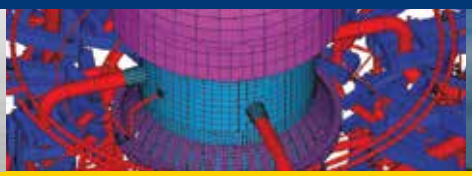
MMI

engineers • scientists • innovators

Nuclear



Engineering a Safer World

www.mmiengineering.com

About MMI Engineering

We provide technical consulting services to most industry sectors, specializing in the management of operational, man-made and naturally-occurring hazards.

Our expertise is drawn from a pool of suitably qualified professionals with a wide range of scientific and engineering backgrounds. We understand the underlying regulatory and statutory requirements that define our clients' needs and apply engineering analysis to develop engineering solutions.

With offices in the United Kingdom, United States, Australia and Malaysia, we work around the clock, and our professionals are just as comfortable on a plant walk down as they are in the board room - whatever it takes to meet our clients' needs.

Major Hazards Engineering

MMI Engineering was established in 2001 and continues to grow year-on-year.

- MMI employs over 100 consultants worldwide, many of whom are qualified to MSc or PhD level
- We have extensive experience across major hazardous industries, specifically in the Nuclear, Defence, Security and Oil & Gas sectors

We are members of the following groups and associations:

- Nuclear Industry Association
- Fire and Blast Information Group
- UK Hydrogen Association
- Register of Security Engineers & Specialists
- Center for Chemical Process Safety
- Society for Earthquake and Civil Engineering Dynamics
- NAFEMS

MMI in the Nuclear Industry

MMI Engineering offers services to the Nuclear Power Industry in a number of specialized areas.

We offer specialist consulting services to the Nuclear Industry in the areas of:

- Civil / Structural Engineering
- Mechanical Engineering
- Structural Integrity
- Internal / External Hazards
- Nuclear Ventilation
- Radwaste & Decommissioning

We employ highly qualified professionals with experience in design, construction, operations and project management. Our SQEP personnel deliver design expertise, engineering analysis, safety report authoring and independent review to clients at all levels of the Nuclear Supply Chain. We provide our clients with innovative solutions based on the sound application of engineering, science and technology, in combination with a realistic and pragmatic approach.

Clients

We offer highly qualified and effective support to Nuclear Power Plant vendors, plant owners and operators.

Some of our Nuclear clients include:

- ACKtiv Nuclear
- AREVA RMC
- AMEC
- Assystem
- AWE
- Babcock
- BOC
- DML
- Duke Energy
- EDF
- Enconet
- Finning
- International Nuclear Services
- Morgan Sindall
- NDA
- Nuclear Technologies
- Nuvia
- RWM Ltd
- Sellafield Ltd
- TVO
- URENCO
- USNRC
- Westinghouse

Innovation & Collaboration

We have worked, and continue to work, with a number of science and technology centres.

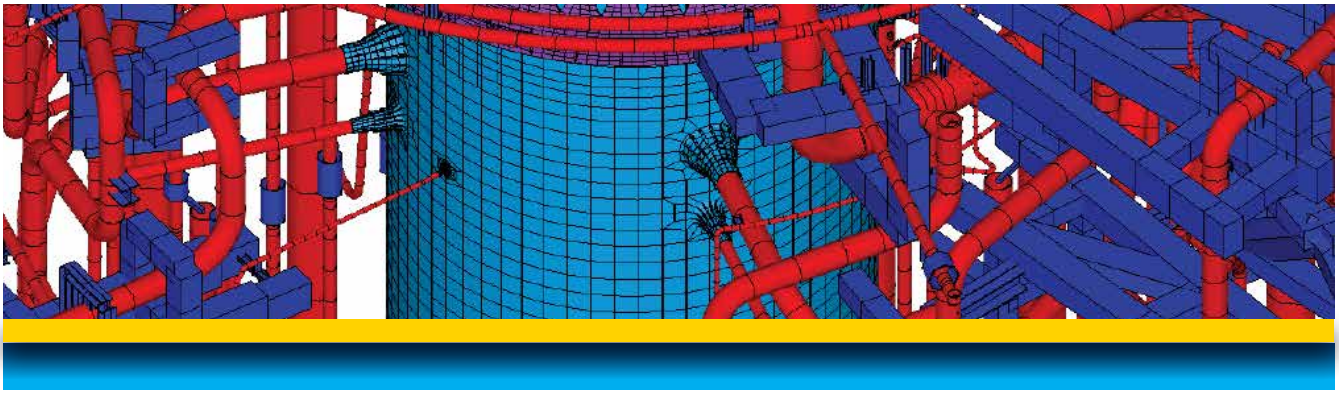
- We are an industrial partner to the DISTINCTIVE consortium of universities carrying out research in key topics of interest for nuclear decommissioning
- We are undertaking a collaborative Research & Development project, co-funded by Innovate UK, with Sellafield Ltd and the University of Leeds. This project will deliver new modelling and measurement technologies for characterizing the behaviour of waste sludges
- We have collaborated on research projects for fire and explosion safety with leading experimentalists and large-scale test facilities, including the Health and Safety Laboratory
- We have worked on methodology development for risk assessment and asset integrity management for HSE
- We have worked on Joint Industry Projects (JIP) to define best practice and produce guidance for a number of industrial applications

