IMIA working Group 109 - Singapore Sept. 2018

Construction and operation of Scientific instruments/infrastructure

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1 Introduction

Over the past decades, Scientists have designed and erected prototypes and research facilities that have allowed them to prove theoretical concepts and develop fundamental knowledge. Scientific instruments have become more and more sophisticated and often require international collaboration, based on costly long-term commitments.

Governments may fund scientific instrument or infrastructure projects through direct contributions of public funds or via subsidies. Funding may also be indirect via tax breaks or through the in-kind contribution of equipment, materials, experience and people.

Lenders, financial sponsors and the scientific community need the security of insurers to mitigate the risk and secure their investment.

But what is the risk profile of scientific instruments vs. "conventional" risks? What do the fusion reactor project ITER, the very large telescope in Chile or the giant particle accelerators in Sweden, Switzerland and Germany have in common? Can Risks Managers and brokers easily find insurance solutions in the market? What risks should underwriters focus on?

In the following pages, we try to address those questions along with many other issues associated with those unique facilities.

2 Categorisation of Scientific Instruments & Infrastructures

Scientific infrastructures have various missions or purposes. The following categorisation of scientific infrastructures according to their scientific mission or purpose is offered to focus discussion on typical attributes of each type:

- telescopes
- materials research probes using either intense light sources
- x-ray free electron lasers, or neutron sources
- nuclear physics research facilities
- high energy particle research facilities
- nuclear fission research facilities
- nuclear fusion research facilities

A list of some of the large scientific infrastructures, both existing or planned, located throughout the world is provided below in Table 1.

It should be noted that medical research facilities are not included in the table since they are small, relative to the large infrastructures listed, and widely distributed in location. It should be further noted that this paper focuses only on civilian scientific infrastructures, eliminating scientific infrastructures funded for military purposes from consideration.

Table 1. Examples of large scientific infrastructures that serve various purposes.

Scientific Infrastructure Type	**Example**
Telescopes	E-ELT, EST, FAST, SKA
Materials research probes using:	
Intense light sources	ALS, APS, COSY, DESY, Diamond, ELI, ESRF, MAX-IV, NSLS-II, SLS, Spring-8
X-ray free electron lasers	LCLS, SACLA, Swiss-FEL, XFEL
Neutron sources	ACNS, CARR, CSNS, ESS, HFIR, ILL, ISIS, J-PARC (MLF), SINQ, SNS
Nuclear physics research facilities	CERN-ISOLDE, CEBAF, FAIR, FRIB, GANIL, LNGS, RHIC
High energy particle research facilities	CERN-LHC, FNAL, RHIC
Nuclear fission research facilities	MYRRHA, JHR
Nuclear fusion research facilities	ITER, JET, JT-60U, KSTAR, W7-X

Although categorising these facilities according to their scientific purpose provides some insight to the risks to be encountered, it is also useful to categorise scientific infrastructures based on the following factors in evaluating the risk profile:

- Size
- Type of hazards
- Ownership: private vs. public and single nation vs. multi-national
- Stand alone or embedded in a larger institute
- In-kind contributions[1] vs. cash based

Each of these factors is discussed below.

2.1 Size

Regarding size, this paper is intended to address large scientific instruments and infrastructures, which we choose to define as those with a valuation greater than several hundred million Euros. The owners of such large scientific infrastructures often seek insurance coverage to protect them from risks of loss or damage to their considerable capital investment, as well as protecting them from liabilities for personal injury or damage to other property.

2.2 Type of Hazards

Such large facilities usually face a variety of types of hazards that threaten the safety of workers, and, in extreme cases, even the general public, as well as the integrity of the infrastructure and its considerable investment itself. Common industrial type hazards, such as electrical, mechanical, chemical, and even cryogenic, and natural phenomenon type hazards, such as earthquakes, wildfires, and meteorological events, are usually a consideration for such facilities, while some also face less common, but serious, hazards such as bio-hazards and ionizing radiation. From an insurance underwriting perspective, the industrial type hazards and associated risk profile are dealt with in a standard way, but even for conventional hazards, these scientific facilities often encounter an unusually large breadth of hazards, e.g. many types of toxic chemicals can be temporarily present at a large scientific user facility.

The risk profile for scientific facilities generally changes to a large degree when transitioning from construction of the infrastructure to its operation. Typically, the hazards during construction are more conventional, while those during the operational phase often include risks associated with use of first-of-a-kind equipment operated by scientific personnel, and may introduce new risks associated with radiation and biological hazards. This obviously requires a re-evaluation of the hazard potential and risk profile.

Many of the facilities identified in Table 1 have ionizing radiation hazards, which are particularly complicated and challenging from a regulatory, as well as insurance underwriting perspective. Generally, the nuclear grade quality assurance and quality control aspects of the facility must follow regulations governed by the authorities within the host nation. Although the general framework for this regulation is well-established, and fairly uniform across much of the world, the specific application can be complex because some of the equipment in these science facilities is first-of-a-kind, and by their very nature, the facility is exploring new frontiers. Systematic and thorough evaluation of off-normal and accident events, as well as so-called bounding events, and implementation of needed safety-credited systems and administrative processes is key to minimizing risk.

1 In-kind contributions are contributions supplied in services, equipment or property rather than money.

2.3 Ownership: Private vs. Public and Single Nation vs. Multi-National

These large scientific instruments and infrastructures are usually owned publicly, either by a single state or regional government, or by a consortium of multiple states. Insurance for such publicly owned infrastructures must be tailored to fit the constraints imposed by public funding, which can differ from those funded through private corporations. Multi-state-owned infrastructures are especially interesting since governance statutes are created through a multi-state negotiation process, and are therefore unique to each infrastructure. Nevertheless, the evaluation of risk exposure is independent of the ownership situation, so the uniqueness in dealing with insurance manifests itself in the process and parties involved in negotiating and establishing the underwriting agreement.

2.4 Stand-alone or Embedded in a Larger Institute

Whether or not a large scientific infrastructure is a stand-alone entity or embedded within a large institute can also affect the insurance underwriting situation. Establishing a new large scientific infrastructure has the potential to greatly impact the overall risk profile of an institute, requiring either a significant modification/addendum to an existing insurance package or the development of a new one covering only the new scientific infrastructure. This could become especially complicated for multi-state infrastructures embedded within a single state's public institute.

2.5 In-kind contributions vs. cash based

Nowadays, many research infrastructures are multi-national and rely heavily on in-kind, rather than straight cash, contributions from multiple institutes within partner countries. The ITER and ESS projects are just two examples, where more than half of the technical equipment scope is provided via in-kind contributions from partner country institutes. Managing these contributions to ensure that the provided equipment functions in an integrated fashion and meets the host state's legal requirements is especially challenging. Transfer of ownership and warranties has an important impact on the insurance risk profile that must be dealt with in underwriting.

2.6 Factors Covered in This Paper

To focus the discussion on key areas of interest, this paper addresses the unique risks and insurance needs for large, publicly-owned, scientific infrastructures, located at a single site, that include conventional hazards, but may also include nuclear/radiation safety hazards. The risk profile for such scientific infrastructures during the construction phase differ from those encountered during the operation phase, so consideration and examples of facilities in each phase are discussed.

2.7 Selected Examples of Scientific Infrastructures

To define the features of each of the types of large scientific infrastructures shown in Table 1, an example facility was selected for each category and its characteristics relative to the factors stated in section 2.2-2.5 are discussed below. It should also be noted that several facilities listed in Table 1 have been selected for extended discussion within this report. They include ITER, CERN, and ESS.

Telescopes

The Extremely Large Telescope ELT, with its 39-metre diameter primary mirror, will be the world's largest optical telescope. At a cost of more than a billion euros, ELT is being built in Chile by the European Southern Observatory (ESO), which is an intergovernmental organisation including 15 states. Some of the funding will be provided as in-kind contributions.

