor cores will be detected well in advance of any defects affecting a safety function.
Safety systems guidance, below, has been assessed as almost completely applicable to novel technologies and new materials and as such requires full consideration.				

Ref. No	SAP.	Page/Para	Applicability	Comment
167	ESS.1 Provision of safety systems	Page 91	Yes	All nuclear facilities should be provided with safety systems that reduce the frequency or limit the consequences of fault sequences, and that achieve and maintain a defined stable, safe state.
168	ESS.2 Safety system specification	Page 91	Yes	The extent of safety system provisions, their functions, levels of protection necessary to achieve defence in depth and reliability requirements should be specified.
169	ESS.3 Monitoring of plant safety	Page 91	Yes	Adequate provisions should be made to enable the monitoring of the facility state in relation to safety and to enable the taking of any necessary safety actions during normal operational, fault, accident and severe accident conditions.
170	ESS.4 Adequacy of initiating variables	Page 91	Yes	The variables used to initiate a safety system action should be identified and shown to be suitable and sufficient for the system to achieve its safety function(s).
171	ESS.5 Plant interfaces	Page 92	Yes	Where the plant contains novel technologies with safety significance, the interfaces between the safety system and the plant to detect a fault condition and bring about a stable, safe state should be engineered by means that have a direct, known, timely and unambiguous relationship with plant behaviour.
172	ESS.6 Adequacy of variables	Page 92	No	Not directly relevant to the introduction of novel technologies or materials.
173	ESS.7 Diversity in the detection of fault sequences	Page 92	Yes	Where a Class 1 protection system employs a novel technology, the system should employ diversity in its detection of and response to fault conditions, preferably by the use of different variables.
174	ESS.8 Automatic initiation	Page 92	No	Not directly relevant to the introduction of novel technologies or materials.
175	ESS.9 Time for human intervention	Page 92	Yes	Where a safety system employs a novel technology, if human intervention is needed to support the safety system following the start of a requirement for protective action, then the timescales over which the safety system will need to operate unaided, before intervention, should be demonstrated to be sufficient.

Ref. No	SAP.	Page/Para	Applicability	Comment
176	ESS.10 Definition of capability	Page 93	Yes	Where a safety system employs a novel technology, the capability of a safety system, and of each of its constituent sub-systems and components, should be defined and substantiated.
177	ESS.11 Demonstration of adequacy	Page 93	Yes	Where a safety system employs a novel technology, the adequacy of the system design to achieve its specified functions and reliabilities should be demonstrated for each safety system.
178	ESS.12 Prevention of service infringement	Page 93	Yes	Should services incorporate novel technologies or materials, adequate arrangements should be in place to prevent any infringement of the services supporting a safety system, its sub-systems or components.
179	ESS.13 Confirmation to personnel	Page 94	Yes	The provision of information to operators should be examined when introducing new technologies.
180	ESS.14 Self-resetting of safety systems	Page 94	Yes	Where a safety system and associated alarms employs novel technology, the system actions and associated alarms should not be self-resetting, irrespective of the subsequent status of the initiating fault.
181	ESS.15 Alteration of configuration, operational logic or associated data	Page 94	Yes	Where a safety system employs a novel technology, no means should be provided, or be readily available, by which the configuration of a safety system, its operational logic or the associated data (trip levels etc.) can be altered, other than by specifically engineered and adequately secured maintenance/testing provisions used under strict administrative control.
182	ESS.16 No dependence on external sources of energy	Page 94	Yes	Where a safety system employs a novel technology, where practicable, following a safety system action, maintaining a stable, safe state should not depend on an external source of energy.
183	ESS.17 Faults originating from safety systems	Page 94	Yes	Where a safety system employs a novel technology, potential faults originating from within safety systems (e.g. due to spurious or mal-operation) should be identified and protection against them provided.

Ref. No	SAP.	Page/Para	Applicability	Comment
184	ESS.18 Failure independence	Page 95	No	Not directly relevant to the introduction of novel technologies or materials.
185	ESS.19 Dedication to a single task	Page 95	Yes	Where a safety system employs a novel technology, it should be dedicated solely to the provision of its allocated safety functions.
186	ESS.20 Avoidance of connections to other systems	Page 95	Yes	Where a safety system employs a novel technology, connections between any part of a safety system and a system external to the facility (other than to safety system support and monitoring features) should be avoided.
187	ESS.21 Reliability	Page 95	Yes	Where a safety system employs a novel technology, the design of safety systems should avoid complexity, apply a failsafe approach and incorporate means of revealing internal faults at the time of their occurrence.
188	ESS.22 Avoidance of spurious actuation	Page 96	Yes	Where a safety system employs a novel technology, spurious actuation should be avoided by means such as the provision of multiple independent divisions within the design architecture and majority voting.
189	ESS.23 Allowance for unavailability of equipment	Page 96	No	Not directly relevant to the introduction of novel technologies or materials.
190	ESS.25 Taking safety systems out of service	Page 96	No	Not directly relevant to the introduction of novel technologies or materials.
191	ESS.26 Maintenance and testing	Page 96	Yes	Maintenance and testing of a safety system containing a novel technology should not initiate a fault sequence.
192	ESS.27 Computer-based safety systems	Page 97	Yes	Where the system reliability is significantly dependent upon the performance of computer software, compliance with appropriate standards and practices throughout the software development lifecycle should be established in order to provide assurance of the final design.
Control and instrumentation guidance, below, has been assessed as somewhat applicable to novel technologies and new materials and as such requires some consideration.				