Tools

MMI uses software as a tool to predict loads or other parameters, assess capacity or performance, or optimize designs.

We use a wide range of analysis tools in our work for structural, civil and fluid flow assessments:

- Stress Analysis: ABAQUS, ANSYS, LS-DYNA
- Structural Analysis: STAAD, USFOS, CAP, SACS, SAP2000, SESAM, ASAS
- Blast Assessment Tools: MMI_BLASDOF, ATBlast, AIR3D
- Pipework Analysis: PSA5, Caesar
- Fluid Network Modelling: Flowmaster, Pipenet & others
- Flow and Dispersion: ANSYS-CFX, FLUENT, OpenFoam
- Hazard Modelling: FLACS, KFX, VESSFIRE, OpenFire, PHAST, Cirrus
- Wind Turbine Load Generation: FAST
- Risk Management: Bowtie XP, MMIQRA, RiskView, FaultTree+



Our Experience

We offer specialist nuclear services, for all parts of the Nuclear Supply Chain.

New Build Power

As a new third generation of nuclear reactors begins construction in the UK based around the EPR, ABWR and AP1000 designs, MMI is working with operators and designers to ensure the safety of this new plant, taking into account modern codes and standards.

Civil Nuclear Power

The industry has come to the end of a pioneering cycle where the first generation (Gen I) Magnox stations have ceased generating and the second generation (Gen II) Advanced Gas Cooled Reactor (AGR) fleet is ageing. New technological solutions are required to extend the life of Gen II plants and decommission the Gen I fleet. MMI is working with station operators on plant life extension and decommissioning projects throughout the UK.

Transport & Storage

Our work is used to support package safety cases for authorizing transport by demonstrating safe containment in normally ventilated environments and under the extreme conditions generated by accident events, including impact and fire.

Decommissioning & Disposal

Finding a solution for the long term disposal of legacy radioactive waste is a key requirement for the continued safe use of nuclear energy in the UK and is a pre-requisite for new nuclear generation. MMI provides a range of experience and skill sets suitable for tackling technical issues surrounding the safe removal and storage of nuclear waste material. We are actively working on projects for the design of safe containment in the proposed Geological Disposal Facility (GDF).

Nuclear Defence

Our work has included advice on nuclear safety cases and the evaluation of hazards at defence installations. We have had been involved in inspection, assessment and the design of systems, structures and components associated with the UK's nuclear deterrent.

Fusion

Nuclear Fusion will play a huge part in the energy market of the future, providing a clean, secure, long- term supply. MMI is in a position to assist researchers working to develop fusion as a new source of clean energy for tomorrow's power stations. We are engaged in several projects associated with the JET and ITER sites.

New Build Power

New nuclear power generation is needed to secure adequate base load capacity.

Nuclear power is the only energy source that can generate electricity reliably, efficiently and continuously with no greenhouse-gas emissions. In order to maintain the current share of nuclear power in the energy mix, around 10 GW of new nuclear capacity needs to be added to the UK's supply. This equates to between 6 and 8 new nuclear plants. The U.S. Nuclear Regulatory Commission is currently reviewing license applications for 22 new nuclear power reactors and more than 300 are planned worldwide. At this present time, more than 60 reactors are being constructed in 15 countries across the world.