Construction of ELT started in 2014, and the ESO plans to complete the first phase of ELT in 2024 and subsequently operate the large infrastructure for 30 years. Hazards and risks during construction and operation are mainly conventional, but the handling and maintenance of sensitive, expensive, and large, yet delicate optical equipment is especially challenging.[2], [3]

Intense light sources

The Diamond Light Source is a UK national facility located on the Harwell Science and Innovation Campus in Oxfordshire that uses a 563 metre-circumference synchrotron to accelerate electrons to near light speeds so that they give off light 10 billion times brighter than the sun. These bright beams are then directed into 22 different instrument stations where scientists use the intense light to probe various types of matter. The construction cost of Diamond, including its 22 instruments, was 283 million GBPs. Diamond is a not-for-profit limited company funded as a joint venture by the UK government through the Science & Technology Facilities Council (STFC) in partnership with the Welcome Trust. Diamond began operating in 2007, and over its expected lifetime of more than 25 years it will deal with usual conventional hazards and risks, as well as those associated with protecting people from radiation-generating devices. Radio-activation hazards and handling of radioactive materials are present at this type of facility, but at a minimal level when compared to nuclear reactors or heavier-particle accelerators. Because of the nature of this type of scientific user facility, a large variety of hazardous chemicals, and even some biologically hazardous substances, will be dealt with over its lifetime. [4], [5]

2 Tamai, R., et al., The E-ELT Program Status, Proc. SPIE 9906, Ground-based and Airborne Telescopes VI, 2016.
3 The Extremely Large Telescope, https://www.eso.org/public/teles-instr/elt/.
4 Materlik, G., et al., Diamond Light Source: Status and Perspectives, Philos. Trans. A Math. Phys. Eng. Sci., 2015.
5 Diamond Light Source, http://www.diamond.ac.uk/Home.html

X-ray free electron lasers

The European XFEL is a facility that began operation in 2017 in northern Germany that uses a 3.4 km-long electron accelerator facility. The electrons are accelerated up to energies of 17.5 GeV to generate the intense x-ray flashes. Researchers from all over the world are just beginning to use these x-ray flashes to study various materials and processes at extremely small length and time scales. The superconducting accelerator structures, as well as the instrument stations used to conduct science experiments, are located in underground tunnels which can be accessed on three different sites. A non-profit limited liability company under German law, European XFEL GmbH, was established to construct and operate the facility. Twelve countries participated in the project, which started in 2009 at a cost of 1.25 billion EUR (2005 prices). The facility used in-kind contributions from partner countries to a great extent to equip the facility. Hazards at this type of facility are similar to those present at intense light sources.[6], [7]

Neutron sources

The European Spallation Source (ESS) is a newly formed multi-disciplinary research facility, which began construction in 2014 on a greenfield site in southern Sweden. Like the intense light source facilities, ESS will allow scientific users to explore the configuration and dynamics of materials over a broad size and energy range. ESS will use a 500-m long, superconducting accelerator to generate 2 GeV protons at an average power of 5 MW that produce neutrons through a spallation reaction that occurs when the protons interact with a four-tonne, helium-cooled tungsten target wheel. When fully constructed, experiments will be simultaneously performed at twenty-two instrument stations. The construction cost of ESS is 1.84 billion EUR (2013 prices), and the first instruments will begin commissioning in 2022. ESS is funded within a European Research Infrastructure Consortium (ERIC) framework with 13 member states providing both cash and in-kind contributions. The tungsten target and nearby components represent a large radioactive inventory that must be addressed through rigorous processes during design, implementation, operations, and maintenance. A large hot cell is used to process, temporarily store, and prepare these spent components for disposal at radioactive waste facilities in Sweden. In addition, like the intense light sources, users will bring a broad spectrum of material samples to the site, some of which will be chemically or biologically hazardous. [8], [9]

Nuclear physics research facilities

The Facility for Rare Isotope Beams (FRIB) is a scientific user facility being constructed on the Michigan State University campus by the U.S. Department of Energy with joint funding from the state of Michigan. The total cost to construct the facility, which will be completed in 2022, is 730 million USD. FRIB will enable scientists to make discoveries about the properties of short-lived nuclei not normally found on earth that are important to nuclear astrophysics, fundamental nuclear interactions, and applications for society, including in medicine, national security, and industry. The 517 m-long accelerator uses the latest superconducting-accelerator technology to provide uranium beams at energies of 200 MeV/nucleon and lighter ions at higher energies (protons up to 600 MeV). The high-power production target and fragment separator are used to produce and deliver rare isotopes with high rates and high purity. Targets and fragment separator systems become highly radioactive leading to the need for hot cells to repair equipment and prepare radioactive waste for off-site disposition. The significant radioactive material inventory at facilities such as this represent a serious hazard that must be properly characterised and mitigated. Since this is a user

[6] Decking, W>, et al., Commissioning of the European XFEL Accelerator, Proceedings of IPAC 2017.
[7] European XFEL, https://www.xfel.eu/.
[8] Garoby, R., et al., The European Spallation Source Design, Phys. Scr. 93, 2018.
[9] European Spallation Source, https://europeanspallationsource.se/.

facility open to scientists with broad areas of applications, many types of hazardous substances will be dealt with over its lifetime. [10], [11]

High energy particle research facilities

The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator and is the latest major addition to CERN's accelerator complex straddling the border between Switzerland and France. The LHC, which began operation in 2008, is comprised of a 27-km circumference ring containing superconducting magnets and a number of accelerating structures used to boost the energy of two particle beams traveling in opposite directions to an ultimate energy of 6.5 TeV (protons) that collide at four locations around the accelerator ring, corresponding to the positions of four huge (~10 000 tonnes) particle detectors – ATLAS, CMS, ALICE and LHCb. LHC was built at a cost of 4.3 billion CHF and included funding support, comprised of a combination of cash and in-kind contributions, from the CERN member states as well as the US, Japan, and India. Many parts of the LHC become radioactive, requiring rigorous control over operations and maintenance activities, but represents a very low risk to the public. [12], [13]

Footprint of the LHC

Source: https://alexeinstein.wordpress.com/2014/10/06/large-hadron-collider-made-music/

Nuclear fission research facilities

Because of the diverse nature of the scientific infrastructures in this category relative to the hazards present in the facility, two examples are described.

The Jules Horowitz Reactor (JHR) is intended to be a research facility for industrial and scientific applications. One of the main missions of the JHR facility, which is being built within the French government's CEA-Cadarache nuclear research facility in southern France, is to provide a materials test facility to support operation of existing nuclear power reactors and research and qualification of future technologies and systems. They also intend to produce radio-elements for nuclear

[10] Bollen, G., FRIB—Facility for Rare Isotope Beams, AIP Conference Proceedings 1224, 432, 2010.
[11] Facility for Rare Isotope Beams, https://frib.msu.edu/
[12] Collier, P., The Technical Challenges of the Large Hadron Collider, Phil. Trans. R. Soc. A 373, 2014.
[13] The Large Hadron Collider, https://home.cern/topics/large-hadron-collider.

medicine and non-nuclear industry. The JHR core uses a high density, low enriched uranium fuel configured as a pool type reactor with a maximum thermal power of 100 MW. The reactor core and its containment structures are housed within a 37-metre diameter reactor building. The facility, which is expected to begin operation in 2021, also includes hot cells, nuclear qualified laboratories, and three storage pools for spent fuel, experimental devices, and mechanical components management. The cost of the facility is 750 million EUR. CEA provides 50% of the funds, and the remainder is provided by other government institutes and private companies, some in the form of in-kind contributions. JHR addresses the serious hazards present in nuclear reactors, hot cells, and fuel storage facilities within the rigorous French nuclear regulatory framework. [14] ,[15]

The Multi-purpose hYbrid Research Reactor for High-tech Applications (MYRRHA) facility is categorized here as a nuclear fission research facility, but it utilizes a hybrid nuclear reactor/particle accelerator scheme that allows the reactor to run in a subcritical, and therefore easily controlled, state. The facility, which is being constructed by the SCK-CEN public utility institute at its site in Belgium, consists of a 600 MeV proton accelerator, a spallation neutron source, and a nuclear reactor core operating at a power level of 57 MW. Its primary mission is as a prototype facility to demonstrate how this accelerator-driven scheme could be used for power production as well as waste transmutation, but it also incorporates provision of a flexible fast-neutron spectrum for irradiation testing of materials for innovative fission and fusion reactors, and is capable of producing radioisotopes for medical and industrial applications. The facility will be implemented using a staged approach, with the first accelerator R&D stage finishing in 2024. The cost of the complete facility is expected to be approximately 1.6 billion EUR and is funded partly by the Belgian government, with additional support from other nations as well as private industrial partners, and includes both cash and in-kind contributions. Radioactive hazards at such a facility are similar to those present at both accelerator installations and nuclear reactors, but it avoids the very serious criticality-type events that must be considered at pure fission reactor facilities [16], [17]

Nuclear fusion research facilities

ITER is an international research facility that is dedicated to being the first nuclear fusion device to produce net energy, thereby demonstrating fusion as a viable, carbon-free energy source for the future. The facility is currently under construction in southern France and is a 35-year collaboration of the seven ITER members, including China, the European Union, India, Japan, Korea, Russia and the United States. Although it is located next to a major nuclear research facility owned by the French government (CEA-Cadarache), ITER is a stand-alone facility. Members provide both cash and in-kind contributions. ITER uses a large array of superconducting magnets configured in a so-called tokamak configuration to confine the dense, high energy plasma that produces the fusion events at a rate corresponding to a power output of 500 MW. The tokamak core has a mass of 23,000 tonnes and the entire site, which includes large electrical and cryogenic refrigerator infrastructures, occupies 180-hectares. The experimental campaign will be carried out at ITER starting in 2025. Large radioactive inventories, including large amounts of tritium, are a serious hazard at this facility that must be rigorously controlled and mitigated, but unlike nuclear fission facilities there is nothing corresponding to a criticality event that would potentially threaten public safety. Design and production costs are predominantly in the form of in-kind contributions from the

[14] D. Parrat, et al., The Future Jules Horowitz Material Testing Reactor: An Opportunity for Developing International Collaborations on a Major European Irradiation Infrastructure, Proceedings of the 11th International Conference on WWER Fuel Performance, Modelling and Experimental Support, 2015

[15] The Jules Horowitz Reactor, http://www-rjh.cea.fr/index.html.

