Issue 45 / Spring 2024

# RISKworld

## The Newsletter of Risktec Solutions

## In this issue

Welcome to Issue 45 of RISKworld. Feel free to pass this edition on to other people in your organisation. You can also sign up here to make sure you don't miss future issues.

We would also be pleased to hear any feedback you may have on this issue or suggestions for future editions.

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Martin Fairclough brings us up to date with developments at Risktec.

### WIND OF CHANGE

As the installed global wind power capacity continues to grow, an ever increasing volume of operational and accident data is available. Michael Kupoluyi explores how this data can be used to inform decision making.

### INTEGRATED ACCESSIBILITY

With an increasing awareness and desire to ensure that the rail environment is safe and accessible for all, Kay Rigby talks us through how to consider accessibility within the risk assessment process.

### TO FINITY AND BEYOND

Emilia Gajda and Michael Kupoluyi introduce us to a new technique that repurposes finite element models of structures, often used for design analysis, to estimate their probability of failure.

### SUNNY WITH A CHANCE OF NEUTRONS

The fact that space weather can impact critical infrastructure on earth has long been known, but what is the nature of the hazard, what wider effects can it have and how do we manage it? Chris Rees discusses the issue.

### DECOMMISSIONING BY DESIGN

David Cooper explains how our hard-won lessons learned can help inform future designs and make decommissioning an easier prospect for future generations.

*"Knowledge has a beginning but no end"*
– Geeta Iyengar, renowned yogi and author

As we near the summer, we are continuing to see demand in all sectors, and are pleased and proud to be involved in unique and interesting projects, many of which involve novel technologies and applications and elements of research and development.

This continuing desire to utilise and develop our knowledge and skills in cutting edge areas and topics, is underlined by our recent agreement with Lancaster University to deliver a collaborative PhD programme. This is an exciting initiative, and we look forward to welcoming the first students onto the programme.

The PhD of course complements our existing training portfolio and postgraduate programme, with the MSc in Risk and Safety Management delivered by Risktec and awarded by Liverpool John Moores University, now accepting applications for the October 2024 intake.

Regarding other interesting work being undertaken within the company, in this issue of RISKworld we are keen to shine a light on some of the wide range of topics being covered.

We take a look at the use of operational data to support wind turbine-related decision making, the use of finite element analysis for predicting failure probabilities, as well as considering space weather and how this can impact us on Earth.

There are also two articles focusing on design; one from the perspective of accessibility as part of the rail risk management process, and the other with a focus on the need to consider decommissioning in design - building on an article from the previous issue of RISKworld.

In delivering all our projects, we endeavour to ensure that we are consistently meeting our client's needs and have again measured client satisfaction in our bi-annual survey. The most recent results show that we continue to maintain very high levels of client satisfaction.

Our overall score of 'good' or 'very good' was 97% for the ease of working with us, and 99% for our flexibility and responsiveness to client requirements.

I hope you enjoy the articles and find something interesting and relevant. As always, we welcome your feedback and look forward to your continued support.

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**Launched:** Sept 2001
**Projects:** 11,074
**Clients:** 2,014
**Employees:** 365
**Offices:** 16
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# Data Powered – Data driven risk-based planning of wind energy projects

As countries race to meet climate goals set in the 2030 Agenda for Sustainable Development by the United Nations, suppliers are pushing to deliver ever more ambitious wind energy generation projects. Effective risk-based strategies based on data-driven predictions has never been more crucial to overcoming this global challenge.

## RISK-BASED PLANNING

Cumulatively, over 900 GW of wind power has been installed globally and the Global Wind Energy Council estimates the milestone of 2 TW in total wind power capacity will be reached before the end of 2030 (Figure 1).

Risk-based planning has become increasingly relied upon by stakeholders to anticipate, mitigate, and manage a wide range of design, operational and financial risks to ensure that projects are financially viable, and thereby help ensure that climate goals can be achieved. However, this approach is heavily reliant upon input data, and a lot of it!

The lifespan of a wind turbine is in the region of 20 to 30 years, and during that time it must be able to operate reliably and safely, even under hazardous conditions. Some of the main hazards that designers must take into consideration include:

- Turbine-related hazards, such as blade throw, overspeed leading to turbine collapse, ice shedding and fire from overheated generators.
- Other hazards, such as fall from height, drop of heavy equipment and electrocution from high voltage equipment.

However, there is a varying amount of data available to support safety management decision making – a good example is the data available for assessing and planning maintenance-related activities.

## OPTIMISING MAINTENANCE

Like any other asset, wind turbines require maintenance to minimise financial losses, maximise performance, and ensure the safety of people and the environment. Crucially though, maintenance costs can account for 10-15% of the total revenue of onshore wind farms, and 20-25% for offshore windfarms (Ref. 2).