Ref. No	SAP.	Page/Para	Applicability	Comment
193	ESR.1 Provision in control rooms and other locations	Page 98	No	Not directly relevant to the introduction of novel technologies or materials.
194	ESR.2 Performance requirements	Page 98	Yes	The reliability, accuracy, stability, response time, range and, where appropriate, the readability of instrumentation containing novel technologies, should be adequate for it to deliver its safety functions.
195	ESR.3 Provision of controls	Page 99	Yes	Where a safety system employs a novel technology, adequate and reliable controls should be provided to maintain all safety-related plant parameters within their specified ranges (operating rules).
196	ESR.4 Minimum operational equipment	Page 99	No	Not directly relevant to the introduction of novel technologies or materials.
197	ESR.5 Standards for equipment in safety-related systems	Page 99	Yes	Where computers, programmable or non-programmable devices which contain novel technologies are used in safety-related systems, evidence should be provided that the hardware and software are designed, manufactured and installed to appropriate standards.
198	ESR.6 Power supplies	Page 99	No	Not directly relevant to the introduction of novel technologies or materials.
199	ESR.7 Communications systems	Page 99	No	Not directly relevant to the introduction of novel technologies or materials.
200	ESR.8 Monitoring of radioactive material	Page 100	No	Not directly relevant to the introduction of novel technologies or materials.
201	ESR.9 Response of control systems to normal plant disturbances	Page 100	Yes	Where a control system employs a novel technology, control systems should respond in a timely, reliable and stable manner to normal plant disturbances without causing demands on safety systems.

Ref. No	SAP.	Page/Para	Applicability	Comment
202	ESR.10 Demands on safety systems in the event of control system faults	Page 100	Yes	Where a control or other safety related system employs a novel technology, faults in control systems and other safety-related instrumentation should not cause an excessive frequency of demands on safety systems or take any safety system beyond its capability limits.
Essential services guidance, below, has been assessed as somewhat applicable to novel technologies and new materials and as such requires some consideration.				
203	EES.1 Provision	Page 100	No	Not directly relevant to the introduction of novel technologies or materials.
204	EES.2 Sources external to the site	Page 100	No	Not directly relevant to the introduction of novel technologies or materials.
205	EES.3 Capacity, duration, availability, resilience and reliability	Page 101	No	Not directly relevant to the introduction of novel technologies or materials.
206	EES.4 Sharing with other facilities	Page 101	No	Not directly relevant to the introduction of novel technologies or materials.
207	EES.5 Cross-connections to other services	Page 101	No	Not directly relevant to the introduction of novel technologies or materials.
208	EES.6 Reliability of back-up sources	Page 101	Yes	Where back-up sources of essential services are designed, back-up sources of essential services should be designed so that their reliability will not be prejudiced by adverse conditions in the services to which they provide a back-up, e.g. from common cause failures.
209	EES.7 Protection devices	Page 101	Yes	Where protection devices provided for essential service components or systems contain novel technologies, they should be consistent with the safe operation of the facility and limited to those justified as necessary in the safety case.

Ref. No	SAP.	Page/Para	Applicability	Comment
210	EES.9 Simultaneous loss of service	Page 102	Yes	Essential services should be designed so that the simultaneous loss of both normal and back-up services will not lead to unacceptable consequences. This is applicable to the application of novel technologies.
Human factors guidance, below, has been assessed as largely applicable to the introduction of novel technologies or new materials.				
211	EHF.1 Integration with design, assessment and management	Page 102	Yes	New technologies should be fully integrated with other safety systems.
212	EHF.2 Allocation of safety actions	Page 103	No	Not directly relevant to the introduction of novel technologies or materials.
213	EHF.3 Identification of actions impacting safety	Page 103	Yes	Where new technologies could impact operator safety, the potential risk should be analysed.
214	EHF.4 Identification of administrative controls	Page 103	No	Not directly relevant to the introduction of novel technologies or materials.
215	EHF.5 Task analysis	Page 103	Yes	Tasks involving new technologies should be adequately analysed with safety as a priority.
216	EHF.6 Workspace design	Page 104	Yes	Where workspaces incorporate novel technologies they should be designed with due consideration for operators.
217	EHF.7 User interfaces	Page 104	Yes	Where user interfaces contain novel technologies, suitable and sufficient user interfaces should be provided at appropriate locations to provide effective monitoring and control of the facility in normal operations, faults and accident conditions.
218	EHF.8 Personnel competence	Page 105	Yes	Operators should be demonstrably competent to operate new or novel technologies.
219	EHF.9 Procedures	Page 105	Yes	Appropriate procedures involving new or novel technologies should be generated.

Ref. No	SAP.	Page/Para	Applicability	Comment
220	EHF.11 Staffing levels	Page 106	Yes	Relevant to the introduction of novel technologies or materials.
221	EHF.12 Fitness for duty	Page 106	Yes	Relevant to the introduction of novel technologies or materials.
222	EHF.10 Human reliability	Page 106	Yes	Relevant to the introduction of novel technologies or materials.
Control of nuclear matter guidance, below, has been assessed as partially applicable to novel technologies and new materials.				
223	ENM.1 Strategies for managing nuclear matter	Page 107	Yes	New materials should be incorporated into a strategy for managing nuclear matter.
224	ENM.2 Provisions for nuclear matter brought onto, or generated on, the nuclear site	Page 107	Yes	Equally applicable to new materials as existing nuclear materials.
225	ENM.3 Transfers and accumulation of nuclear matter	Page 108	No	Not directly relevant to the introduction of novel technologies or materials.
226	ENM.4 Control and accountancy of nuclear matter	Page 108	No	Not directly relevant to the introduction of novel technologies or materials.
227	ENM.5 Characterisation and segregation	Page 109	Yes	New materials should undergo characterisation.
228	ENM.6 Storage in a condition of passive safety	Page 109	Yes	The impact of new materials on passive storage over extended periods should be understood.
229	ENM.7 Retrieval and inspection of stored nuclear matter	Page 110	No	Not directly relevant to the introduction of novel technologies or materials.
230	ENM.8 Nuclear material accountancy	Page 110	No	Not directly relevant to the introduction of novel technologies or materials.
Chemical (Process) Engineering, below, has been assessed as fully applicable to novel technologies and new materials and as such requires full consideration.				