[16] MYRRHA: an innovative research installation, http://sckcen.be/en/Technology_future/MYRRHA.

[17] MYRRHA An innovative and unique irradiation research facility, https://www.oecd-nea.org/pt/iempt11/documents/VI-4_11th_EIM-PT_HAA_MYRRHA_4.11.2010.pdf.

partner countries, and the total value of these contributions are not centrally tracked, but current estimates indicate that the cost is above 20 million EUR. [18] [19]

Acronym	**Definition (Location)**
ACNS	Australian Centre for Neutron Scattering (Australia)
CARR	China Advanced Research Reactor (China)
CEA	Commissariat à l'Energie Atomique
CERN	European Organization for Nuclear Research (Switzerland/France)
COSY	COoler Synchrotron (Germany)
DESY	Deutsches Elektronen-Synchrotron (Germany)
Diamond	Diamond Light Source Ltd. (UK)
E-ELT	European Extremely Large Telescope (Chile)
ELI	Extreme Light Infrastructure (Czech Republic, Hungary, and Romania)
ESRF	European Synchrotron Radiation Facility (France)
ESS	European Spallation Source (Sweden)
EST	European Solar Telescope (Spain – Canary Islands)
FAIR	Facility for Antiproton and Ion Research (Germany)
FAST	Five-hundred-meter Aperture Spherical radio Telescope (China)
FNAL	Fermi National Accelerator Laboratory (USA)
GANIL	Grand Accélérateur National d´Ions Lourds (France)
ILL	Institut Max von Laue-Paul Langevin (France)
ISIS	Spallation neutron source (not an acronym) (UK)
ISOLDE	Isotope mass Separator On-Line Detector facility (Switzerland)
ITER	Not an acronym (France)
JET	Joint European Torus (UK)
JT-60SA	Japan Torus-60 Super Advanced (Japan)
JHR	Jules Horowitz Reactor (France)
KSTAR	Korean Superconducting Tokamak Advanced Research (Korea)
LHC	Large Hadron Collider (Switzerland/France)
LNGS	Gran Sasso National Laboratory (Italy)
MAX IV	Not an acronym; fourth generation synchrotron light source (Sweden)
MYRRHA	Multi-purpose hYbrid Research Reactor for High-tech Applications (Belgium)
SACLA	SPring-8 Angstrom Compact free electron Laser (Japan)
SCK-CEN	Studiecentrum voor Kernenergie; Centre d'Étude de l'énergie Nucléaire
SINQ	Swiss spallation neutron source (Switzerland)
SKA	Square Kilometre Array (Australia and South Africa)
SLS	Swiss Light Source (Switzerland)
Spring-8	Super Photon Ring – 8 GeV (Japan)
Swiss-FEL	Swiss x-ray Free Electron Laser (Switzerland)
W7-X	Wendelstein 7-X stellerator reactor (Germany)
XFEL	European X-ray Free-Electron Laser Facility (Germany)

[18] Bigot, B., ITER: A Unique International Collaboration to Harness the Power of the Stars, C. R. Physique 18, 2017.
[19] ITER - the way to new energy, https://www.iter.org/.

3 Regulation & Legal Environment

Legal Environment

The legal environment applicable to scientific infrastructure, depends on the country in which the installation is being located and the governance and agreements associated with the body responsible for the establishment of the project. Two reports by the OECD in 2010 outline how globally backed scientific infrastructural projects can be arranged. [20], [21]

Regulation

The regulations applicable to a scientific infrastructure project are dependent on the following:

- The topography, seismology, and climatic conditions of the project location
- The local and global regulations adopted by the country where the project is located
- The hazard types associated with the construction, testing and operation of the facility

Given that scientific infrastructure projects, by their nature, will be prototypes and first-of-a kind type installations, the development of detailed and living risk registers will be key to identifying the most significant and unique risks to the project and the associated regulations.

One risk aspect to such projects that can prove challenging from a regulatory perspective is the presence of a nuclear component to the installation or more importantly those that involve high levels of radioactivity or have the potential to generate significant levels of radioactive contamination. Table 2 below lists countries that have nuclear power installations and the liability conventions to which they are party. The most onerous regulatory regime is the 2004 Paris Convention on nuclear third-party liability[22], which is not fully adopted.

Within the Paris Convention, nuclear installations are defined as: reactors other than those comprised in any means of transport; factories for the manufacture or processing of nuclear substances, for the enrichment of uranium, and for the reprocessing of irradiated nuclear fuel; and facilities for the storage of nuclear substances. Facilities which do not involve high levels of radioactivity, such as those for uranium mining and milling and for the production of radioisotopes, are covered by general tort law rather than the Convention. This last distinction is very relevant to the required levels of third party lability coverage (and from a different perspective property coverage) as the risk registers from scientific infrastructure projects are reviewed. By way of example Section 4 of this paper outlines the regulatory challenges faced by the ITER project, because of the mismatch between the licensing of the site and the non-applicability of the nuclear conventions to fusion technology.

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[20] Establishing Large International Research Infrastructures: Issues and Options – OECD, https://www.oecd.org/science/sci-tech/47027330.pdf

[21] international distributed research infrastructures (IDRIS) – OECD, https://www.oecd.org/sti/sci-tech/international-distributed-research-infrastructures.pdf

[22] Convention on Third Party Liability in the Field of Nuclear Energy – OECD https://www.oecd-nea.org/law/nlparis_conv.html

Table 2: Nuclear power states and liability conventions to which they are party[23]

Countries	Conventions party to	Countries	Conventions party to
Argentina	VC; RVC; CSC	Lithuania	VC; JP; (CSC signed)
Armenia	VC;	Mexico	VC
Belgium	PC; BSC; RPC; RBSC	Netherlands	PC; BSC; JP; RPC; RBSC
Brazil	VC	Pakistan	
Bulgaria	VC; JP	Romania	VC; JP; RVC; CSC
Canada	CSC	Russia	VC
China		Slovakia	VC; JP
Czech Republic	VC; JP; (CSC signed)	Slovenia	PC; BSC; JP; RPC; RBSC
Finland	PC; BSC; JP; RPC; RBSC	South Africa	
France	PC; BSC; RPC; RBSC	Spain	PC; BSC; RPC; RBSC
Germany	PC; BSC; JP; RPC; RBSC	Sweden	PC; BSC; JP; RPC; RBSC
Ghana	(CSC signed)		
Hungary	VC; JP	Switzerland	PC; RPC; BSC; RBSC
India	CSC	Taiwan	
Iran		Ukraine	VC; JP; (CSC signed)
Japan	CSC	UAE	RVC; CSC
Kazakhstan	RVC	United Kingdom	PC; BSC; RPC; RBSC
Korea		United States	CSC

PC = Paris Convention (PC). RPC = 2004 Revised Paris Protocol. Not yet in force.
BSC = Brussels Supplementary Convention. RBSC = 2004 Revised Brussels Supplementary Convention. Not yet in force.
VC = Vienna Convention. RVC = Revised Vienna Convention 1997 (in force 2003)
JP = 1988 Joint Protocol.
CSC = Convention on Supplementary Compensation for Nuclear Damage (CSC), in force from 15 April 2015.

[23] WNA – Liability for Nuclear Damage
http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/liability-for-nuclear-damage.aspx

4 ITER - an interesting issue - Nuclear liability and fusion installations

4.1 Background

The two international nuclear liability conventions, the Paris Convention on Third Party Liability in the Field of Nuclear Energy (Paris Convention) and the Vienna Convention on Civil Liability for Nuclear Damage (Vienna Convention) concluded in the early 1960s cover fission installations and the damage caused by a nuclear incident in a nuclear installation or involving nuclear substances coming from such an installation.

The definition used for nuclear installation in the Paris Convention (Article 3) excludes nuclear fusion facilities.

In the framework of the Nuclear Energy Agency (NEA), a specialized agency of the Organisation for Economic Co-operation and Development (OECD), possible revisions of the conventions were discussed on several occasions in the period between 1990 and 2005, and the question was asked in view of the construction of ITER whether it would be feasible to have fusion covered by the Paris or Vienna Convention. Presentations were made by experts on the radiological risks of fusion, how these differ from fission, and whether the regulatory regimes established by the nuclear liability conventions would be appropriate for application to fusion reactors and related installations.