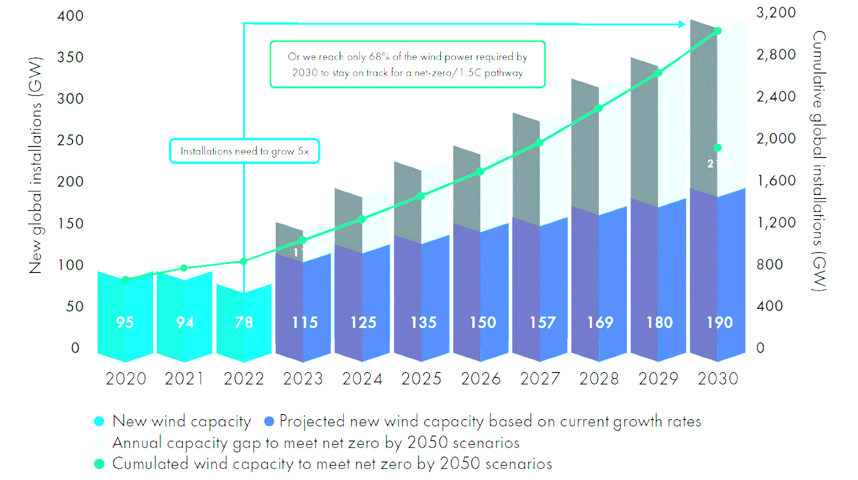

**Figure 1 -** GWEC market intelligence projected wind capacity for 2030 (Ref. 1)

Statistics show that while electrical system and sensor failures account for the largest proportion of repairs, the associated maintenance tends to be simple. In contrast, mechanical breakdowns tend to be less frequent, but result in the longest downtimes and usually attract much higher costs of repair.

From the safety perspective, prior to commencing maintenance activities, weather forecasting data, sensor readings and site images from drones are reviewed to determine how to address hazards safely prior to approach. The ability to interpret this data well is the key to determining the cause of any failures and making the right decisions on when and how to send out the maintenance crew.

## DATA DEFICIT

The availability of data to inform risk assessment depends on the extent to which incident data is reported and shared, as well as its quality. As depicted in Figure 2, data on turbine accidents, failures and breakdowns is mostly from the USA, UK and Germany. This does not align with installed capacity, and therefore suggests an incomplete or inconsistent availability of accident data.

Moreover, even though wind turbines have been in operation for many years, historical data is not always directly applicable. With larger and more powerful wind turbines being produced, data from turbines installed before about 2000 are not necessarily relevant, since only a few existed with a capacity above 1 MW.

There can also be uncertainties in the data quality due to:

- Limited number of site observations
- Data errors or collation issues
- Inconsistencies in hardware or software-based measuring tools
- Low temporal and spatial resolution
- Limited forecast durations

Improvements in data collection, quality and management have been achieved using Supervisory Control Data Acquisition (SCADA), Structural Health Monitoring (SHM) and Condition Monitoring System (CMS) technologies.

Each of these systems rely on sensors to provide technicians with a clear and comprehensive image of a turbine's real-time conditions. SCADA is used to monitor and control the operational status of wind turbines, whereas SHM monitors structural components, and online/offline CMS is for monitoring of other key components (Ref. 2).

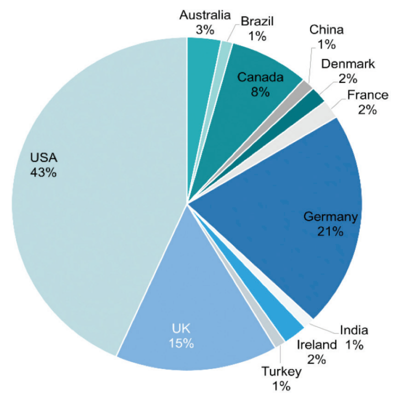

**Figure 2 -** Distribution of wind turbine accidents 2010 to 2019 (Ref. 3)

That said, the usefulness of sensory data is a function of the detection rate and the rate of false alarms. Significant improvements in sensory data quality have been found from simply optimising placement of monitoring systems, for instance.

Another challenge is the huge quantities of data generated, all of which potentially need to be stored and analysed. In practice, this means that an intelligent and automated process is required to sort, filter, analyse and store the complex information.

## ARTIFICIAL INTELLIGENCE (AI)

In recent years, machine learning, a subset of AI, has gained popular attention for its ability to provide predictions based on complex multi-dimensional data. In this case, the idea is that machine learning uses operational data to train a black-box model to provide early advice for predictive maintenance.

Although progress has been made on this front, there's still some way to go to deal with data uncertainty and missing data; and methods are needed for proving stability and robustness of predictions. This is especially true when using historical data to train the model, as there can be a lack of required detail as a result of data collection or storage methods. With respect to failure data, there may not necessarily be sufficient information on the causes of failure.

To some extent the methods employed in big data analysis can help with some of these issues – for example, post-processing can reduce the data storage requirements and help accommodate patchy data.

## CONCLUSION

Using tools and techniques that are rapidly evolving, big data collection and analysis for operational wind turbines has the power to transform the industry. By integrating operational data into strategic risk-based planning processes, wind energy project stakeholders can make informed decisions, optimise resource allocation, ensure safety, and maximise the long-term value and sustainability of wind energy investments.