Many of the new reactors will be evolutionary designs, building on the technology of those currently operating. New reactors with improved, passive safety systems and significant new technology are also being developed. To ease the challenge of huge capital demands associated with the large nuclear units, Small Modular Reactors (SMR) less than 300 MW are also being developed for implementation in scalable farms, with 12 to 24 units built at a single location.

At MMI, we are applying our Engineering Substantiation and independent technical assessment experience in assisting designers, operators and contractors working on these evolutionary and revolutionary designs to ensure safety in this new generation of Nuclear Power Plant.

Hinkley Point C in Somerset will be one of the first new generation (Gen III) EPR reactors to be built in the UK

Civil Nuclear Power

The recent concerns surrounding climate change have altered the public's perception of Nuclear Power and placed it firmly back on the agenda of many governments.

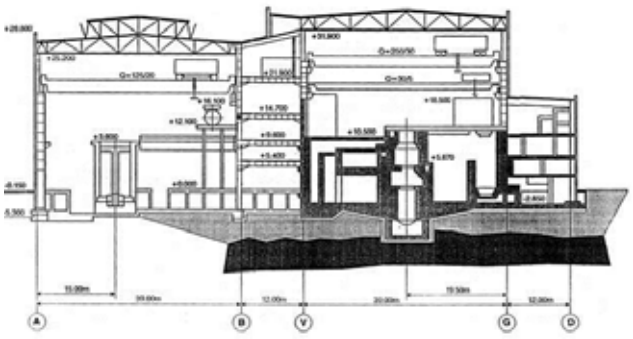
Project Description: Plant Life Extension

MMI were asked to support the design of a new nitrogen deluge system, including Liquid Nitrogen (LN) tank farms, at Hinkley Point B (HPB) and Hunterston B (HNB) Nuclear Power Stations. The system converted stored liquid nitrogen, contained in tall vessels, to gaseous nitrogen, before delivering it to the reactor. The vessels were assessed for the potential to fail under both wind and seismic loading and critical checks were made on local buckling of the tank skin, including the anchorage into the base slab. In order to transport the nitrogen from the vessels to the reactor, a number of pipeline systems were required, and so recommendations were made by MMI in order to reduce the expected localised stresses and to produce a more efficient design. Results from the analyses meant that the nitrogen deluge system was fully qualified prior to installation.

Nitrogen deluge system

Project Description: Seismic Fragility Analysis

MMI was appointed to undertake the seismic fragility analysis for Unit 2 of the Armenian Nuclear Power Plant (ANPP) in support of a Probabilistic Risk Assessment (PRA). Seismic fragilities of structures and equipment were prepared following the methods of PRA Procedures Guide (USNRC, 1983), IAEA-TECDOC-724 (IAEA, 1993), and the EPRI Methodology for Developing Seismic Fragilities (EPRI, 1994). Visits to the site were undertaken to perform limited walkdowns of the Structures, Systems and Components (SSCs) that are needed for the plant's safe shutdown following a seismic event and to provide seismic PRA training of plant personnel and specialists from the Armenian Nuclear Regulatory Authority (ANRA). For purposes of the seismic PRA, more than 50 fragilities were developed based on current and previous walkdown findings and by comparing the walkdown observations to Seismic Margin screening levels based primarily on seismic experience. Results from new Soil-Structure Interaction (SSI) and structural evaluation analyses of the Main and the Diesel Generator buildings recently performed by the Nuclear and Radiation Safety Centre (NRSC) were used as a basis for fragility calculations for these structures.