The result of these discussions was that fusion was considered to have a low level of radiological risks and that in the absence of a near-term perspective of commercial use of fusion energy no need was identified to bring fusion under the aegis of a revised Paris Convention. This technology has long been considered insufficiently advanced to consider extending the scope of the Paris Convention to cover such facilities implementing nuclear fusion[24].

However, ITER is now a reality, a nuclear installation under construction in France.

At this moment, no indemnification under the existing international nuclear liability regimes is available for fusion installations. This implies that claims from radiological damages to third parties would have to be dealt with under general tort law and that claims could be brought forward to the operator (the ITER Organization) or to the suppliers of the components that caused such damages without limitation. With respect to possible radiological damages arising from an incident caused by the operation of the ITER facility, it must be emphasized that, as stated above, these will be relatively low and that in practice it will be very difficult for third parties that suffered damages to prove that these arose from the failure of a specific component and thus must be remedied by the supplier of that component.

The Paris Convention provides an appropriate framework, taking into account the low level of risk associated with nuclear fusion facilities while leaving the possibility open to integrate them into a 'reduced-risk facility' category for domestic-based legislation.

4.2 Situation of ITER Facility

The ITER facility is governed by French law in terms of nuclear safety in accordance with Article 14 of the ITER international treaty; it is classified as a licensed nuclear facility (Installation nuclear de base or INB). Its creation was authorized by a French ministerial decree on 09 November 2012[25].

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[24] According to Section 12 of the explanatory memorandum of the Paris Convention as revised on 16 November 1982, "given that the possible applications of nuclear fusion are not yet clear, it does not seem possible or necessary to take this form of nuclear activity into consideration in the Convention".

[25] Decree No. 2012-1248 dated 9 November 2012 authorizing ITER Organization to build the licensed nuclear facility called ITER in Saint-Paul-lez-Durance (Bouches du Rhone department),

Its design, construction and operation are subject to the inspection by the French Nuclear Safety Authority (ASN). The technical requirements have been defined by the ASN by way of decision dated 12 November 2013[26].

From a nuclear safety viewpoint, the fact that the ITER machine was classified as a licensed nuclear facility is due to its maximum tritium inventory and the quantity of radioactive waste that will be produced during its operation and dismantling.

4.3 Insurance considerations

Construction of the ITER facility involves the signing of many contracts with various different suppliers, with ITER Organization being responsible for ensuring the integration and assembly of the components delivered to the Cadarache site by the different ITER members. Ordinary liability laws, which are unlimited in principle, burden suppliers and transport companies with a high level of risk in the event of nuclear damage, whereas the insurance policies available to them systematically exclude the cover of any nuclear risks regardless of the degree of severity. This risk is only covered within the scope of nuclear civil liability insurance, which is only available to nuclear facility operators whose liability is channelled in the event of a nuclear accident, i.e. operators covered by an international nuclear civil liability system.

Furthermore, a civil liability system that takes into account the concerns of the general population while making it easier to compensate for any damage caused by fusion reactors, would provide a safe legal framework making it possible to ensure suitable compensation for any damage caused by a nuclear accident, while encouraging the development of nuclear fusion.

https://twitter.com/iterorg/status/984363457247174656 12 Apr 2018

[26] Decision No. 2013-DC-0379 issued by the French Nuclear Safety Authority on 12 November 2013 establishing the requirements applicable to ITER Organization for licensed nuclear facility INB No. 174 called ITER based in Saint-Paul-lez-Durance (Bouches du Rhone department).

5 Underwriting considerations

There are numerous challenges associated with the insurance of scientific and research projects particularly during construction. The first of a kind nature of most projects coupled with the unique method of financing and procurement alongside often lengthy project durations presents some significant challenges.

In underwriting generally, projects are typically put into specific project categories such as power generation or mining. In the development of new and experimental scientific or otherwise special projects, the existing categorisation and knowledge may not apply requiring a green field approach to underwriting the risk. Very close collaboration between the parties is desirable to achieve an efficient and effective risk financing.

This section seeks to highlight the challenges associated with these specialised facilities, relative to conventional risks. Some potential solutions are offered later in this section, in the form of clauses and risk management techniques.

5.1 Technology risks

There are challenges regarding proven nature vs prototypical risks. Often the scope and focus of the project will be new/unique/state of the art/research/"one of a kind". This leads to initial concern, however the type of equipment to be installed, layout and process flow warrants further investigation to determine whether the equipment is truly prototypical or is more conventional but arranged in a unique configuration and new application.

Care should be taken to evaluate the proven nature of each individual project element with particular focus on the interaction and interface between each project element – this is often where the risk exists. If interface points exist where different stages of a process have not been configured together previously, it is important to ensure that the inputs and outputs of each element have been specified to the correct tolerance both from a physical perspective as well as an electrical output/pressure/temperature/feedstock specification. Such processes which involve the use of proven equipment in a non-conventional arrangement may be viewed as having more of a prototypical configuration exposure, which is perhaps easier to manage than equipment which is unproven in itself. With the correct approach to risk management, such as the use of and continuous update of risk registers, control of change procedures, interface management as well as general contractor, general project management, contractor management and quality control, these exposures can be largely mitigated. If the underwriter is confident of the robust approach to these exposures, a restriction to the level of design coverage may not be of primary importance.

Of course, equipment may be prototypical in itself, consisting of new/unproven technology, esoteric materials, high pressures and extremely high temperatures (or low, in the case of superconductivity). Equipment may also be viewed as unproven due to reasons of scale up, which could be due to a variety of reasons such as increase in physical size, throughput, current, voltage, temperature or pressure. Investigation of similar facilities and processes is essential to gauge the level of scale-up or prototypical nature. Once this evaluation has taken place, a considered approach may be made to the most suitable level of design exclusion.

Exposures also exist due to the repetition of equipment, for example within particle accelerators which contain a significant number of high power/current electromagnets and cooling systems, which work in series along a linear accelerator or around a toroidal accelerator. Such accelerators work on the principle of a controlled pulse fed sequentially which is then increased in speed to create the required acceleration of a particle. The exposure exists where a defect exists in a number of items, which may lead to a series of repeat failures attributable to the same original cause.

Equipment may require significant levels of power, it is important to consider the resilience of the internal supply network, along with the availability of external grid supplies, dedicated substations and so on. Failure of such power supplies can lead to delays and additional costs incurred to complete the project. Investigation of back-up supplies, both internal and external is suggested as part of the underwriting review process.

Due to the bespoke nature of some items of equipment and resultant reduced number of vendors it is probable that increased replacement timescale durations will exist. If equipment needs to be repaired quickly, this will likely result in higher repair costs and additional transportation cost if the only supplier is located in a different continent compared to the location of the project.

5.2 Fire risk

If equipment is installed within a ‘clean-room’ type environment, such as seen in semiconductor factories or research laboratories, the exposure to smoke damage due to small fires can be significant. The costs associated with clean-up of smoke and water damage can be significant, as can the replacement costs of sensitive electronic equipment damaged by corrosive smoke or fire extinguishing water. Evaluation of lifting and handling processes as well as the non-combustible nature of building materials and fire compartmentalisation is recommended. Additional review of the permanent fire protection/detection measures as well as ventilation, dust and smoke extraction is also an important part of the underwriting process. This can be challenging as there are no off-the-shelf standards for this type of project, due to their bespoke nature of each project. Therefore, it is likely that a number of differing local and International standards may apply including industry specific standards such as NFPA or FM Global. Occasionally, Insureds may involve their Insurers for commentary on required protections, however it is more advisable for an independent fire risk consultant to be engaged by the project to design a system specific to the risks associated with the facility. This can, of course be reviewed by Insurers pre-inception and during the course of the project, often during the risk engineering process.

Some processes may involve the use of hazardous, flammable or highly toxic materials. This may enhance the exposure to fire, corrosion/erosion and higher costs of clean up and pollution. If such materials are to be utilised; methods of storage, handling, and fire detection/protection should be evaluated. Projects with very high power requirements will also employ significant amounts of cabling, which may create fire communication through cable trays located above or below equipment. For example, in the case of toroidal particle accelerators; achieving fire compartmentalisation of both the equipment and cable trays can be extremely challenging due to the nature of the layout being a continuous ‘process’.

5.3 Project management and control

The management of quality at site only is insufficient, it is essential that quality control activity is extended to include vendor locations. If any responsibilities for quality control are passed on contractually through to vendors and EPC contractors, it is essential that the owner has their own layer of QA/QC or has made arrangements to audit any delegated responsibilities.

This type of project is often developed by an international consortium of countries seeking to jointly build a research facility. Costs are often extremely high, hence the need for risk and finance sharing. Due to the involvement of many countries, the project management structure may be complex, hence decision making by committee which could cause delays on control of change for design and specification alterations. It is essential that a risk register is developed at the commencement of the project and updated where design or regulation changes take place.