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# Accessibility in the Rail Industry

The railway industry has a rich history of improving safety performance through lessons learnt and design innovation. However, with an ageing global population and inclusive societal expectations, how can we ensure that the railway environment is both safe and accessible for all; and that key considerations for accessibility are considered as part of the risk assessment process?

## INTRODUCTION

Railways have been providing transport for the masses for almost two hundred years. Historically, railway design focused on increased efficiency, capacity and safety performance. However, as society becomes ever-more inclusive, passengers now expect public transport to be accessible to all, regardless of age or disability. This in turn has led to diversity and inclusion increasingly becoming a mandatory requirement for railway projects.

Accessibility can relate to many things, from the design of train stations to the choice of materials. Regulations and innovative solutions inform the creation of a more inclusive environment for every passenger, and early consideration of accessibility needs can ensure that they are accurately captured and addressed.

## A SAFE FOUNDATION

The Common Safety Method for Risk Evaluation and Assessment (CSM-RA) establishes a common mandatory risk management process and is triggered by technical, operational or organisational changes which impact the safety of the mainline railway within Europe (including the UK). Large-scale projects such as the introduction of new, more accessible rolling stock or the redevelopment of a station to provide level access would, therefore, be required to follow CSM-RA. The regulation provides a consistent approach to system safety management, while ensuring that levels of safety are maintained or even improved where reasonably practicable.

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**Figure 1 -** Safe and accessible rail travel for all

One of the foundations underpinning CSM-RA is the application of Risk Acceptance Principles (RAPs) to derive safety requirements, which are legal safety targets that the project must meet. This approach means that the design takes into account how the system is operated and maintained, ultimately ensuring that people (including those with accessibility requirements) can safely interact with the system. By complying with explicit safety requirements, we can demonstrate that the level of risk associated with the change has been controlled to an acceptable level.

The three RAPs are:

- Application of Codes of Practice – application of standards which are widely used and accepted within the rail industry. This can include European, national or company standards.
- Comparison with a Similar Reference System – a system which is proven in use within the rail industry and has an acceptable safety level. The system in question must have similar functions, environmental conditions and interfaces.
- Undertaking an Explicit Risk Estimation – Where Codes of Practice or Similar Reference Systems cannot be used to fully control the level of risk, an Explicit Risk Estimation must be employed. The extent of the risk assessment (either qualitative or quantitative) should be proportional to the level of risk.

## CODES OF PRACTICE

When it comes to consideration of accessibility, the key EU code of practice governing accessibility design for publicly-accessible infrastructure and passenger rolling stock is the Persons with Reduced Mobility Technical Specification for Interoperability (PRM TSI) (also known as PRM National Technical Specification Notice in the UK).

In the UK, for example, the Department for Transport (DfT) has published a code of practice for the design of accessible railway stations, providing guidance on inclusive railway design. The code is currently under review and is to be updated, showing that the landscape for accessibility is rapidly changing.

These codes of practice define the features required for new or upgraded infrastructure to make journeys easier for people with accessibility requirements. Level access, lifts and accessible toilet facilities are well understood; however, some perhaps lesser known requirements include:

- Low reflecting properties for floors and walls, as well as markings on glass surfaces to mitigate slips, trips and falls, particularly for those with visual impairments.
- Audibility levels of public address systems, including consideration of volume, location of speakers and sound reverberation on solid surfaces, to ensure that all passengers can hear emergency announcements and safely evacuate.
- Tactile and contrasting surfaces on platforms to mitigate the risk of people with visual impairments from being struck by a train or falling onto the track.
- Lighting uniformity and lux levels, as well as the avoidance of flashing lights, shadows and dark areas. This acts to reduce slips, trips and falls in both normal and emergency scenarios, particularly for those with visual or cognitive impairments. Emergency lighting levels are also key for evacuation.
- Provision of level access for all escape routes or the installation of evacuation-compliant lifts.

## INTEGRATED RISK ASSESSMENT

When following the CSM-RA process, cognisance of the PRM TSI (code of practice) can enable requirements to be considered within the standard risk assessment process. This helps informed decisions to be made early on in a project that consider safety risks as well as ensuring compliance with the PRM TSI, rather than considering accessibility as a separate issue or late addition.

Although accessibility can be addressed through the application of codes of practice, there may be additional complexities when upgrading existing assets. Where CSM-RA principles require an explicit risk estimation to be undertaken, consideration of accessibility can inform the method and parameters to be assessed. For example, bespoke flow modelling can consider the predicted behaviour of passengers with luggage or infrequent users who are unfamiliar with rail travel, including during emergency scenarios. From this modelling, we can derive the safety requirements which may include improved signage to clearly define level access walking and evacuation routes or relocation of information screens to influence people movement and dwell areas.

## CONCLUSION

With an ageing global population, it is more important than ever for the rail industry to make improvements to ensure that the railways are safe and accessible for all.

By understanding the safety risks posed to those with accessibility requirements at an early stage, suitable controls to manage the level of risk to an acceptable level can be implemented in an integrated manner.