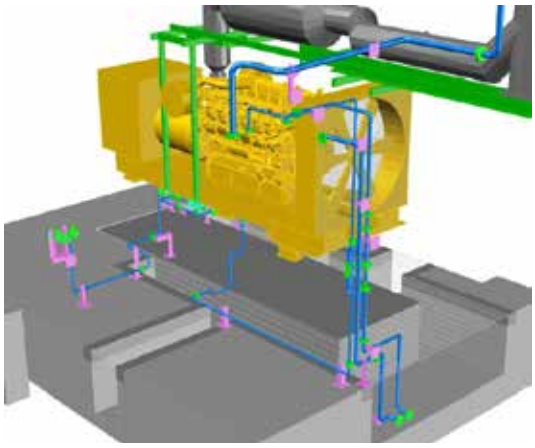


Plan of the ANPP

Civil Nuclear Power

Project Description: Plant Life Extension

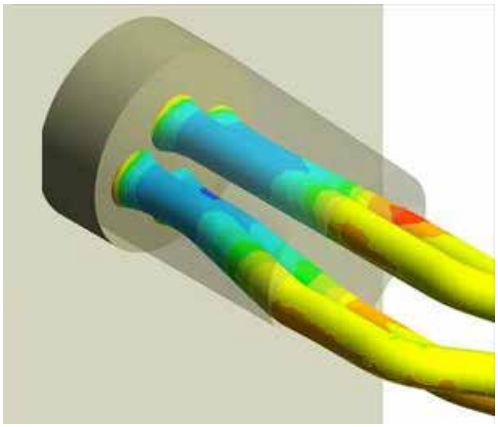
Installation of two replacement Battery Charging Diesel Generators (BCDGs) at EDF Energy's Sizewell B Nuclear Power Station was required. The supporting equipment was to be designated Seismic Category 2 and provide flood protection. MMI Engineering undertook the seismic justification of all off-skid BCDG ancillary plant items - the seismic justification of the BCDGs being based upon previous shaker table test results, including BCDG support frame, diesel day tank, fuel pipework, exhaust flue, control panels, and the fire-fighting pipework and access walkway as potential seismic interaction concerns. A range of assessment techniques were adopted to qualify the system, including simple equivalent static hand calculations, finite element modelling using STAAD, pipe stress analysis using PSA5 and non-linear dynamic analysis to investigate potential impact behaviour of the anti-vibration mounts under the BCDGs.



Battery charging diesel generator to be installed at Sizewell B

Project Description: Boiler Tailpipe Shrouds

Our client had identified that there were problems within the boilers of the Hinkley Point B and Hunterston B AGR power stations. High temperature differences were present in some of the boiler "tail pipes", particularly where they entered penetrations in the boiler walls. This high temperature difference was causing cracks to appear in the pintle welds at the tail pipe penetrations. A potential solution had been put forward for "shrouds" to be fitted around the pipe/ wall intersection, which would provide shielding for the welds from some of the high temperature CO_2 - reducing their temperature and the thermal stressing. The boilers themselves had a very congested interior space and there were a number of physical and radiological barriers to access. Therefore, the design of the shrouds had to be tested robustly through modelling and test-rigs to ensure that they would provide the thermal shielding required and be simple to fit. MMI Engineering were asked to provide Computational Fluid Dynamics (CFD) modelling to test the shroud design. These were complex models requiring the CO_2 flow outside the pipes, steam flow within the pipes and the heat flow through and along the pipe walls and shroud. MMI's CFD models demonstrated that the shrouds could be a successful solution to reduce the thermal stresses on the pintle welds; and were used to optimize the shrouds' design. The CFD models were also used to show that there was limited sensitivity in the thermal shielding to the thermal conductivity of the shrouds internal packing material. This was an important demonstration as it helped show the robustness of the shroud design before it was installed in a radioactive environment.



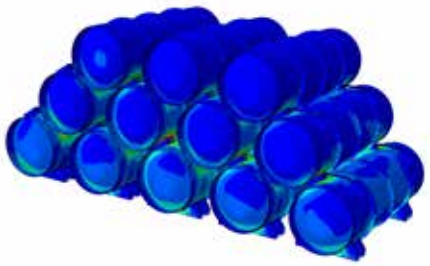
Temperature on the tail pipe surface with baseline final design

Transport & Storage

MMI has experience in the application of modelling tools to assess the behaviour of radioactive waste packages.

Project Description: Seismic Load Analysis

In this study MMI were asked to assess the stability of a triple stack of storage cylinders containing radioactive materials taking gravity and seismic load cases into account. Simply stacking the cylinders on top of each other resulted in unacceptably high stresses, so we incorporated a number of rubber blocks into the design to distribute the loading over a larger surface area, thereby reducing the stress. The stop blocks were made from a hyperelastic material, which was affected by both temperature and strain rate effects, and so these were included within the model so that bounding stresses could be predicted. The maximum stresses within the blocks during the seismic load case were calculated using a simplified response spectra analysis. Following this, detailed time history analyses were performed in order to calculate the actual stress distribution. Not only did we assess stresses within the key components, we also considered the stability of the arrangement. The results of the analysis were used to improve the design of the support blocks, ensuring optimum safety levels on-site.