The above issues may cause complications and delays where decisions have to be made following loss or damage. Reinstatement of damage can also take longer, particularly where local or international safety agencies may investigate or suggest design changes.

Even minor fires can lead to smoke contamination of switchgear and specialised components. Smoke driven corrosion, or damage as a result of contamination by extinguishant or fire water is possible. Prevention is far better than cure for projects of this type, therefore a robust hot works procedure with management and audit of its application is necessary. Also, the correct type of temporary fire extinguishing systems should be specified to ensure that activation of the system itself does not cause more damage than the system was designed to prevent

5.4 Project duration

Often the original project periods may be lengthy (almost 10 years in the case of the ITER project). Long durations create challenges for underwriters in being able to accept the risk and may limit the markets that are prepared to underwrite a particular project. This of course could impact on the competitiveness of the programme.

Project duration requires careful consideration, in order to ensure periods are in accordance with Insurers' treaty reinsurance limitations, internal underwriting guidelines and market guidelines such as Lloyds. Ordinarily projects would be placed for their full period, however occasionally when project periods exceed placeable limits, break clauses are sometimes introduced.

It should also be borne in mind that periods are often extended due to delays in the procurement of equipment and delays due to final testing/commissioning in order to meet expected performance levels.

In addition, delays may be experienced due to the effect of external events and influences, such as nuclear events. For example, the Fukushima nuclear event of 2011 caused a number of countries to rethink their approach to nuclear power, and drove a widespread review of nuclear safety design. If the project in question involves the use of nuclear fuel, and a similar event occurs in the future, there is significant potential for project delays due to design review, redesign, re-specification, and reassessment by the regulatory authorities which will largely be beyond the control of the project.

Occasionally Insurers may need to be replaced part way through a project due to changes in reinsurance treaty arrangements, mandate changes, security changes or simply via entering a run-off status. It is often viable to overplace such projects to enable markets to sign back up to their original line, helping to alleviate a reduction in capacity. Alternatively, seeking additional support from new capacity providers mid-way through a project can often result in additional insurance cost to the buyer.

5.5 Valuations

Traditionally underwriters seek both estimated project values on commencement of a project and then on-going reports of values as the work progresses. Typically, premiums are adjusted on the final values against actual project values. However, for projects where governments contribute in kind it may not be possible to establish 'value' and governments may well be reluctant to provide any declarations of such values. In such cases an alternative means of updating premiums may need to be agreed with underwriters. For the larger scale projects, this could be a significant mismatch between underwriters' expectations and what can be actually obtained. It would seem that further work with underwriters should be carried out here to find an alternative measure of risk.

5.6 Insurance of revenue streams

Due to the 'first of a kind' nature of some projects of this nature, it is very difficult to insure for gross profit coverage, any revenue could be very speculative unless based upon capacity or availability of the asset. As there may be no other projects of this type already in existence, it may prove extremely difficult to estimate potential revenue. Any request for insurance of delay in start-up should be backed up by detailed and demonstrated calculations, both for the total sum insured, and a split monthly through the indemnity period to determine linearity of the sum insured.

Fixed costs and debt service exposures may also be considered, although the amount of debt associated with any given project may be significant. Financing may not follow typical structures, and may involve more sovereign financing rather than via traditional capital markets and banks. If this form of limited coverage is to be considered, a detailed understanding of the debt structure is necessary, alongside the method of repayment, and whether repayments are declared based on interest only or including capital repayments. The authors will not go into full detail here, however further reading is recommended, there are many available IMIA working group papers on this topic.

It will beneficial if the Insured is able to complete the LEG/IMIA DSU sum insured calculation sheet to provide a transparent viewpoint of the sum insured.

As well as achieving a thorough understanding of the DSU sum insured, it is important to note the additional delay exposures associated with this type of project. For example, delay periods may be extended due to one or a combination of the following factors:

- Extended replacement timescales due to the technical and complex nature of equipment.
- A reduced number of potential suppliers.
- Difficulties associated with payment for replacing what were originally in-kind contributions
- Locations of specialist repairers and suppliers in continents far away from the project site.
- Availability of skilled labour.
- The involvement of government and local agencies in the investigation of losses.
- Lack of mitigation available for single line processes.
- Potential for delay associated with clean-up and decontamination of nuclear sources.

The above exposures may or may not be insured, dependent on the proposed policy wording. Careful analysis of mitigation and contingency arrangements should be considered in parallel with review of the DSU policy section.

5.7 Performance guarantee

It appeared recently that the Owner of a new particle accelerator, designed for the medical industry had to find performance guarantee cover to meet the requirement of the Lenders. Without such a cover, the banks would not finance the project. It was quite difficult for the Insurance market to propose this cover, given the difficulty to benchmark the equipment with similar units and run actuarial formulas based on big data. But should some markets succeed to build intelligence on such sophisticated equipment and find the right parameters, then performance guarantee products are likely to find insurers willing to Underwrite them.

5.8 Other exposures

Due to the nature of the process, there may be a higher susceptibility to damage of delicate instruments with tight tolerances. Light impact damage could lead to loss of tolerance and higher repair costs due to recalibration within tolerance. The lifting and handling of such delicate equipment both on site and during transit is certainly a concern.

Projects may also be exposed to the use of the facility for experiments during the testing phase, during the construction phase and during operation when new features may be trialled. Some of these trials and tests may never have been attempted before, and may lead to an enhanced risk of equipment failure. It is important to differentiate between the actual testing of the facility and use under operational conditions involving experiments.

Structures may contain radioactive shielding, heat protection and sometimes lead-lined walls to isolate radioactivity or the very high temperatures associated with a nuclear reaction. Such methods of isolation may be expensive to repair, particularly where higher costs are necessary for decontamination or radioactive waste disposal costs. It should be noted that treaty cover restrictions will apply for such exposures, however certain buy-back endorsements are available, for example M.RE 212 Cover for Radioactive Decontamination Costs.

Enhanced risk of water damage due to leakage, high powered electromagnets will require additional and substantial cooling systems, often water is used as a coolant.

Precise tolerances required for civil structures will often require an extremely stable base/foundation to maintain the correct focus of electron beams, particle targets and the like. It is essential that piling and foundation design is in line with the geotechnical report conclusions.

Civil structures may also contain unique parts embedded into heavy foundations. If quality control measures are not adequate to discover defects within such embedded parts, the demolition and breakout costs of structures to access the damaged parts can be considerable.

Where equipment is supplied by different countries as an in-kind contribution to an international project it is often difficult to determine the replacement costs.

As above, compatibility may also be a concern where equipment is supplied from different countries where different voltages, standards, codes and legislation will apply. Concerns may arise with the interfaces between different items and systems unless this risk is specifically managed by the project.

Offsite storage and fabrication facilities which may be exposed to fire, flood, theft, impact damage need to be evaluated if the sites involve the storage of anything beyond bulk materials and structural steel.

Projects may involve the construction of single-use assembly buildings, which are effectively used once to construct or assemble a module or piece of equipment, then demolished. If projects include this feature, it should be borne in mind that the value of such building will be dramatically reduced once it has fulfilled its purpose on the project site. This can create issues regarding valuation and assessment of loss should an incident take place once the asset involved has become redundant.

In the case of large scale telescopes, very large mirrors or lenses may form part of the project, either in sections or as a complete section. Locations are often very remote, and often at very high altitudes to avoid light pollution (also starlight appears less distorted in the thin atmosphere of a mountain top). There are challenges associated with the handling of such large and heavy items, which are susceptible to cracking, scratching and breakage. Evaluation of heavy lift and materials handling methods is a necessity.

Aside from large scale telescopes, very heavy structures, vessels and items of machinery are often in use within specialised projects, and may require the use of specialised craneage. Heavy lifts may be seen at loads of up to 1,500T. Evaluation of any heavy and/or dual lifting is recommended to ensure that procedures are well developed and designed to minimise risk.

Contractor experience is important. The general contractor may be very experienced both in respect of building/civil works as well as for the erection of industrial plant and machinery. The initial stages of work may well therefore be extremely well managed from a construction quality perspective. However, once the installers of highly specialised equipment arrive on site, who are often teams of scientific specialists, experience of normal day to day construction management techniques may be less of a priority. At this stage of handover, it is essential that the specialist teams work alongside the contractors to ensure continuation of procedures such as hot works processes, safe working within enclosed spaces, QA/QC and so on.

Often new technologies can be viewed with suspicion and caution both by indigenous populations and nations not involved with the project. Hackers may simply see a new large project as a challenge. Projects have the potential of becoming the target of cyber-attacks. This could take the form of the introduction of viruses into control systems or hacking into systems via inadequately protected networks/wirelessly controlled equipment. A cyber event may cause damage instantly at the time of the attack, or could be a timed event, or may cause damage at a much later date if control or alarm parameters are interfered with. Evaluation of the protection measures in place should be considered, and to ensure that the project has undertaken a full risk assessment of the cyber exposure.