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## COLLABORATIVE APPROACH

Although good design may act to break down the barriers to accessibility, collaboration and consultation also have a part to play.

Since 2017, community rail partners, train companies and charities have been working together to make travel on the Bentham Line in the north of England easier and safer for those living with dementia. Initiatives proposed by the group include staff awareness training, improved clarity of information and signage, and the development of dementia friendly walks starting from train stations (Ref. 1)

**References:** 1. https://thebenthamline.co.uk/wp-content/uploads/2020/03/Bentham-Line-Dementia-Friendly.pdf

# Divide and Conquer – Deriving structural failure probabilities using Finite Element (FE) analysis

Many applications in mechanics require the consideration of uncertainty, and it can be useful to represent this uncertainty statistically, not least for informing probabilistic safety analysis or quantified risk assessment. However, with increasing complexity in system design and geometry, is there a practical method for deriving failure probabilities?

## INTRODUCTION

Optimising structural form, so that a design can meet normal and extreme loads in an efficient way, requires a fundamental understanding of structural integrity, or rather the opposite – structural failure – in all its potential guises.

With the power of modern computational technology, the FE analysis method has become an essential part of structural analysis. Whether structures have mixed materials, diverse boundary conditions, time-dependent loadings, or nonlinear material behaviour, FE analysis is a proven technique for assessing structural integrity.

## FE ANALYSIS 101

The core principle of FE analysis is partitioning a structure (such as a beam or a plate) into smaller, much simpler regions known as 'finite elements'. Structures theory provides us with equations for each element in terms of its behaviour (e.g. stress and strain) under defined loads (e.g. point loads or pressure) and its interaction with immediately adjacent elements. All the equations can then be solved simultaneously to determine the behaviour of the structure as a whole, including the stress distribution (see Figure 1).

Whilst FE analysis is, without doubt, an excellent design tool, it is intrinsically deterministic – our structural FE model provides a definitive output, determined by our input data (model geometry, material properties, boundary conditions and loading).

In the real world, however, very little is certain. A designer will compensate for uncertainty by using conservative data – applying a corrosion allowance, pessimistic material properties, and bounding loadings – or by deliberately varying parameters to explore how influential they may be. But what if the same FE model could be repurposed to help us estimate the probability of structural failure?

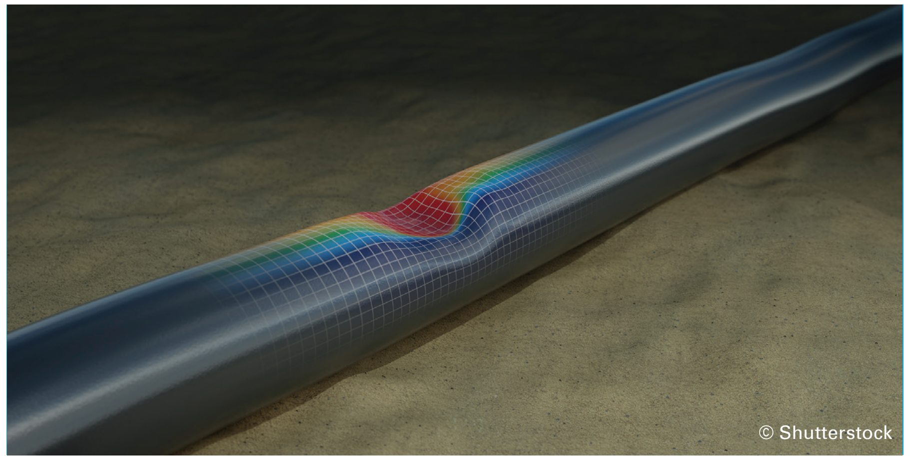

**Figure 1 -** 3D pipeline buckling predicted by FE analysis

## CHARACTERISING FAILURE

As with design, a crucial step on the road to probabilistic assessment is to define our failure criteria – relating perhaps to the ultimate limits of cracking, stretching (tension), compression, or plastic deformation. These failure criteria are defined on a best estimate basis, as opposed to the conservatism adopted during design, and are usually expressed as a 'limit state function'. In basic terms, the limit state function is a measure of how far away a structure is from failure (e.g. the difference between the ultimate tensile stress and the imposed tensile stress).

To make analysis more tractable, we also want to limit the number of variables if we can. For this we can use the FE model directly to examine the effect that extreme values of a wide range of parameters might have on structural behaviour, discounting those that are of little influence.

## ESTIMATING FAILURE PROBABILITY

Once left with a smaller handful of key parameters, the ideal would be to vary them all randomly according to their intrinsic probability distributions, using Monte Carlo simulation say, and feed each analysis case into the FE model to see whether failure occurs. If we did this 100,000 times and saw 2 failures, we would conclude that the probability of failure is 2E-5 for a given load demand. Unfortunately, while computing power has grown exponentially, approximately doubling every two years (Moore's law), running a serious FE model 100,000 times is not economically viable if the answer is required in a useful timescale.