Ref. No	SAP.	Page/Para	Applicability	Comment
231	EPE.1 Design and operation	Page 111	Yes	If nuclear chemical processes are designed with novel technologies or materials then they should be fault tolerant and ensure safety functions are delivered with suitable capability and sufficient reliability and robustness.
232	EPE.2 Process stability	Page 112	Yes	Nuclear chemical processes possessing novel technologies or new materials should be designed and operated so as to maintain suitable and sufficient stability.
233	EPE.3 Experimental processes	Page 113	Yes	Where an experimental chemical process is proposed which contains a novel technology or new material, the safety case should establish an appropriate degree of confidence in the safety of the process and that it will deliver as intended.
234	EPE.4 Severe accident data	Page 113	Yes	Process behaviour under severe accident conditions should be analysed where processes employ novel technologies or new materials.
235	EPE.5 Process design and commissioning	Page 114	Yes	The process design and commissioning should provide inputs to operational safety parameters defining limits and conditions necessary in the interests of safety (operating rules). This should apply where a process has included a novel technology or new material.
Chemistry guidance, below, has been assessed as fully applicable to novel technologies and new materials and as such requires full consideration.				
236	ECH.1 Safety cases	Page 115	Yes	Safety cases should, by applying a systematic process, address all chemistry effects important to safety. Where novel technologies or new materials have been used, the safety case should reflect this.
237	ECH.2 Resolution of conflicting chemical effects	Page 115	Yes	Where the effects of different chemistry parameters conflict with one another, the safety case should demonstrate that an appropriate balance for safety has been achieved. Where novel technologies or new materials have been used, the safety case should reflect this.
238	ECH.3 Control of chemistry	Page 116	Yes	Suitable and sufficient systems, processes and procedures should be provided to maintain chemistry parameters within the limits and conditions identified in the safety case. Systems which contain novel technologies or materials should be

Ref. No	SAP.	Page/Para	Applicability	Comment
				suitably substantiated.
239	ECH.4 Monitoring, sampling and analysis	Page 116	Yes	Suitable and sufficient systems, processes and procedures should be provided for monitoring, sampling and analysis so that all chemistry parameters important to safety are properly controlled. Systems which contain novel technologies or materials should be suitably substantiated.
Containment and ventilation guidance, below, has been assessed as almost fully applicable to novel technologies and new materials and as such requires full consideration.				
240	ECV.1 Prevention of leakage	Page 117	Yes	Radioactive material should be contained and the generation of radioactive waste through the spread of contamination by leakage should be prevented.
241	ECV.2 Minimisation of releases	Page 117	Yes	Containment and associated systems containing novel technologies or new materials should be designed to minimise radioactive releases to the environment in normal operation, fault and accident conditions.
242	ECV.3 Means of confinement	Page 118	Yes	The primary means of confining radioactive materials should be through the provision of passive sealed containment systems and intrinsic safety features, in preference to the use of active dynamic systems and components. This is applicable to containment systems possessing novel technologies or new materials.
243	ECV.4 Provision of further containment barriers	Page 119	Yes	Where the radiological challenge dictates, waste storage vessels, process vessels, piping, ducting and drains (including those that may serve as routes for escape or leakage from containment) and other plant items that act as containment for radioactive material, should be provided with further containment barrier(s) that have sufficient capacity to deal safely with the leakage resulting from any design basis fault. Containment barriers with novel technologies or new materials should also be designed to meet the radiological challenge.
244	ECV.5 Minimisation of personnel access	Page 119	No	Not directly relevant to the introduction of novel technologies or materials.

Ref. No	SAP.	Page/Para	Applicability	Comment
245	ECV.6 Monitoring devices	Page 119	Yes	Suitable and sufficient monitoring devices with alarms should be provided to detect and assess changes in the materials and substances held within the containment. Where novel technologies or new materials have been employed, devices should be substantiated.
256	ECV.7 Leakage monitoring	Page 120	Yes	Appropriate sampling and monitoring systems should be provided outside the containment to detect, locate, quantify and monitor for leakages or escapes of radioactive material from the containment boundaries. Where novel technologies or new materials have been employed, devices should be substantiated.
257	ECV.8 Minimisation of provisions for import or export of materials or equipment	Page 120	No	Not directly relevant to the introduction of novel technologies or materials.
258	ECV.9 Containment and ventilation system design	Page 120	Yes	The design should ensure that controls on fissile content, radiation levels, and overall containment and ventilation standards are suitable and sufficient. Where novel technologies or new materials have to be employed, the design should be substantiated.
259	ECV.10 Ventilation system safety functions	Page 121	Yes	The safety functions of the ventilation system should be clearly identified and the safety philosophy for the system in normal, fault and accident conditions should be defined. Where novel technologies or new materials have to be employed, the design should be substantiated.
Reactor core guidance, below, has been assessed as fully applicable to novel technologies and new materials and as such requires full consideration.				
260	ERC.1 Design and operation of reactors	Page 123	Yes	The design and operation of the reactor should ensure the fundamental safety functions are delivered with an appropriate degree of confidence for permitted operating modes of the reactor. Where novel technologies or new materials have to be employed, the design should be substantiated.