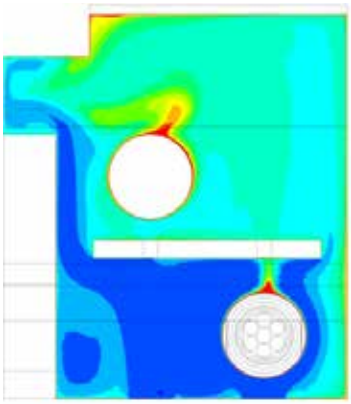


Rendered image of 3 tier stack with blocks

Project Description: Thermal Assessments

In 2011, The Pacific Grebe, one of PNTL's (Pacific Nuclear Transport Ltd) fleet of ships, commenced a maiden operational voyage to Japan with a shipment of vitrified residue from spent fuel reprocessing. The residue product was transported inside flasks within the vessel's cargo holds. There were four holds, each capable of transporting a number of flasks. To support the safety case, MMI undertook thermal assessments to determine:

- Resin temperatures in a flask (to demonstrate whether the resin was maintained below the limiting temperature when transporting the maximum heat load)
- The hold air temperature, as measured by two thermocouples, which would be used as a control in the Shipment Approval Certificate
- The average hold air temperature (to determine whether it was within the limit specified by the Irradiated Nuclear Fuel [INF] code)



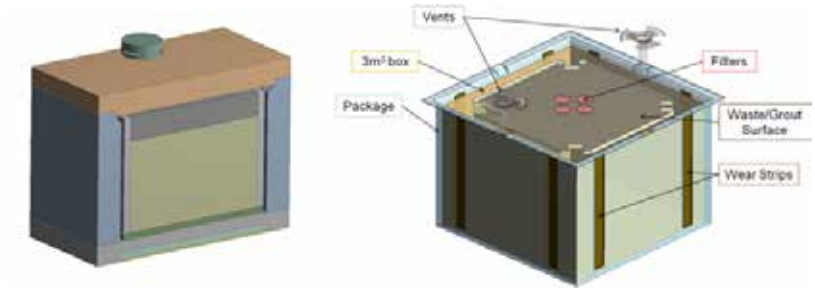
Air temperature within ship hold carrying two flasks

Our results demonstrated that the flasks were maintained below the critical temperature, which we were able to define so that PNTL could ensure it was maintained. This information allowed the shipment to be licensed and deliveries were made to schedule.

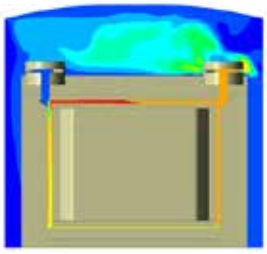
Transport & Storage

Project Description: Medium Term Storage

It is currently proposed that legacy wet wastes will be recovered from various plants and silos where they are stored and transported to an encapsulation plant, in order to be sorted, mixed with wet cement grout and cast into stainless steel boxes for future long term dry storage. During transport, separation of the waste and curing of the grout mixture, heat, hydrogen and water vapor are released. This combination presents a significant challenge to the package containing the waste form. MMI used the ANSYS CFX software to construct a solid model of a package for CFD and thermal assessments - the figure below shows a half model section of the package, which was inserted inside a transport canopy in order to calculate the local build-up of hydrogen within the flask ullage and the surrounding louvred canopy. We investigated various accident scenarios, including the effect of the package rolling onto its side and impact on the vent structures, which would result in blockage and subsequent hydrogen accumulation. The use of CFD allowed a number of scenarios, including normal operation and accident, to be investigated within a relatively short time scale compared to undertaking experimental trials.