One alternative approach is to use a much more limited number of FE analysis cases (e.g. 100) to generate a 'response surface' for the limit state function across the key parameter space (see Figure 2). Whilst the details are quite technical, there are established methods, such as Sobol sampling, for producing a set of nicely spaced analysis cases; and Gaussian Process Regression, for achieving reasonable interpolative accuracy with relatively few known points. Some FE analysis software codes even include response surface modules, normally intended to aid design optimisation.

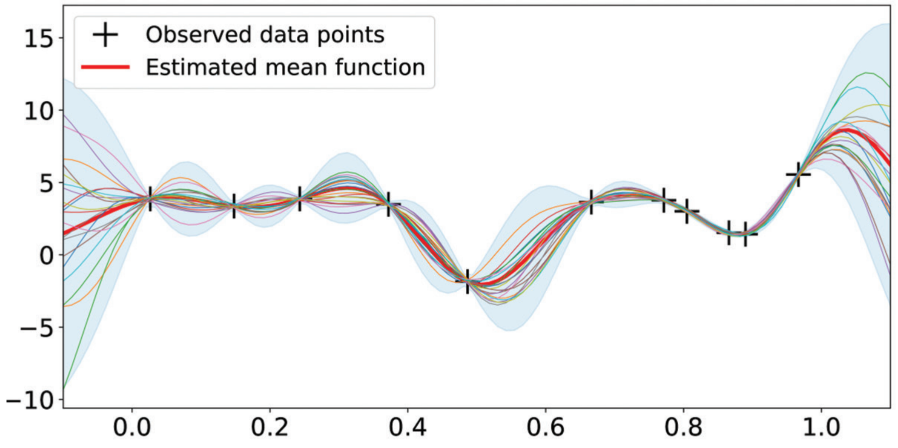

**Figure 2 -** Example of a limit state response surface (Ref. 1)

With our response surface defined, we can very rapidly interrogate it with an increasing number of randomly generated combinations of key parameters, looking for failures at every cycle and calculating the implied probability of failure until convergence is reached.

If failures are few, which might well be the case for conservatively designed structures, we can also validate the failures we see (or a sample of them) by further FE model runs, with results then used to update the response surface and our probabilistic predictions.

## CHALLENGES

The beauty of this technique is that it makes use of a pre-existing FE model, which could otherwise be costly to develop, but it is not without its own challenges. First and possibly foremost is that it relies on defining the probability distributions of influential parameters. For material properties, this is normally straightforward, unless novel materials are proposed with sparse mechanical testing data.

More problematic can be defining loading probability distributions, which may be poorly characterised or may fluctuate with time. With respect to dynamic effects like this, it is important that the probability distribution is consistent with a specified unit of time – evaluating a frequency of failure per year, for example, requires a loading probability distribution for a year. Other challenges include:

- How to address geometrical variations in important design features caused by build tolerances in a way that minimises re-modelling time.
- Estimating the uncertainty in probability of failure evaluations, since not only does this require the definition of uncertainty of probability distributions themselves, but also greatly increases the number of randomised trials and the demand on computing time.
- Recording sufficient results data to support a meaningful and useful interpretation of results, while discarding other data to minimise data storage requirements.

On the last point, it is worth remembering that while computing the expected probability of failure is clearly of interest, it is as important to understand the most significant contributions to failure – i.e. the conditions, locations and failure modes – which may provide useful risk-related insights for the designer.

## CONCLUSION

FE analysis is very often the design tool of choice for physical problems, including structural analysis. Until recently though, its application has, understandably, been limited to deterministic assessment. Where probabilistic assessment of integrity is also needed, however, the repurposing of an existing FE model to support Monte Carlo sampling of a response surface represents a practical, design-specific and cost-effective strategy, with potential applications we are only now beginning to appreciate.

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## POTENTIAL APPLICATIONS

### Nuclear power plant primary pipework and pressure vessels

Despite almost 160 years of study, there are still gaps in knowledge for predicting the probability of fatigue crack initiation under variable loading at high temperatures (Ref. 2). FE analysis-based defect tolerance and total-life approaches (the two main types of assessment) are typically employed for assessing high integrity components deterministically. Such models could also be used to provide complementary probabilistic assessment.

### Seismic fragility analysis

While FE analysis is used extensively to understand and improve the response of structures in an earthquake, the estimation of the failure probability of key structures (termed fragility analysis) only makes use of the evaluated margin to failure, together with empirical definitions of uncertainty. Deploying FE models to support probabilistic analysis more directly could provide more relevant estimates or, alternatively, could help validate existing empirical approaches.

### Carbon storage containment risk

Although projects involving the geological storage of $CO_2$ can benefit from the insights provided by quantitative containment risk assessment, there is much uncertainty involved. Site-specific geomechanical FE models can, however, be re-used to characterise the probability of failure of key geological features, such as the primary seal and nearby faults (Ref. 3).

### Wind turbine composite blade design optimisation

Composite materials are increasingly being used in industry, but there are numerous uncertainties around the fibre weaving and how this would behave on-site with variable wind conditions. As FE-based analysis tools are developed to address the unique properties of composites (e.g. Ref. 4), deploying them to make probabilistic failure predictions becomes a realistic prospect.