Ref. No	SAP.	Page/Para	Applicability	Comment
261	ERC.2 Shutdown systems	Page 123	Yes	At least two diverse systems should be provided for shutting down a civil reactor. Where novel technologies or new materials have been incorporated, these shall be adequately substantiated.
262	ERC.3 Stability in normal operation	Page 123	Yes	Where novel technologies or new materials have been incorporated into the reactor core, the core should be stable in normal operation and should not undergo sudden changes of condition when operating parameters go outside their permitted range.
263	ERC.4 Monitoring of parameters important to safety	Page 125	Yes	Where novel technologies or new materials have been incorporated into the reactor core, the core should be designed so that parameters and conditions important to safety can be monitored in all operational and design basis fault conditions and appropriate recovery actions taken in the event of adverse conditions being detected.
Heat transport guidance, below, has been assessed as fully applicable to novel technologies and new materials and as such requires full consideration.				
264	EHT.1 Design	Page 125	Yes	Heat transport systems which contain novel technologies or new materials should be designed so that heat can be removed or added as required.
265	EHT.2 Coolant inventory and flow	Page 125	Yes	Applicable if the design of the heat transfer systems i.e. pumps etc. contain novel technologies or new materials.
266	EHT.3 Heat sinks	Page 126	Yes	Applicable if the heat sink contains novel technologies or new materials.
267	EHT.4 Failure of heat transfer system	Page 126	Yes	Should a heat transfer system contain novel technologies or new materials, provisions should be made in the design to prevent failures of the heat transport system that could adversely affect the heat transfer process, and to maintain the facility in a safe condition following such failures.
268	EHT.5 Minimisation of radiological doses	Page 127	Yes	Should a heat transfer system contain novel technologies or new materials, the heat transfer system should be designed to minimise radiological doses.

Ref. No	SAP.	Page/Para	Applicability	Comment
Criticality safety guidance, below, has been assessed as some applicability to novel technologies and new materials, and as such requires consideration.				
269	ECR.1 Safety measures	Page 127	Yes	Wherever a significant amount of fissile material may be present, there should be safety measures to protect against unplanned criticality. This is also applicable to safety systems containing novel technologies or new materials.
270	ECR.2 Double contingency approach	Page 128	No	Not directly relevant to the introduction of novel technologies or materials.
Radiation protection guidance, below, has been assessed not to be applicable to the introduction of novel technologies or new materials.				
271	RP.7 Hierarchy of control measures	Page 129	No	Not directly relevant to the introduction of novel technologies or materials.
272	RP.1 Normal operation (Planned Exposure Situations)	Page 130	No	Not directly relevant to the introduction of novel technologies or materials.
273	RP.2 Fault and accident conditions (Emergency Exposure Situations)	Page 130	No	Not directly relevant to the introduction of novel technologies or materials.
274	RP.3 Designated areas	Page 131	No	Not directly relevant to the introduction of novel technologies or materials.
275	RP.4 Contaminated areas	Page 132	No	Not directly relevant to the introduction of novel technologies or materials.
276	RP.5 Decontamination	Page 132	No	Not directly relevant to the introduction of novel technologies or materials.
277	RP.6 Shielding	Page 132	No	Not directly relevant to the introduction of novel technologies or materials.
Fault analysis guidance, below, has been assessed not to be applicable to the introduction of novel technologies or new materials.				
278	FA.1 Design basis analysis, PSA and severe accident analysis	Page 135	No	Not directly relevant to the introduction of novel technologies or materials.
279	FA.2 Identification of initiating	Page 136	No	Not directly relevant to the introduction of novel technologies or materials.

Ref. No	SAP.	Page/Para	Applicability	Comment
	faults			
280	FA.3 Fault sequences	Page 136	No	Not directly relevant to the introduction of novel technologies or materials.
281	FA.4 Fault tolerance	Page 137	No	Not directly relevant to the introduction of novel technologies or materials.
282	FA.5 initiating faults	Page 137	No	Not directly relevant to the introduction of novel technologies or materials.
283	FA.6 Fault sequences	Page 138	No	Not directly relevant to the introduction of novel technologies or materials.
284	FA.7 Consequences	Page 139	No	Not directly relevant to the introduction of novel technologies or materials.
285	FA.8 Linking of initiating faults, fault sequences and safety measures	Page 139	No	Not directly relevant to the introduction of novel technologies or materials.
286	FA.9 Further use of DBA	Page 140	No	Not directly relevant to the introduction of novel technologies or materials.
287	FA.10 Need for PSA	Page 141	No	Not directly relevant to the introduction of novel technologies or materials.
288	FA.11 Validity	Page 141	No	Not directly relevant to the introduction of novel technologies or materials.
289	FA.12 Scope and extent	Page 141	No	Not directly relevant to the introduction of novel technologies or materials.
290	FA.13 Adequate representation	Page 141	No	Not directly relevant to the introduction of novel technologies or materials.
291	FA.14 Use of PSA	Page 143	No	Not directly relevant to the introduction of novel technologies or materials.
292	FA.15 Scope of severe accident analysis	Page 144	No	Not directly relevant to the introduction of novel technologies or materials.
293	FA.16 Use of severe accident analysis	Page 145	No	Not directly relevant to the introduction of novel technologies or materials.
294	FA.25 relationship to DBA and PSA	Page 146	No	Not directly relevant to the introduction of novel technologies or materials.

Ref. No	SAP.	Page/Para	Applicability	Comment
Assurance of validity guidance, below, has been assessed not to be applicable to the introduction of novel technologies or new materials.				
295	AV.1 Theoretical models	Page 146	No	Not directly relevant to the introduction of novel technologies or materials.
296	AV.2 Calculation methods	Page 147	No	Not directly relevant to the introduction of novel technologies or materials.
297	AV.3 Use of data	Page 147	No	Not directly relevant to the introduction of novel technologies or materials.
298	AV.4 Computer models	Page 147	No	Not directly relevant to the introduction of novel technologies or materials.
299	AV.5 Documentation	Page 148	No	Not directly relevant to the introduction of novel technologies or materials.
300	AV.6 Sensitivity studies	Page 148	No	Not directly relevant to the introduction of novel technologies or materials.
301	AV.7 Data collection	Page 148	No	Not directly relevant to the introduction of novel technologies or materials.
302	AV.8 Update and review	Page 148	No	Not directly relevant to the introduction of novel technologies or materials.
Numerical targets guidance, below, has been assessed not to be applicable to the introduction of novel technologies or new materials.				
303	NT.3 Applying the targets	Page 151	No	Not directly relevant to the introduction of novel technologies or materials.
304	NT.1 Assessment against targets	Page 152	No	Not directly relevant to the introduction of novel technologies or materials.
305	NT.2 Time at risk	Page 163	No	Not directly relevant to the introduction of novel technologies or materials.
Accident management guidance, below, has been assessed not to be applicable to the introduction of novel technologies or new materials.				
306	AM.1 Planning and preparedness	Page 165	No	Not directly relevant to the introduction of novel technologies or materials.
Radioactive waste guidance, below, has been assessed to be applicable to the introduction of novel technologies or new materials.				
307	RW.1 Strategies for radioactive waste	Page 169	Yes	A strategy should be developed for radioactive waste containing new materials.