5.9 Potential solutions

Series loss clauses are designed to mitigate the effects of multiple failures due to the same original cause. This is particularly useful where the project involves the installation of a large number of identical items.

Defects exclusion. Depending on the make-up of the project and the territory in which the project is located, DE, LEG, Munich RE or Swiss RE clauses may prove suitable. Of course availability and appetite to provide LEG3 or DE4/5 may be limited for such complex projects.

It should be highlighted, that in some countries like France or Germany, brokers tend to rewrite the defect exclusion clause and to obtain a buy back the consequences of the excluded defect (faulty workmanship or faulty materials). In such cases, the risk of a discrepancy with reinsurance treaties or misunderstandings in case of claims becomes more likely.

Piling clauses are of particular importance where ground conditions are poor and significant ground improvement and deep piling is required, or where the civil structures need to have a particularly stable base in order to achieve tight tolerances for equipment located above.

Flood/inundation clauses are required where projects are in flood zones or areas prone to significant exposure from heavy rainfall and inundation. These clauses are of particular importance for projects which contain sensitive equipment exposed to water damage, where such equipment is stored away from the site.

Fire-fighting/hot work warranties, are important where hot working is taking place within confined spaces and to equipment which carries a higher fire loading or is susceptible to smoke damage or may require replacement even in the event of minor fire damage.

Warranties are required for final fire protection/detection systems to be in place prior to first energisation. It is essential that such final protection/detection systems are fully operational prior to first energisation of the equipment. It may also be worth considering similar warranties for certain fuels/feedstock/hazardous chemicals and materials from their first arrival on site, when such materials are designed to have their own specific protections.

Nuclear exclusion clauses are essential for projects involving radioactive sources. It should be noted that most nuclear exclusions are designed for reinsurance/treaty purposes. Careful review of the wording is required to ensure that they are both suitable for direct placements and the nature of the technology, alongside checking of reinsurance treaty language to ensure consistency. Newer technologies may also stimulate a nuclear reaction in the form of nuclear fusion, without necessarily utilising heavier radioactive nuclei, as such the nuclear clauses in current use may not be fit for purpose, their intention and history being focussed on nuclear fission. (Aspects of this issue are discussed in more detail in Section 4 of this report).

Caution should be exercised to ensure that reinsurance treaties will respond adequately. In the case of newer nuclear based projects, current definitions that exist within some of the nuclear conventions, for example the Paris Convention, may not allow for such projects within their agreed definitions. This may cause more of an issue for ongoing coverage of nuclear liability risk, rather than our main consideration here. However, lack of inclusion within a convention definition may cause challenges for the operational nuclear pools to respond and provide coverage during periods of testing post first criticality, leading to gaps in cover and potential pressure on conventional markets to provide coverage.

Nuclear fuel elements, in the form of radioactive sources may require cover. Standard clauses from Munich RE (211) and Swiss RE are available, however it should be considered whether these are suitable for use with such projects. Consideration should be given to a suitable sublimit, and whether reinsurance treaties will allow this cover extension as a DSU trigger.

Nuclear decontamination costs cover extension are intended for exposures relating to radioactive sources or other nuclear fuels to be used within the project. Consideration should be given to a suitable sublimit, and whether reinsurance treaties will allow this cover extension as a DSU trigger. Standard clauses from Munich RE (212) and Swiss RE are available.

Cyber exclusion clauses are often contained in reinsurance treaties. Following review of the cyber exposure at the project it may be necessary to pay particular attention to the cyber exclusion clause. Market standard clauses have been introduced, such as NMA2914 and 2915 being the more common clauses in use for construction, as well as a complete exclusion as CL380. IMIA has also released a clause within the WGP 98(16) paper which is recommended as further reading on the subject.

Time schedule clauses are often used, where projects are located in catastrophe exposed locations subject to seasons, or where the DSU exposure has been underwritten and evaluated based upon significant float in the time schedule. Underwriters may wish to consider a time schedule clause which allows the re-consideration of terms and conditions following a pre-agreed level of deviation from the original project time schedule.

Schedule/project monitoring is often the subject of a condition relative to the provision of progress reports in policies with a DSU section. Such reports are usually required on a monthly, quarterly or six-monthly basis. The evaluation of such reports will often provide the Insurer with information on progress to date according to design, procurement and erection targets. For projects with lengthy periods and significant DSU exposures, a more focussed approach may be beneficial relating to monitoring of the progress of critical path activities. A more in-depth approach may be taken with regard to schedule related risk, with project monitoring being available from specialist analysis consultants, loss adjusters and other consulting engineers. These services are usually funded via a proportion of the risk engineering fee. An amendment to the usual progress reporting condition within the DSU section is advisable in order to reflect the information required by the project monitoring organisation.

For very large-scale projects, especially with involvement of governments, it may not be possible or allowed to release regular project progress reports. These may, in any event, be too extensive for regular review and thus the right balance needs to be struck between receipt of reports and regular site visits.

Risk engineering is often desirable and it is worthwhile pre-agreeing the structure and costs associated with a risk engineering programme in advance. Bearing in mind the duration of projects of this nature, it is likely that projects will be subject to some period extensions and design/detail changes. A properly costed, well executed risk engineering programme will deliver mutual benefits for both Insured and Insurer over the duration of the project and will allow monitoring of a wide range of exposures, both indemnifiable and non-indemnifiable.

5.10 Summary and conclusion

Overall, complex projects with a number of unique underwriting features, require careful consideration, some of which can be dealt with via risk specific clauses, both bespoke and market standard. The management of line size is also critical, both from the standpoint of challenging PML calculations on challenging and previously unseen project types.

However, these projects are often constructed utilising world-class experience and knowledge, alongside a great degree of regulatory caution, which mitigates the level of risk exposure.

For Insurers considering a lead position on such projects, ongoing risk management via the use of insurer risk engineering specialists is recommended, with regular visits in order to keep abreast of changes during the project period.

6 Supply Chain Management and End to End Cover

As set out above, major Scientific Infrastructure Projects often involve many different nations, each making contributions in terms of hardware, software and know how.

A huge amount of the equipment to be installed will have been supplied on the basis of In-Kind Contributions, including bespoke one-off items, with long lead times for replacement (sometimes lasting years). Availability of funding from the governments of involved countries will dictate their contributions. Funding cannot be guaranteed to be repeated and so, in the event of a loss, the project often cannot afford to pay to replace damaged items. The cost and associated time delay because of a loss could be substantial enough to derail the project in its entirety without the support of insurers.

It is of fundamental importance therefore that the project team is set up with sufficient resources to manage and control the supply chain, with full oversight of the various contributing parties – no easy task given the normal scale, complexity and number of stakeholders involved.

6.1 Supply Chain

The supply chain for science projects begins with equipment manufacture at the various commercial sites and in-kind partnership labs. Quality control at these sites, an understanding of the overall delivery schedule and the required standards for storage and transit need to be addressed at a very early stage.

Insurance policies often incorporate a wide definition of what constitutes "the site" as well as generous limits for inland transit and offsite storage. High value bespoke equipment is an exposure for project insurances (CAR/EAR) for significantly extended risks often beyond what is seen in a more common policy that covering only construction/erection at one location.

A proactive approach from the client in understanding and managing its supply chain is crucial to the success of the project.

Logistics and procurement issues

Most research facilities are not set up to have their own logistics department. This function is either outsourced or simply does not exist. There is a danger at In-Kind manufacturing sites for there to be an 'it will be ready when it is ready' approach unless the main project manages matters accordingly.

Finished products will be normally subdivided into several smaller segments each with their own schedule and budgeting pressures making it particularly challenging to deliver o the overall budget and schedule. The process is very fragmented creating many areas which have the potential to cause overall project delay which is an important consideration for projects that may have tight budgets and already have very long durations.

Science projects need to devote time and investment in visiting the numerous work/manufacturing locations, gaining an understanding of their delivery commitments, work conditions and timing constraints at the earliest opportunity. Information obtained needs to be used in the creation of the logistic plan for the supply chain, both by the internal team as well as any outsourcing. It will give an understanding of pinch points in the manufacture and delivery schedule across all work sites so that risks can be mitigated accordingly.

Professional outsourcing agencies offer a solution to logistical/procurement challenges and can be engaged on a standalone basis or in conjunction with the project team to build and manage a logistics/procurement model. This would be designed to cater for the challenges associated with the manufacture/ transit and storage of the equipment, and have the flexibility to evolve with the project as the picture changes.

In Kind Contributors / Commercial Contractors Manufacturing Sites

It is to be expected that when a scientific facility comprises contributions from multiple countries and commercial contractors, in order to achieve something ground breaking, there will be novel challenges. An off-the-shelf working solution is unlikely to exist and a bespoke approach will be needed with each partner's contribution depending on the level of their resources and sophistication.