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# Storm Warning – Understanding the risks associated with extreme space weather events

In recent years, concerns have been raised around the potential for space weather events to adversely affect critical infrastructure here on Earth. In order to manage such hazards, we need to understand them – so, what are space weather events, and what impact can they have?

## INTRODUCTION

Space weather is a natural consequence of the behaviour of the Sun and Galactic Cosmic Rays (GCRs), and relates to their interaction with the Earth's magnetic field and atmosphere.

The sun is a highly dynamic body, and many processes can affect solar activity, including solar flares (see Figure 1). Where a sudden increase of energetic particles at ground level is induced by solar activity, this can result in dramatic changes in potential radiation exposure at lower altitudes, causing fluctuations in power systems and disrupting electronic devices, with a potential significant effect on critical infrastructure and plant.

## NATURAL RADIATION

Exposure to low levels of natural background radiation is part of everyday life, and most people are not aware of this exposure and the potential risks to health. Personal behaviour can affect the dose received – for example taking a commercial flight from the UK to the USA results in a ~80μSv effective dose (Ref. 2), or about 4% of the average UK annual background radiation dose.

In contrast, exposure to elevated levels of ionising radiation (>100mSv), such as those possible during a severe space weather event, has been noted by the UK Health Protection Agency, as having the potential to cause damage to DNA, lead to mutations, uncontrolled cell division and lead to malignancy (Ref. 2).

## SPACE WEATHER

Space weather is best understood as the variation in the Earth's surrounding space environment, and is caused mainly by energetic charged particles from the Sun that interact with the Earth's magnetic field. The most visible sign of this interaction is the Aurora, where charged particles enter the atmosphere at the poles, channelled by the Earth's magnetic field lines. Reassuringly, this magnetic field and the atmosphere largely protect us on the ground from potential exposure to these energetic particles; however, there are some space weather events that can result in dramatic changes in potential radiation exposure at lower altitudes.

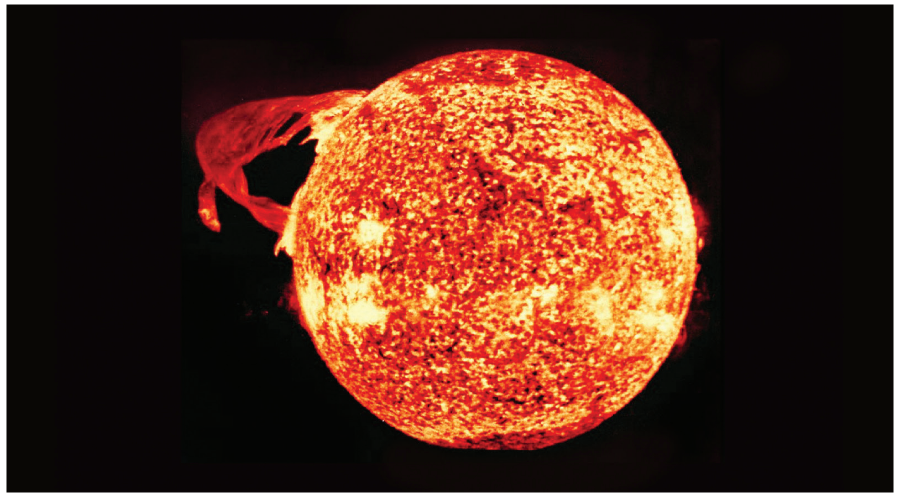

**Figure 1 -** Photograph of the Sun (December 19, 1973), from the third and final manned Skylab mission, showing one of the most spectacular solar prominences ever recorded, spanning more than 588,000 kilometres (365,000 miles) across the solar surface (Ref. 1)

## GROUND LEVEL ENHANCEMENTS

When energetic particles from Solar Energetic Particle (SEP) events, driven by shocks from Coronal Mass Ejections (CMEs), hit the atmosphere, a large influx of protons can result in showers of secondary particles, especially neutrons, which can potentially reach ground level if high enough in energy to penetrate the atmosphere. These events are called Ground Level Enhancements (GLEs) (Figure 2).

GLE events involve the interaction of energetic particles over ~350MeV in energy with the Earth's atmosphere. These energies are high enough to interact with atomic nuclei of the atmosphere, generating a cascade of secondary particles at ground level. This air shower can consist of neutrons, protons, electrons, pions, muons and others, with high energy neutrons (>10 MeV) being the main concern.

Higher energy particles observed during a GLE event have sufficient energy to penetrate the magnetosphere, even at non-polar regions, and result in a cascade of secondary particles at lower latitudes. There have been 73 GLEs recorded since measurements began in the 1940s – approximately one GLE event per year. Although these are difficult to predict with constantly varying solar conditions, they show some alignment with the solar maximum. The largest GLE ever recorded was in 1956, with the observed neutron count rate at one station (Leeds, UK) increasing by ~4760% (15-minute average) (Ref. 4).