Ref. No	SAP.	Page/Para	Applicability	Comment
308	RW.2 Generation of radioactive waste	Page 171	Yes	The generation of radioactive waste containing new materials should be minimised.
309	RW.3 Accumulation of radioactive waste	Page 172	Yes	Equally applicable to existing materials as new materials.
310	RW.4 Characterisation and segregation	Page 172	Yes	Equally applicable to existing materials as new materials.
311	RW.5 Storage of radioactive waste and passive safety	Page 173	Yes	Equally applicable to existing materials as new materials.
312	RW.6 Passive safety timescales	Page 175	Yes	Equally applicable to existing materials as new materials.
313	RW.7 Making and keeping records	Page 176	Yes	Equally applicable to existing materials as new materials.
Decommissioning guidance, below, has been assessed as to be generally not applicable to the development of new technologies or new materials. However, facilities designed for the purposes of decommissioning may contain novel technologies or new materials (DC.1).				
314	DC.1 Design and operation	Page 178	Yes	Facilities containing novel technologies or new materials should be designed and operated so that they can be safely decommissioned.
315	DC.2 Decommissioning strategies	Page 178	No	Not directly relevant to the introduction of novel technologies or materials.
316	DC.3 Timing of decommissioning	Page 180	No	Not directly relevant to the introduction of novel technologies or materials.
317	DC.4 planning for decommissioning	Page 181	No	Not directly relevant to the introduction of novel technologies or materials.
318	DC.5 Passive safety	Page 183	Yes	Relevant to the introduction of novel technologies or materials.

Ref. No	SAP.	Page/Para	Applicability	Comment
319	DC.6 Records for decommissioning	Page 183	No	Not directly relevant to the introduction of novel technologies or materials.
320	DC.7 Decommissioning organisation	Page 184	No	Not directly relevant to the introduction of novel technologies or materials.
321	DC.8 Management system	Page 185	No	Not directly relevant to the introduction of novel technologies or materials.
322	DC.9 Decommissioning safety case	Page 186	No	Not directly relevant to the introduction of novel technologies or materials.
Radioactive Land guidance listed below has been assessed as generally not applicable to novel technologies or new materials. However, it is entirely possible that novel technologies could be used for survey, investigation and monitoring purposes (RL.5).				
323	RL.1 Strategies for radioactively contaminated land	Page 187	No	Not directly relevant to the introduction of novel technologies or materials.
324	RL.2 Identifying radioactively contaminated land	Page 189	No	Not directly relevant to the introduction of novel technologies or materials.
325	RL.3 Discovery of contaminated land and management of leaks and escapes	Page 189	No	Not directly relevant to the introduction of novel technologies or materials.
326	RL.4 Characterisation of radioactively contaminated land	Page 190	No	Not directly relevant to the introduction of novel technologies or materials.
327	RL.5 Survey, investigation, monitoring and surveillance	Page 191	Yes	Radiological surveys, investigation, monitoring and surveillance of radioactively contaminated land should be carried out such that its characterisation is kept up to date. Entirely possible that novel technologies may be employed in this area.
328	RL.6 Plan for control and remediation	Page 191	No	Not directly relevant to the introduction of novel technologies or materials.

Ref. No	SAP.	Page/Para	Applicability	Comment
329	RL.7 Records for radioactively contaminated land	Page 192	No	Not directly relevant to the introduction of novel technologies or materials.
330	RL.9 Radioactively contaminated land safety cases	Page 193	No	Not directly relevant to the introduction of novel technologies or materials.
331	RL.8 Construction on radioactively contaminated land	Page 194	No	Not directly relevant to the introduction of novel technologies or materials.

Appendix 2. Review of ONR TAG, TIG and Selected IAEA Guidance

GUIDANCE ON THE INTRODUCTION OF NEW MATERIALS AND TECHNOLOGIES

Introduction

ONR issues Technical Assessment Guides (TAGs). The primary purpose of these TAGs is to act as Guides for its assessors in their assessment of a number of regulatory issues, e.g. technical aspects of safety cases, arrangements to comply with License Conditions (LCs) and the assessment of the competence of Licensees, e.g. management organisation, culture for safety etc. Although this is the primary purpose of TAGs and facilitates ONR in achieving a consistent approach to its regulatory activities. [TAGs should not be confused with Technical Inspection Guides (TIGs), the latter being the on-site inspection of how LC compliance arrangements are being implemented.] Although the primary use of TAGs is for ONR's internal use they also play a role in assisting Licensees and their stakeholders in meeting ONR's regulatory requirements.

The UK nuclear industry is currently in a state of greater change than it has been for many years. There are a number of new reactor types being proposed with their attendant novel fuel manufacturing facilities and potentially novel waste management and processing facilities as well as modifications to existing types of reactor. These novel facilities have the potential to require ONR to assess the introduction of new materials, technologies and systems. Currently there is no specific guidance upon how these novel approaches should be assessed (N.B. ONR's public GDA report on the UK EPR defines "novel" as "any major safety system structure or component of a type not previously licensed to operate in a nuclear power plant anywhere in the world." Clearly in this context this definition should also be taken to apply to any nuclear facility licensed by ONR, not just nuclear power plants.). ONR's assessors have to infer how this should be carried out from other relevant TAGs. ONR has therefore decided to produce a new TAG specifically dealing with the introduction of new materials, technologies and systems and has commissioned Wood Group to assist in this work.