There are likely to be significant variations in standards and experience from country to country and differing levels of engagement will be required. Commercial manufacturers, no doubt selected for their competency in manufacturing individual components, may not be experienced in being part of a team working towards a product of the size and scale of the final project. Installation experience may have mostly focussed on operational facilities as opposed to a working construction site with multiple parties to liaise with/ work around. There may also be challenges associated with upscaling size or performance of previously tested technology.

A risk management approach from the project team which disseminates to suppliers the importance of project delivery, the potential hazards, expected minimum standards and the impact of mistakes is an essential part of the logistics/procurement process. Special conditions/facilities are likely to be needed to accommodate equipment during storage, transit and delivery and neither individual countries or commercial manufacturers can be assumed to be familiar with these.

Equipment Transit

The delicate nature of some equipment that is to be integrated into scientific instruments/ infrastructure means that specialist care will need to ensure safe transit. Dedicated vehicles with shock/ tilt indicators and appropriate security may be required as well as regular inspection of the condition of the equipment.

Expertise in terms of executing shipments of equipment is likely to vary from country to country. The project team will need to have very early engagement with each partner/ supplier on the transport and storage items, covering specialist shipping conditions and the specifics of how to deploy the equipment to site.

Another important consideration is the nature of the Incoterm agreement signed up to with each contributor. This will dictate the tasks, costs, and risks associated with the transportation and delivery of goods making it clear who is responsible at each point in the process and when ownership has passed from one party to another. This will also outline the rules for foreign trade and customs compliance, insurance and taxation.

Ideally the Incoterms will leave the maximum obligation for the equipment with the seller until delivery to the site. However, unless the rules and regulations on the buyer's country are well understood there can be a significant risk both in terms of delays and in unforeseen extra costs. A collaborative approach is important if such risks are to be minimised.

Depending on the nature of transit agreements, cover for the transit and storage of the equipment may fall under the CAR/EAR insurance policy on a primary basis.

Off Site Storage Facilities

For many items of scientific equipment highly specialist storage facilities need to be researched and engaged. These storage facilities will not only need to be 'fit for purpose' but will also need to have the flexibility to cope with variable rates of equipment arrival and duration of the storage. Delays in project construction may cause a backlog, resulting in additional storage demands and/ or long extensions in the storage period.

Equipment may have particular requirements in terms of weight, height, length, humidity, light sensitivity, cooling and contamination. This will need to be known in advance in order to procure the appropriate facilities for the storage area. Clean rooms are often needed, as are bespoke loading and unloading equipment as well as high specification construction to cope with the various size / weight requirements of the equipment stored.

Such storage facilities may not be easy to come by and may be costly to rent. Careful logistic management that identifies when equipment is ready, when it will be delivered, how long it will be stored for is of primary importance.

Tracking the whereabouts of the equipment when in storage can also present a problem and without a comprehensive warehouse management system significant time can be lost in locating items.

Depending on the structure of the CAR/EAR insurance policy, sub limits for transit and storage may come into play and will need to be regularly revisited to check the appropriateness throughout the life of the project as the demand changes.

Given the more delicate nature of the equipment being stored, insurers are likely to be wary of the exposure and the presentation of the underwriting submission will be very important in giving them comfort in this area.

Manufacturers' Warranties

For equipment that is being delivered from commercial manufacturers there will be a corresponding performance guarantee or warranty attached. Warranties may expire before performance tests are carried out if delays in progress occur. Extended guarantee periods within supply contracts may be needed at the outset, however there are cost implications associated with this. If unplanned delays are overly long extensions of guarantee periods may still be insufficient.

This can have implications for the insurance policy in the event that damage occurs, whereby subrogation rights effectively expire alongside the warranties. Very strict equipment qualification protocols need to be in place at the acceptance of such equipment in order to minimise the exposure here.

Delivery to Site / Installation

Coordination of the delivery and installation of the equipment to site is a complex process and needs to be given careful consideration. Specialist access/ equipment may be required including roof removal/ wide doors/ bespoke cranes etc.

Many parties may need to be very involved in the delivery process in order to ensure safe deployment with the appropriate conditions since delivery will be to a working construction site as opposed to a specialist storage facility. As such there may be multiple potential interferences with existing equipment and a heightened exposure to damage.

Temporary controlled storage areas capable of producing specialist conditions may be need to be erected on site before the final installation.

6.2 Off 'Site' Testing

Insurers are likely to be comfortable with the very high standards that can be expected on the project site, where the work is under the management of both the project team and top tier contractors with significant experience of projects of this nature. However, similar standards may not be in force when it comes to the "off-site" locations.

Scientists may have a different set of priorities, understanding and perception of risk management to those running the construction site and it may be difficult to ensure the same high standards at offsite testing labs as are found on the main site. Underwriters may be concerned the scientist's objective of pushing the boundaries as to what can be achieved may outweigh considerations of only operating within safe working parameters. The client's control/ philosophy is key here in asserting sound principles of risk management and ensuring that they are adhered to in off-site areas as well as the main site.

An insurance policy with a wide definition of the site and flexibility built into the wording regarding testing and commissioning means that insurers may be on risk for the increased exposure at "off-site" locations. Temporary testing labs are often at shared sites attached to Universities or similar making the standard of risk management potentially more difficult to control.

There is also the question of what is damage when testing new technology which is being pushed to establish performance limits. Incidents may test the definition of "unforeseen" events. When is a failure the reasonably expected outcome of an experiment? Does this constitute insured damage under the CAR/EAR insurance policy?

6.3 Changes

Since scientific infrastructure projects are generally government funded by either a single or a collection of nations, the injection of capital is unlikely to be repeatable in the event of a loss making appropriate insurance protection very important. Budgets are normally tightly control and under close scrutiny. Cost escalations can present a significant challenges, particularly given the long construction duration. Project scope may also be subject to change having an effect in increasing the costs.

6.4 Marine Cargo Insurance

The Incoterms agreed between the project and the various suppliers will dictate the insurance responsibility for the goods in transit and storage. Insurance for the risks that sit with the project can either be catered for via the inland transit and storage extensions of the CAR/EAR policy or a Marine Cargo policy can be arranged.

If intending to utilize the CAR/EAR policy for this cover, consideration will have to be given to the locations that the shipments are being transferred from, the values to be shipped and the shipping schedule. A CAR/EAR policy will not cover marine or air transit. It will include sub limits which will cap the amount claimable in any one occurrence and is only current for the period of insurance.

A Marine Cargo Policy can be tailored specifically to the project's needs in terms of values, duration, location and mode of transport. Deductibles will also be tailored to the nature of the equipment being shipped and as such are likely to be more appropriate to that of the CAR/EAR Policy.

The interface between the Marine Cargo and CAR/EAR insurance is an area where potential gaps in coverage can arise. Depending on the Incoterms, the completion of successful unloading of the equipment at the project site would normally signify handover and as such transfer of risk from the Marine Cargo to the CAR/EAR policy.

Should equipment be found to be damaged, once unloading has been completed and installation initiated, it is possible that the origin of the damage may not be identified. CAR/EAR policies will normally incorporate a form of 'Undiscovered Damage' clause which is designed to cater for this circumstance. This brings the cover back within the CAR/EAR policy and gives the project team certainty that cover is in place.

In an ideal scenario, the risk for the transit of high value machinery and equipment will be left with the suppliers until safe delivery at the Project Site, however for the reasons discussed within this section, this is often not feasible. As such a combination of both a Marine Cargo Policy and sufficiently wide cover included within the CAR/EAR is desirable. It is important for the CAR/EAR insurers to have an understanding of how the two policies are designed to interact and at which points within the supply chain they are exposed.

7 Lessons learnt from claims

7.1 Features of claims

The claims associated with this sector share many features with more traditional claims, depending on the cover provided, be it construction, delay in start-up, operational property damage or liabilities. Notwithstanding this, there are some particular issues that arise in this sector which we attempt to highlight in the following section.

This section is principally focussed on construction and property insurances. As detailed elsewhere in this report, often the liability covers associated with such facilities are limited and a full analysis of such liability risks falls outside of the scope of this paper.

The principal issues that arise for consideration in claims in this sector often include the following:

Prototypical equipment: As detailed earlier in this report, often the equipment and property is prototypical and first-of-a-kind. In such circumstances insurers might be wary of paying for the insured parties' research and development. For an experimental project establishing the cause of the failure of a project is further complicated by the project being an experiment itself with the expected outcome not readily proven. However, by the time a claim occurs it has to be assessed purely on the basis of the evidential facts published and the policy wording in place.

Standards: Often such facilities are built to more exacting standards than traditional commercial property and /or construction projects, with specified tolerance being extremely precise. In such instances, there may be a limited number of contractors available to perform repairs.