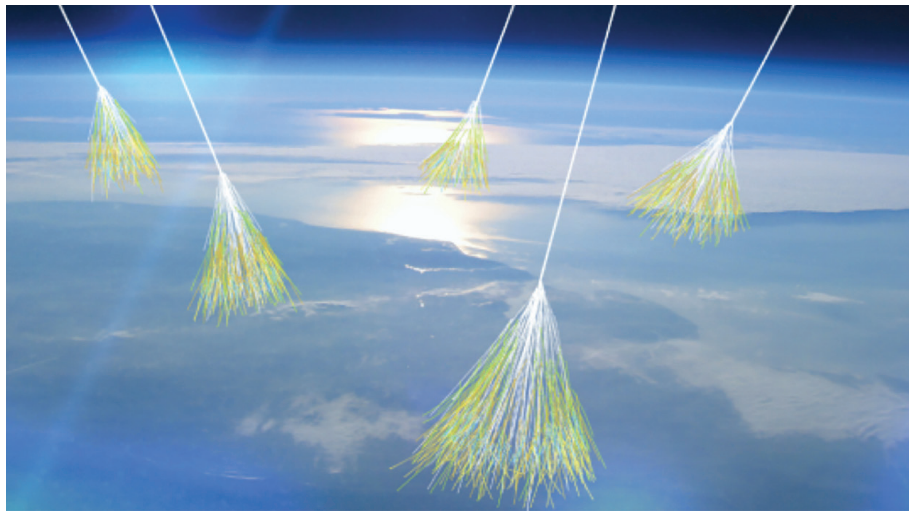

**Figure 2 -** Cascade of particles within the atmosphere from incident protons during a GLE event (Ref. 3)

## WEATHER EFFECTS

The vulnerability of power transmission systems to the effects of geomagnetically induced current surges, and the subsequent potential for widespread black-outs, are generally well known, largely thanks to the collapse of the Hydro-Quebec power network in 1989 during a severe solar storm.

What is less well known is the potential for GLEs to disrupt electronic devices. Semiconductor devices made of silicon are particularly vulnerable. The most common result is a bit flip (a 1 changing to a 0 or vice versa), affecting running processors or a rapid energy discharge in power devices, with local effects ranging from none to temporary or permanent malfunction.

With the widespread use of semiconductors in modern communication, control and protection systems, modern plant are potentially vulnerable to associated equipment loss or spurious behaviour during a severe GLE, together with coincidental loss of offsite power.

## BAD WEATHER DAY

In an extreme example, for a nuclear power station, a severe GLE impacting reactor control and supporting safety systems could, in principle, result in a complete loss of their functionality if they are solely based on microcontroller technology. It is worth noting, however, that being the product of scattering and location-specific impacts, adverse events are stochastic in nature, not certain, and currently difficult to assess in terms of probability.

Although loss or impairment of affected equipment is unlikely to prevent a reactor trip, the subsequent operation of supporting safety systems, e.g., electrical, air supply, etc. may require manual interaction to ensure post-trip cooling.

There could also be an impact on electronic systems that support plant operators, such as monitoring, warnings and alarms, which may behave spuriously or fail, causing confusion. Internal and offsite communications may also be unavailable, preventing operators from co-ordinating response efforts or requesting assistance.

Performing the necessary manual actions during a severe GLE, in a timely manner with a lack of reliable indication, could be extremely challenging; as could correctly diagnosing any false alarms, without any systems currently available to alert them of an occurring GLE.

While it is clear that the potential consequences of a severe GLE could be serious for a nuclear power station, evaluating the frequency of such accidents is fraught with uncertainty. Further research is needed to characterise the spectrum of event frequency versus GLE energies at varying locations, and the vulnerability of device types and their effects in probabilistic terms, before the associated risk can be quantified. Only then will we be in an informed position to decide whether the hazards of space weather merit specific design provisions (such as shielding or use of analogue protection systems).

## CONCLUSION

As the effects of space weather on people and equipment become better understood, we have the capability to identify the wider potential consequences on safety-related plant, indication and operator response.
To understand the associated risk, however, will require more research into not only the frequency (and forecasting) of severe events at varying locations, but also their inherently stochastic effects on electronic devices.

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# Decommissioning by Design – Designing for the future

The design of early nuclear facilities often ignored or paid little attention to the future need for decommissioning and dismantling, a legacy from which we are still paying the price. How, though, can our hard-won lessons learned help inform future designs and make things better for future generations?

## INTRODUCTION

It is now over 75 years since the first civil nuclear facilities were being designed. At the dawn of the atomic age many nations sought to exploit the potential of nuclear energy with a wide variety of fuel fabrication, research reactors, fuel reprocessing and power station facilities being developed.

Enthused by the white heat of this scientific revolution little regard was placed on the eventual decommissioning and dismantling of these pioneer facilities, other than assuming that future generations, and the technology available to them at the time, would find a way to manage this process.