ONR Technical Inspection Guides (TIG)

Although all of the ONR safety TIGs were examined only a few were of relevance to this task. This is perhaps not surprising as the TIGs relate to the inspections to be carried out to ensure compliance with License Conditions so it is only where the introduction of new materials or technology affect a Licensee's compliance arrangements that the content of TIGs becomes relevant for this task. Consequently no TIG explicitly contained relevant information for novel materials and technologies although the Table below does indicate several TIGs where LC arrangements are potentially directly relevant and where it would possibly have been appropriate for ONR to consider providing advice upon specific inspection concerns if new materials or technology was to be introduced.

No.	Title	Section	Para	Relevant Text	Comments
TIG – 021 Rev 4	LC21: Commissioning	6	6.2(c)	Text states commissioning programme should demonstrate safe functioning and address all aspects that cannot be demonstrated inactively.	Although novelty is not mentioned commissioning clearly can play a significant role in justifying new materials and technologies.
"	"	"	6.2(r)	Text states commissioning should provide a successive challenge to the plant, e.g. inactive commissioning before active commissioning.	Again novelty is not mentioned but the important aspect here is that new materials and technologies should be justified as much as possible before entering active commissioning.
TIG-022 Rev 4	LC22: Modification or Experiment on Existing Plant	4	4.4	Text outlines why modifications or experiments may take place but does not explicitly cover new materials and technologies.	Although not mentioned explicitly it is clear that tests and experiments on plant could play an important part in justifying new materials and technologies and hence LC22 arrangements will play an important part.
"	"	5	5.7	Text relates to the need to classify modifications (and implicitly experiments although this is not stated) according to their safety significance.	Clearly relevant depending upon the safety function of the new material or technology.

No.	Title	Section	Para	Relevant Text	Comments
TIG – 028 Rev 5	LC28: Examination, Inspection, Maintenance and Testing (EIMT)			The text makes no mention of novelty playing a part in these arrangements, although safety significance is mentioned. Indeed the text focuses on examination, inspection and testing as part of the maintenance function.	It is reasonable to assume that the introduction of new materials or technologies should require enhanced examination, inspection and testing to support the safety case at least in the first instance. (see comments on TAG009)

ONR Technical Assessment Guides (TAG)

The TAGs contain much more relevant information pertinent to new materials and technologies than the TIGs although much of this guidance refers to general Assessment Principles which should be adopted to mitigate the risk.

No.	Title	Section	Para’	Text	Comments
TAG – 009 Rev 4	Examination, Inspection, Maintenance and Testing of Items Important to Safety	5	5.2.2	“the likelihood of being required to assess a totally novel nuclear facility with its operational requirements for EIMT is low, however, there is a likelihood that novel design features for modifications to existing facilities and for new build facilities will be encountered. Such novel features should require R&D programmes and pilot testing prior to consideration of deployment in an operational environment. Testing, Inspection and Examination is required during any installation and commissioning phase	The principle of examination, inspection and testing of important novel plant is very important.

No.	Title	Section	Para'	Text	Comments
				and operation coupled with maintenance to confirm the adequacy of the facility in safety terms" it then refers to SAP para 281 as being typical.	
"	"	5	5.3.3 11th bullet	"Where appropriate Inspectors should look for evidence that PSA has been used in determining appropriate EIMT strategies both in terms of identifying when it is acceptable for safety important equipment to be released for EIMT and the extent to which the proposed EIMT activities provide the level of assurance that the safety case reliability claims are met,"	This introduces the concept that the extent of EIMT should be dependent upon the safety claim/importance of the new material/technology and the extent to which further justification may be required.
"	"	5	5.3.3 12th bullet	"Inspectors should look for evidence that adequate development work on novel systems or components is undertaken between concept design and manufacturing."	Another important principle that the extent of EIMT will depend upon the amount of other substantive work to justify the novel material, Technology or facility.
"	"	General		The TAG describes that various tests (and implicitly, examinations and inspections) are available such as Factory tests and commissioning tests.	For new materials, components and technologies it should be important to carry out the maximum requisite amount of testing prior to being installed and prior to operation of the facility to minimise the risk and subsequent cost if a problem is discovered. However this important principle is not described within this TAG.

No.	Title	Section	Para'	Text	Comments
TAG – 016 Rev 5	Integrity of Metal Structures, Systems and Components	5	5.10 5.11 5.14	"The starting point for design is compliance with relevant national and international codes and standards." "The general lack of adequate reliability data, particularly for higher reliability SSCs leads to assessment being based primarily on established deterministic engineering practice." This lists the number of separate arguments that need to be addressed as part of a deterministic safety case.	This is an important ONR pre-requisite as it means that any new material, component and system must satisfy relevant codes as a minimum for ONR to consider them satisfactory. Furthermore, novel materials and SSCs do not necessarily need extensive data to satisfy probabilistic requirements. However many different aspects need to be addressed to make a deterministic justification.
"	"	5	5.26-5.35	This states sound design concepts etc. and proven design features are used.	This does not rule out novel approaches but just that they follow and meet accepted concepts.
"	"	"	5.30 5.32	This stipulates the use of model tests to validate methods. This demonstrates the importance of examination/monitoring to provide assurance against potential degradation mechanisms.	This is especially important to new SSCs where such tests are scalable but although not explicitly mentioned in the TAG the use of material test data from lab tests for new materials further supported by the use of ISI.
"	"	"	5.33	This important text recognises that some designs may not be to a recognised code. It then states that the design should be supported by suitable experimental verification and validation as well as appropriate research and development with novel features adequately tested before	This recognises that where a novel SCC is not covered by a design code it can still be validated but the emphasis here is upon model testing.