Solid model for the transport package



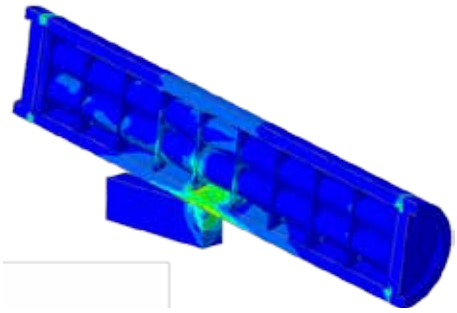
Contours show hydrogen concentration

Project Description: Integrity Assessments for Long Term Containment in the GDF

MMI used CFD to determine the thermal and hydrodynamic conditions within a conceptual spent fuel canister for geological disposal. These assessments were used to understand the potential for canister material corrosion as a result of water carried-over at the point of canister closure whilst in above-ground storage. The model also provided information on the potential for canister pressurisation due to vaporisation of water caused by heat from the fuel. We also conducted dropped object analysis using ABAQUS Explicit Finite Element Analysis, considering two potential scenarios:

- An 8m vertical drop onto a flat unyielding target
- Impact onto a mild steel ledge mounted on a flat unyielding target after toppling freely from an upright position

Our project indicated that the residual stresses in the system, combined with corrosion due to water carryover, could have implications for the long term integrity of the canister.



Container impact assessment shows integrity even if the container is dropped onto a ledge

Decommissioning & Waste Management

Our experts have decades of experience providing detailed studies as well as experience in working with Nuclear waste.

Project Description: Hazard and Risk Reduction for the Sellafield Site

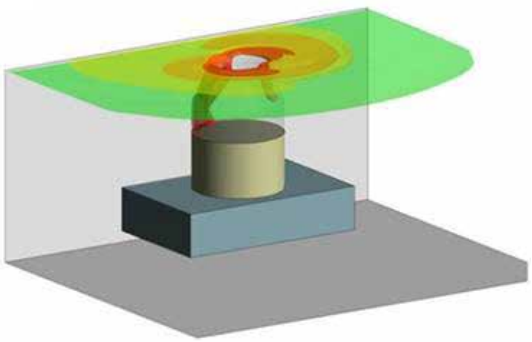
Sellafield's Legacy Ponds & Silos consist of four historic plants: Pile Fuel Storage Pond (PFSP), First Generation Magnox Storage Pond (FGMSP), Pile Fuel Cladding Silo (PFCS), and Magnox Swarf Storage Silos (MSSS). These plants were constructed in the 1950s and 60s, and were used either to store waste or to prepare fuel for reprocessing. Hazard and risk reduction for the Legacy Ponds and Silos has been identified as a national priority by the Nuclear Decommissioning Authority. MMI has worked on a range of projects in support of waste retrieval and continued safe operations for the Legacy Ponds and Silos. Our specialist knowledge and analysis techniques for sludge rheology have been deployed to assess and optimize designs for radioactive sludge settlement equipment for the PFSP and FGMSP. For the PFCS and MSSS, we have deployed our expertise in buoyancy driven flows to assess the performance of inerting systems and predict behaviour of hydrogen released from the waste in order to provide key input to safety assessments.

Sellafield site (© Sellafield)

Project Description: Intermediate Level Waste Processing

The Silos Direct Encapsulation Plant (SDP) will process intermediate level waste from the MSSS into a form suitable for long term storage. MMI has provided consulting advice and specialist CFD analysis services to the SDP project over a number of years, and since 2011 we have been an integrated part of the design team, providing additional problem definition support. A significant part of our delivery for SDP has been CFD analysis of hydrogen dispersion in the plant to underpin the engineering design and safety case for the ventilation system. However, the flexible working approach has allowed us to provide support on a range of other design issues, including:

- Prediction of wasteform curing behaviour & coverwater evaporation rates
- Consequence modelling for overpressures produced by hydrogen explosion fault cases
- Assessments of particle pick-up & transport within the product box handling & monitoring area
- Optimization of the nitrogen supply nozzle arrangements for the waste skip transport flask
- Evaluation of efficiency of hydrogen monitoring systems