And, by and large, these future generations are finding a way to decommission these facilities. However, it's not been easy and there is widespread recognition that this process would have been significantly quicker, simpler and cheaper had such processes formed part of the original planning of these facilities. Even so, many nations are still grappling with the thorny issue of ultimate disposal of their legacy nuclear wastes within, for example, underground geological disposal facilities.

## THE PRESENT DAY

Fast forward 75 years and the multitude of new nuclear power plant designs in development is reminiscent of those early days of the nuclear industry. Many of these new designs are for Small Modular Reactors (SMRs) which promise advantages in terms of their economic models, deployability, manufacture and safety.


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**Figure 1 -** Sunset over Dungeness A Nuclear Power Station, UK

Many current designs are based on smaller versions of established large reactor technologies (such as PWRs and BWRs) whereas others are for advanced (so-called Generation IV) technologies which offer more exotic designs based on different reactor technologies that rely on novel fuel and/or coolant systems and, potentially, greater inherent safety and security, often associated with fully passive safety systems. The opportunity for fleets of identical, rather than bespoke designs, promises efficiencies beyond the reach of the early designers.

Things are different now. It is widely recognised that safety, security, safeguards and environmental issues need to be considered 'by design' throughout the development cycle. The application of mature risk management techniques drives the desire to design-out rather than protect against hazards and vulnerabilities. Lessons learned in terms of materials selection, access, maintenance and operational management bear fruit during the operational phase, particularly in terms of operator dose.

## PLANNING AHEAD

A similar thought process applies to 'decommissioning by design', and regulators now typically require an initial decommissioning strategy to form part of the licensing application for a new facility. Even during early design development in the pre-licensing stage designers now need to consider decommissioning issues, whether this relates to the type and/ or volume of waste to be generated throughout the lifecycle.

Here, there are some advantages to more conventional SMR designs that use standard fuel and coolant systems in terms of precedent and proven solutions, at least as far as interim storage is concerned. Of course, modular construction


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does not necessarily mean modular deconstruction (although some microreactors offer this promise).

Designers may need to tackle other issues including waste volume and activity; counterintuitively, an SMR may actually generate more waste per GW generated because of its lower output and potential for increased activation of materials, given its smaller footprint and increased neutron leakage compared to a larger reactor.

## NEW DESIGNS, NEW CONSIDERATIONS

But, what about the advanced reactor designs? Many of these are currently in the process of trying to turn a physics concept into an engineered power station design. It's a tricky task particularly where codes and standards don't yet exist and historical precedent is limited or non-existent.

However, at this stage the opportunity for decommissioning by design to be incorporated is high. So, as well as trying to achieve an operational and licensable design, the designers need to demonstrate that, for example, the resultant waste profile is well-understood and can be managed effectively. Perhaps Artificial Intelligence could help predict waste generation over the facility lifetime and optimise plant operations accordingly.

For long term storage and disposal of novel fuels this requires early consideration; for instance, is the proposed fuel, fuel can or cladding material suitable for interim and long term disposal or does fuel need to be reprocessed or repackaged at some point, generating yet more waste? Could unusual enrichment or burnup pose a difficulty down the line? If the fuel is encapsulated in moderator does this affect how it can be managed? How will the coolant (which may be contaminated or activated) be handled at the end of life? Will a future geological disposal facility accept the proposed wastes?

Such questions are likely to be the subject of ongoing research and development activities to increase confidence in the suitability of the design.

And, who knows? Perhaps the inherent constructability of a modular design could lead to these same modules being disconnected and transported offsite to a fleet-wide centralised waste management facility for automated processing followed by recycling or disposal. Perhaps key modules could be switched out to turn our old power station into its own decommissioning centre.

## CONCLUSION

Decommissioning by design is increasingly becoming an expectation from regulators who are recognising that understanding what happens at the end of a facility's operational life is a priority even early in the licensing process. Arguably, the viability of a new design may ultimately depend on minimising its legacy footprint. So, thinking caps on. Our grandchildren will thank us.

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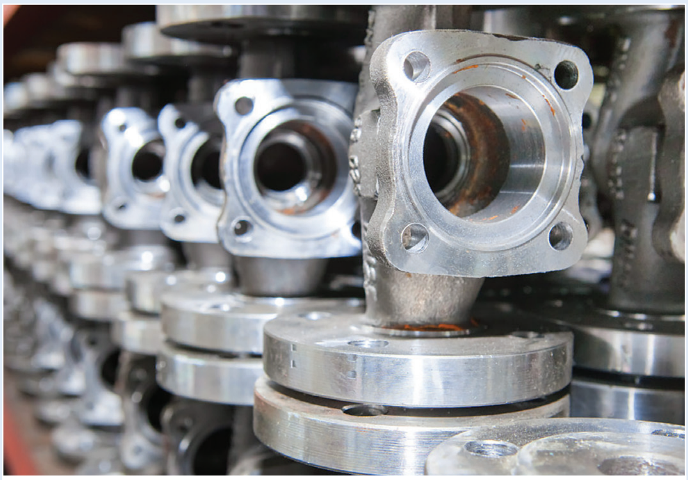

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