No.	Title	Section	Para’	Text	Comments
				coming into service followed by monitoring during service. Conservative data should be used in analyses taking into account uncertainties.	
			5.42	This latter point is re-emphasised but includes the need for sensitivity analyses.	In terms of stress and fracture analyses clearly all would expect those of conservative data but where the approach is novel additional validation would be expected together with a consideration of uncertainties.
“	“	“	5.47	This covers the use of proof pressure tests to validate components and structures.	The use of proof testing is not confined to pressurised components and can provide confidence in the integrity of systems and components as long as potential damage during the proof test is considered and the possible weakening of the SSC during service is also considered. Proof tests should ideally form part of Factory tests in the first instance with further testing perhaps being appropriate after installation and almost always before any radioactive material is introduced.
“	“	“	5.53	This reiterates the SAP that safety significant SSCs are constructed from materials with well-established properties and behaviour. In fact the title of this sub-section is “Use of Proven Materials”.	It is important to recognise that this SAP refers to metal SSCs. Hence the use of novel coolants even if metal would not be included and it is a moot point whether novel metallic fuels and cladding would also be included. It appears unlikely that this was the intent of this TAG as separate TAGs

No.	Title	Section	Para'	Text	Comments
					deal with fuel. It is therefore highly likely that any new proposed material could be validated by the production of suitable laboratory tests although without a materials test reactor (MTR) in the UK the validation of materials in a radiation environment may be difficult.
"	"	"	5.55 & 5.83	This mentions the use of surveillance specimens to provide prior warning of issues related to degradation in a radioactive environment.	This is a potential solution to the absence of a MTR but usually means the material is being tested after being installed.
TAG – 028 Rev 4	Control and Instrumentation aspects of Nuclear Plant Commissioning	5	5.1 (2) &(3)	The text describes that commissioning is concerned with proving functionality and validating design assumptions.	Although the text does not explicitly deal with novel C&I systems the overall principles are considered the same.
"	"	Discussion	(1)	"Make no assumptions". The text indicates all plant safety items should be proved under the full range of operating conditions.	This philosophy should apply to all safety related equipment, not just C&I. However this is especially true for novel SSCs.
"	"	"	(2)(x)f	This mentions the need for documentation covering specialist measures for dealing with novel processes or systems "(the tests for which will need to incorporate type testing to some extent)".	This is the only explicit mention of "novel" processes but again should be applicable to any novel aspect of a facility.

No.	Title	Section	Para'	Text	Comments
TAG – 030 Rev 5	Probabilistic Safety Advice	4	4.9	"The data used in the analysis of safety related aspects of plant performance should be shown to be valid for the circumstances by reference to established physical data, experiment or other appropriate means."	This indicates that where the safety case requires a PSA as well as a deterministic approach then suitable testing will have to be carried out.
TAG – 031 Rev 5	Safety Related Systems & Instrumentation	8	8.4	"Novel forms or applications of SRI should be avoided if at all possible because of the associated uncertainties in performance." SAP ERL1 states that if a novel approach is used its claimed reliability should take into account its novelty.	This appears too dogmatic and does not encourage innovation. As long as adequate reliability and availability can be shown (along with suitable mitigation methods where appropriate) novel approaches should not be discounted.
TAG – 042 Rev 4	Validation of Computer Codes and Calculational Methods	General		The approach advocated is one of a conservative approach which considers uncertainties and uses experimental data to validate where possible the extent of validation required being proportionate to the safety significance of the code or method being validated.	This conservative approach would be applicable to any new design requiring models or calculational methods to validate it.
TAG – 046 Rev 4	Computer Based Safety Systems	5	5.3.1	This indicates the need to test the system prior to being installed at site.	This is analogous to proof tests and post manufacturing inspection and examination of SSCs.
"	"	"	5.4	Confidence Building.	This general approach is analogous to approaches that can be used for other novel

No.	Title	Section	Para'	Text	Comments
					materials or SSCs, by models, testing and inspections.
TAG – 056 Rev 5	Nuclear Lifting Operations	5	5.39	This illustrates the further use of proof tests to validate components (especially at start of life) but also introduces the concept of through life testing to ensure safety (together with associated inspection and fracture mechanics assessment.	Although novel systems are not explicitly mentioned, the concept of proof testing would be particularly important in this safety area especially as this could normally be carried out with little safety significance ,e.g. at the factory or in situ with no nuclear loading.
"	"	"	5.51	This text illustrates the use of redundancy and diversity in terms of mitigating the effect of a failure.	Although the text here refers to lifting operations the concept of designing in redundancy, diversity (and segregation) to mitigate against the failure of a new material or technology would be a sound methodology for justifying these novel approaches without the same onerous demand for robust proof.
TAG – 057 Rev 5	Design Safety Assurance	General		This states how individual aspects of a facility should be designed and justified to meet the design intent (no accidents and minimal release of radioactivity).	This TAG identifies a generic process for ensuring the safe design of any safety related nuclear component and is therefore specifically relevant to the introduction of novel features such as materials, components, safety systems etc.
TAG – 075 Rev 2	Safety of Nuclear Fuel in Reactors	General			Although not identified as such this is a particularly difficult technical area. The introduction of new fuel concepts is highly likely, e.g. PRISM, MOLTEX, Pebble Bed, yet how are these to be justified without recourse to building an extremely expensive prototype?

No.	Title	Section	Para'	Text	Comments
"	"	4		Section 4 identifies the factors that need to be considered in designing a new core.	Section 4 identifies the sound criteria that should be met but it does not go into detail about how a core designer should demonstrate that these criteria are met, for example would conservative models alone be sufficient if suitable monitoring and fault tolerance was shown.
"	"	5	5.4.2(90) 5.4.3(92)	These para's illustrate the use of experimental data to substantiate core behaviour and quotes an IAEA Guide that requires experimental data to demonstrate the margin to the critical heat flux limit.	Contrary to the statement above this would indicate that models alone may not be sufficient.
TAG – 088 Rev 2	Chemistry of Operating Civil Nuclear reactors	General		The TAG explicitly states that it relates to nuclear power plant.	It is considered that much of it could equally well be applied to other nuclear facilities, e.g. reprocessing facilities and fuel manufacturing facilities.
		5	5.27	Although there is no explicit mention of novel chemistry regimes there are general principles that would apply: demonstration of safety margins, capability to monitor and the ability to rectify if control is in danger of being lost.	These principles would apply to any nuclear facility with a chemistry regime that contributes to safety.