Hydrogen concentration around process vessel in the SDP transfer tunnel

Decommissioning & Waste Management

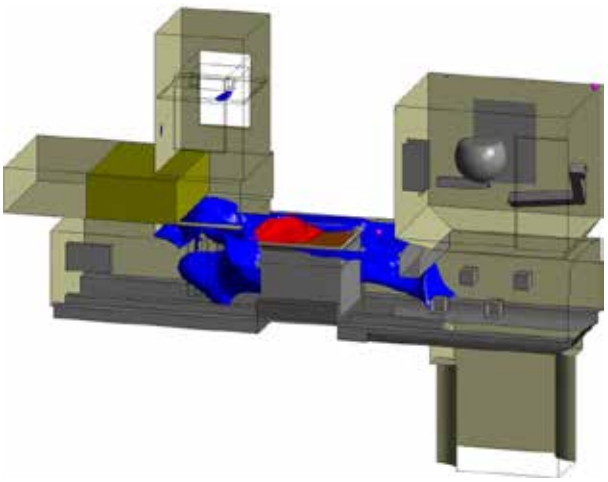
Project Description: Sludge Retrieval in the PFSP

Building on the foundations of our sludge retrieval work for the Legacy Ponds and Silos, MMI Engineering is undertaking a collaborative research and development project, which is being co-funded by Innovate UK under the “Developing the Civil Nuclear Power Supply Chain” competition. For this, our project partners are Sellafield Ltd and the University of Leeds. The objective of this collaboration is to develop improved techniques for the measurement and modelling of sludge separation and transport processes. While our previous work had given reasonable predictions of sludge settling behaviour and how this might be improved by various design options, we identified that modelling of particle agglomeration and break -up would be necessary to truly characterize the system behaviour. Through our academic links, we identified that researchers at the University of Leeds were developing an innovative Acoustic Backscatter Array (ABA) tool for the measurement of sludge concentrations and particle size. The synergies between the workstreams are obvious and the collaboration has been strengthened by the involvement of Sellafield Ltd to provide support to large-scale trials.

Pile fuel storage pond (© Sellafield)

Waste Retrievals Project Description: Sellafield Silos Emptying Plant

Waste retrieval from the MSSS is a key activity for hazard and risk reduction, and will enable ultimate decommissioning of the legacy facility. The Silo Emptying Plant (SEP) will retrieve the waste from the silos. The waste material generates hydrogen, and so management of the flammable gas hazard is crucial. MMI has provided consulting advice and CFD modelling services in support of design justifications to optimize and assess the performance of nitrogen supply systems for hydrogen management in the SEP Retrieval Machine and SEP package. Our analysis of the retrieval machine, which will extract the waste from the silos into skips, required us to consider all operating steps, including interface with the transport flask during import and export of waste skips, waste retrieval activities and fault cases. For the package, which will transport the skips of untreated waste across the site, we undertook detailed calculations to determine the inerting efficiency for various arrangements of nitrogen supply nozzles. This allowed an optimum configuration to be identified, along with nitrogen supply requirements.



Regions with elevated concentrations of oxygen (blue) and hydrogen (red) during waste skip export fault scenario

Nuclear Defence

MMI Engineering supports clients at Nuclear Submarine Dockyards and shore-based facilities in the management of associated risks.

Project Description: Submarine Systems Development (New Reactor Plant)

The new power plant for the next generation of nuclear submarines is currently under development. MMI Engineering were engaged to verify the designs of various rigs being developed to support testing of reactor components. One-dimensional network analysis models of the proposed test rigs were constructed using the Flowmaster pipe systems modelling software. The models were constructed using accurate representations of the rig pipework and fittings, as well as representation of the resistances of the test equipment. These models were analysed to confirm the required operational range of each rig by assessing the operational range of flow rates and thermal targets. Additionally, several of the rigs' overpressure protection systems were assessed for compliance to design guides and safety requirements by considering the selected relief valves and the relief pipework. MMI made a number of recommendations to improve the discharge pipework compliance to design guides.

Project Description: Nuclear Manufacturing Facility

MMI provided structural safety assurance services for a key project at the AWE Aldermaston facility. On this project, MMI provided technical advice to the assurance team to assist in the development of safety reports. This was achieved by providing technical commentary on specialist aspects including seismic loading, dynamic response, dropped load, impact, fire and structural collapse behaviour for a range of structural components, process plant and equipment. This input helped the safety team to construct safety arguments and understand claims made by the design team.