Expertise: As noted above, there may be a very limited number of specialists and contractors available to manage, supervise and perform repairs in the event of an insured incident. Often this can lead to delays – when the parties have to wait for the specialist contractors and/or equipment to become available; and the costs might be significantly higher than insurers might usually expect.

A further feature in this regard is that the insured parties may be best positioned to supervise, manage or effect repairs. In such circumstances, the claims professionals representing insurers' interests must work closely with the insured parties to clarify the precise scope of work for which the policy might respond.

Repair vs. Replacement: Often, the owners of such facilities/projects are inherently risk averse. Consequently, following a loss (in particular a fire incident that may lead to potential smoke contamination) the insured interests will often be pursuing a 'replacement' rather than a 'repair' strategy. Again, whether this is fully reimbursable under the policy might depend on the precise wording of the coverage in place. In such circumstances, the potential cost of testing affected equipment could be uneconomic; it might be cost-effective to agree a replacement strategy in some circumstances. This is particularly a factor where there is some time-element cover in place, be it delay in start-up during construction or business interruption once operational.

Stakeholder Environment: The number of stakeholders and public funding can lead to significant delays in decision-making following an incident. This is principally an issue where there is time element cover in place. Therefore, it is critical for the claims' professionals to be aware of the stakeholder environment and insured parties' decision-making process.

Insured's Priorities: Often due to the financing structures of such facilities insured parties' decision-making concerning repair is driven by technical requirements rather than the potential extent of the policy's response. In such circumstances, it is key for the claims professionals involved on behalf of insurers' interests to highlight at the earliest possible stage what policy coverage might extend to, and more particularly, what it will not. This proactive approach to assessment and communication can avoid difficult conversations after the reinstatement, when the insured parties might be expecting all expenditure to be recoverable.

Logistical Challenges: Either due to the nature of the insured equipment or often the remote and/or inaccessible location of the facilities involved, post-incident repairs can be disproportionately expensive by comparison to the original construction costs. There might be significant access challenges requiring the construction of temporary roadways, power and accommodation facilities, air freight deliveries of equipment, and the attendance of specific equipment and specialist labour.

Quantum Assessment Challenges: Often with prototypical equipment the claims professionals face a challenge associated with determining its monetary value in accordance with the policy provisions. This might entail consideration of:

- assessing what functionality is proven,
- what functionality has a monetary value,
- whether replacement equipment is available (and if not, then should the claim be considered on an 'unrepaired damage' basis – which is often disadvantageous to the insured parties).
- The appropriate cost of replacing something that was originally supplied on an in-kind basis.

7.2 Summary

In summary, discrete aspects of the potential claims might entail specific challenges and demand different approaches.

As noted earlier in this report, many such installation involve significant civil engineering works. Natural catastrophes or defect issues that affect this aspect of the project might be extremely serious and require significant review of the original design assumptions and construction works performed to assess the validity of the claim.

Other claims might be solely associated with equipment, perhaps that have been affected by fire, power surges, or flooding. In such circumstances, the claim assessment process might require significant communication with the insured, the original equipment manufacturers and other specialists to verify the causal factors and scope of repairs that would be reimbursable.

Such claims also often require detailed analysis of the original equipment and its functionality. On occasion, particularly in operational facilities it has been observed that accurate equipment / asset registers are not maintained on a regular basis. This can lead to a situation where the insured parties believe that the equipment affected has a far greater level of functionality (and therefore monetary value) - due to upgrades and refinements being made during its operational life by the technicians at the facility - than the documentation can demonstrate.

7.3 Case Study: Claim Example Research Institute

In this example, a claim arose at a research institute that had arranged an operational property policy with sums insured associated with:

- buildings,
- contents,
- stock, and
- business interruption.

The research facility was a world leader in the telecommunications sector.

The facility experienced a serious fire leading to extensive damage to the building and its contents, entailing a reinstatement period of more than two years.

The building claim was relatively straightforward, with sums insured being deemed to be adequate, and the precise scope of damage established and agreed. The insured parties did wish to make some changes to the original design to optimise the functionality of the replacement facility, which entailed some discussion that was concluded successfully.

The contents claim was more challenging. The insured's management claimed to have unique equipment, knowledge base and a materials library that were used by the Institute in the development and commercialisation of technologies for a global customer base. In part, the Institute's reputation was supported by the materials library available for use in the development of these new technologies.

Because of the fire, there was significant damage to contents, including equipment and the materials library.

On investigation, it became apparent that the research equipment utilised in the Institute's various laboratories was not recorded in any central asset register. This therefore presented a challenge for the insured parties to demonstrate precisely what equipment they had, what its functionality was and likely associated value. The claim verification process entailed lengthy interviews with various laboratory technicians involved to try to establish a full inventory of affected equipment.

Some of this equipment was not likely to be replaced, or it was to be replaced with new equipment offering different functionality. Therefore, significant discussion ensued regarding:

- the reinstatement of the functionality; and
- the policy terms concerning the basis of indemnity, principally concerning an assessment of repair, replacement and unrepaired damage.

The most challenging aspect of this matter was the materials library owned and maintained by the insured parties, who perceived it to have a significant value both in terms of:

- the prestige and reputational factors associated with having reportedly the largest library in the world, and
- the commercial advantages of having such an extensive facility, which reportedly enabled the Institute to develop bespoke new technologies more quickly than competitors.

However, the perceived value of this library appeared to have been largely uninsured, and the materials that were damaged were to all intents and purposes irreplaceable. The insured parties did receive a significant settlement from insurers in accordance with the policy's terms and conditions, but inevitably there was a perception that some of their ongoing losses were inadvertently uninsured and therefore that the settlement did not represent the institute's true economic and reputational losses.

7.4 Case study: Large Hadron Collider

Below are two articles which reported on problems at the Large Hadron Collider:

An article from Brighthub.com reported:

"Scientists and engineers alike at the European Organization for Nuclear Research, or CERN, were greeted on September 19, 2008 with troubling news: The Large Hadron Collider (LHC) encountered a failure known as a "quench," which forced them to halt the massive physics experiment.

The problem, after a thorough investigation, has been linked to a leak in the machine's liquid helium source, which is used to cool down LHC's super-cooled, superconducting magnets. This led 100 of these magnets to overheat, not to mention the loss of the machine's vacuum conditions."[27]

An article from nature.com reported: "A cable feeding current between two of the LHC's beam-focusing quadrupole magnets suddenly heated to above superconducting temperatures and melted. The failure seems to have happened at a joint where two sections of cable were spliced together. Tens of thousands of joints run around the LHC and many of them had already been tested without incident.

The failure caused the liquid helium that was being used to cool the magnets to boil off, apparently rupturing the machine and releasing as much as a tonne of the gas into the LHC tunnels. During testing the tunnels are evacuated and no injuries were reported.

Such failures are not uncommon during the early commissioning of an accelerator, Gillies says. "With a normally conducting machine you could fix it in a couple of days." But the LHC's superconducting status also makes it difficult to service. To fix the broken sector, physicists must heat thousands of tonnes of magnets from near-absolute-zero to room temperature, make the necessary repairs, and then slowly cool the system back down. Just warming and cooling will take at least two months, Gillies says."[28]

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27 https://www.brighthub.com/science/space/articles/8955.aspx

28 https://www.nature.com/news/2008/080922/full/455436a.html

8 Conclusion

In this paper, we have seen that many parameters can impact the construction and operation of scientific instruments. Some of them are real threats to the project feasibility:

- The long project duration (over 10 years) challenges the resilience of the coinsurance. Some companies might withdraw from the panel because of a merger or run-off.
- The sum insured might increase significantly (even more than 50% or 100 %) leading to a higher MPL and the necessity for some markets to reduce their line size.

In both cases, the broker will likely face difficulties to replace the missing capacity.

- On the underwriting side, assuming the Scientific Instrument projects are highly internationally based, the location, value and protection of pre-fabrication sites should be carefully assessed notably regarding natural perils exposure.
- Finally, the legal environment might change during the project life, causing sensitive issues, like on ITER where the slow evolution of the Paris Convention regarding nuclear third party liabilities stopped the Organisation accessing the nuclear pool capacity. On the other hand, external events like Fukushima can change the rules for Nuclear Plants during the period of construction.

However, the construction of scientific instruments also opens the door to new opportunities for insurers, such as:

- End to end cover from manufacturers' sites to erection sites, including all phases of transport
- Bespoke rewriting of Defect exclusions by brokers notably to cover damage resulting from faulty material or faulty workmanship
- Performance guarantees even if this is quite challenging given the difficulty to benchmark a scientific instrument.

The complexities of the construction and operation of scientific instruments and infrastructure create challenges both in their financing and in the arrangement of insurances both for the construction and operational phases. However, these challenges have broadly been overcome with work required only in a few areas.

The future of science is just a few steps ahead of the future of Insurance.