IAEA Guides

Within the bounds of practicality of this project it is not feasible to examine the total plethora of IAEA documents for Guidance in this area. Consequently a selection of Guides has been chosen that it was anticipated would yield the best prospect of providing either additional or more detailed guidance on introducing new materials and technology for nuclear facilities.

No.	Title	Section	Para'	Text	Comments
NS-G-2.3	Modifications to NPP	General		The explicit expectation throughout the document is that any new technology (and presumably material) should be adequately tested before installation wherever possible.	This illustrates the overall principle of minimising the risk to the facility (and individuals) by doing as much validation work as possible either before installation or before taking the plant critical.
NS- G- 4.1	Commissioning of Research Reactors	Scope	1.6	The content of the commissioning programme should be based on the complexity of the activity and the importance to safety.	This reinforces the concept of the extent of required validation being proportionate to both safety importance and complexity.
"	"	Process Implementation	2.23 & 2.24	"Inspection, testing, verification and validation activities should be completed before the implementation or operational use of SSCs." "Valid monitoring and measurement should be performed to provide evidence of conformity to requirements and satisfactory performance in service."	Again the need to justify/validate SSCs before use to minimise risk and the need for appropriate review to confirm everything is going as expected.
"	"	Commissioning Stages	3.16	Commissioning should be divided into stages.	The example shown in the Guide is consistent with the principle of validating the facility gradually to reduce risk.
"	"	"	5.6	"The sequencing of tests should be ordered so that the safety of the facility is not dependent on the performance	As above, this is about minimising risk and would equally apply to the introduction of any new material or technology (as much as is

No.	Title	Section	Para'	Text	Comments
				of the component being tested."	feasible.)
"	"	Commissioning of new experimental devices and modifications	8.2	"All new experimental devices, experiments and modifications should undergo commissioning to demonstrate functionality and safety. New experimental devices, experiments and modifications having major safety significance should be subject to procedures for commissioning equivalent to those of the reactor itself."	This explains the important principle that any new materials and/or technologies having major safety significance that are being introduced onto the facility should be subject to the highest standards of commissioning.
NS-G-4.4	Operational Limits and Conditions and Operating Procedures for research Reactors	General		OLCs are stipulated to ensure the safety of the facility. It was anticipated that this Guide would contain information regarding the need for conservatism in these OLCs depending upon the uncertainty, especially for the introduction of new technologies and materials.	Unfortunately the Guide does not deal with uncertainties and new technologies.
SSG- 20	Safety Assessment for Research Reactors and preparation of the Safety Analysis Report	Utilization and Modification	2.41	"The safety analysis report provides boundaries for OLCs that have been demonstrated to be safe and any experiments and modifications should fall within these boundaries."	This guidance should apply equally well to new materials and technologies, i.e. their introduction should not lead to a change in OLCs nor jeopardise the ease with which these are complied with.
"	"	"	2.43	"Commissioning of the experiment or	Again, this guidance applies equally to the

No.	Title	Section	Para'	Text	Comments
				the modified research reactor should be conducted to demonstrate compliance with the design intention"	introduction of new materials or technologies, i.e. they must be shown to be consistent with the design intent and demonstrated to be so during commissioning.
"	"	"	"	"If changes to the safety analysis report or to some analyses are made it should be ensured that the other safety analyses are still valid."	This Guidance equally applies to the introduction of new materials or technologies, i.e. as well as providing a safety analysis for the introduction of the new materials/technologies, it should be checked to ensure that the introduction does not adversely affect other existing safety analyses.
SSG- 28	Commissioning for Nuclear Power Plants	Objectives of Commissioning	2.3	Amongst the cited objectives is to verify SSCs and to validate procedures.	This further illustrates the importance of an adequate decommissioning programme to validate any new material, technology or process.
"	"	Commissioning Tests	4.8	"If first of a kind – that is, new, unique or special – principal design features will be used in the NPP, the in-plant functional test requirements necessary to verify their performance should be identified at an early date to permit these test requirements to be appropriately accounted for in the final test design."	This is some of the rare explicit guidance on novel approaches and emphasises the need for their special consideration during commissioning.
SSG- 39	Design of Instrumentation and Control	Use of Life Cycle Models	2.13	"Verification and validation activities are necessary for ensuring that the final product is suitable for use."	This guidance not only emphasises the need for verification and validation but also a properly assured development process in

No.	Title	Section	Para’	Text	Comments
	Systems for Nuclear Power Plants			”confidence in the correctness of modern systems derives more from the discipline of the development process.”	defining the new technology that is being proposed.
“	“	System Validation	2.139 & 2.147	“The use of simulators for system validation should be considered.” “Testing within the plant environment is an important part of commissioning.”	“Simulators” are clearly beneficial to “off facility” validation but this guidance can be extended to indicate that any new technology/ material should be validated using tests that simulate the real plant condition as closely as possible. The second point here is that irrespective of simulator testing, plant testing should be carried out if possible.
SSG - 43	Safety of Nuclear Fuel Cycle Research and Development Facilities	Operation	7.3	“Research programmes should comply with the existing safety case or be considered as a modification.”	This emphasises that any new material, technology or process that is introduced onto an existing facility must be treated as a modification.
“	“	Facility Operation	7.11	“To ensure that the R&D facility operates well within its OLCs under normal circumstances a lower level of sub-limits and conditions should be defined.”	This text introduces the concept of operating a facility well within its OLCs while introducing new processes or technologies.
“	“	“	7.18	“In the R&D facility measures should be taken to ensure that experiments and processes can be placed in a safe shutdown condition.”	Where new technologies and processes are being trialled on a facility the operator should ensure that it can still safely shut down the facility.

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