Project Description: Nuclear Building Safety Assessment

It is a safety assessment principle that Structures, Systems and Components (SSCs) can collapse provided the consequences are tolerable. For one key project at the Devonport dockyard, our client had undertaken sophisticated analyses to support their claim that in the event of an earthquake, "pancake" collapse of a building would occur. The client also stated that resulting ground borne vibrations would be bounded by seismic motions. We supported this study by supplementing analytical work with assessment methodologies based on basic theories of reinforced concrete and test programmes, which although confirmed pancake collapse, suggested that the collapse would generate collateral debris. Our involvement not only justified the original findings, but we also advised of the consequences of the collapse.

Nuclear Defence

Project Description: Submarine Facility Safety Case

Nuclear safety cases require Periodic Safety Reviews (PSRs)to be undertaken in order to ensure that facilities remain fit for continued operation, taking into account changes in design standards, changes in use, redefinition of hazards and degradation of facilities. MMI Engineering assisted our client with the delivery of a 20-year Periodic Safety Review (PSR). Initially, a site visit was undertaken to appreciate the scope, scale and context of the facilities - as well as to form an impression of current condition. Available records were reviewed to gain an understanding of the design assumptions and standards adopted originally. Standards were compared against modern standards and each design assumption was considered against current practice, with thought being given as to whether or not the original design remained valid in light of modern standards developments. We also specified a scope of inspection works required to supplement existing maintenance and inspection records to inform the PSR process. A number of findings and recommendations were made as a result of our assessments, which were incorporated into a wider set, including safety case and mechanical / electrical aspects.

Excavations were undertaken to confirm condition of components

Understanding of local failure mechanisms in reinforced concrete structures

Project Description: Fuel Manufacturing Facilities

We provided Independent Technical Assessment (ITA) services in support of design activities relating to a nuclear fuel manufacturing facility. MMI won this appointment in part due to the historic involvement of MMI staff in both the existing and proposed new facilities, along with our track record in seismic engineering and ITA services. Some MMI staff were involved in the multi-hazards assessment of the existing facility some years ago, and this led to the development of plans for the new facility. Other MMI staff have since been involved in the seismic design of the new manufacturing facility. This ITA role relates specifically to a seismically-qualified sub-structure within the facility related to the safe storage of materials.

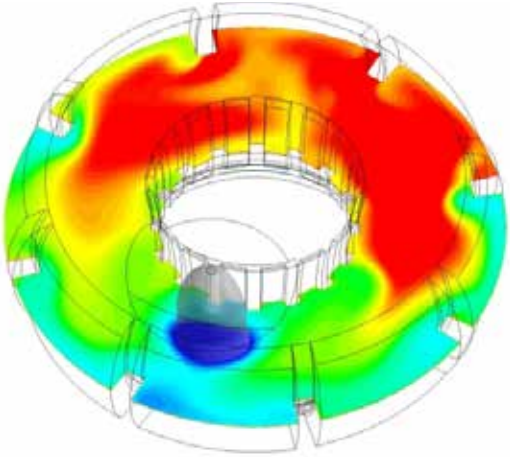
Fusion

Nuclear fusion power is one of the most promising options for generating large amounts of carbon-free energy in the future, but it also presents significant scientific and engineering challenges.

A number of large-scale fusion experiments are currently under construction internationally, such as JET (Joint European Torus) and ITER (International Thermonuclear Experimental Reactor). MMI has been providing specialist technical support to the organisations designing these experiments in order to overcome the engineering challenges and help make nuclear fusion power a reality.

Project Description: Joint European Torus (JET)

JET had been planning a tritium operation sequence, for which some of the safety analyses had to be repeated. In this framework, three different scenarios of Loss of Vacuum Accident (LoVA) required an inventory release assessment. The starting event for all investigated scenarios was local failure of the vacuum system integrity, resulting in an initial ingress of the surrounding air and a later release of the system inventory. The heat transfer between the hot torus walls and the inflowing air determined the extent of the later release (where the air heated up and the pressure in the torus increased above the ambient pressure). This thermal effect was significantly underestimated in the initial safety study.



Temperature in the JET Torus during a LoVA event

A transient CFD analysis was conducted for one of the cases with a fixed failure size. The torus was initially under ultra-high vacuum with a uniform temperature of the inventory and the walls. The numerical simulation was conducted for a fixed time interval. During the simulation, the heat transfer from the wall to the air flow was monitored. The calculated heat transfer coefficient was later used in a MELCOR model of the torus to calculate the extent and behaviour of the released inventory.

MMI

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Engineering a Safer World

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