AN INTEGRATED NUCLEAR DIGITAL ENVIRONMENT

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SUMMARY

Modelling and simulation are becoming ubiquitous in engineering and at the same time the availability of sensors is increasing rapidly so that large amounts of data, known as ‘big data’, are being generated from both observations and simulations. Substantial progress has been made in developing quantitative comparison methods for such data, particularly in the field of structural mechanics, which enables the processes of validation and condition or state assessment. These factors, taken together, offer the prospect of creating a digital environment for the life-cycle of nuclear infrastructure in which data from simulations and sensors are integrated to provide a comprehensively validated digital twin for an infrastructure asset. The vision for an integrated nuclear digital environment is presented and the technology gaps that need to be addressed to allow its implementation are discussed briefly.

1: Introduction

High performance computing and big data analytics are perhaps the latest in a series of technologies enabled by rapid advances in silicon-based digital devices. These devices not only allow faster, more powerful computers to be produced month-by-month but have also revolutionised sensors so that huge quantities of data can be collected. The aerospace industry has taken advantage of these advances and introduced the concept of the digital twin [Glaessgen & Stargel, 2012] in which design and in-service data are collated in a digital format for individual aeroplanes and can be used in the prediction remanent service life, particularly after an unexpected event. Recently, it has been proposed that a ‘strain continuum’ can be created [Patterson et al, 2013], in which full-field strain measurements acquired from prototypes during validation of computational design models could be used as the basis for monitoring the state of the structural integrity of a engineering system throughout its life-cycle. This would involve using strain measurements during quality assurance to assess the performance of the as-manufactured parts and subsequently carrying out the same measurements in non-destructive inspections during service. Whilst this vision has been enabled by new techniques for strain measurement such as digital image correlation, Patterson et al identify a number of technology gaps to be addressed prior to the implementation of the 'strain continuum'. However, it is also possible to imagine other 'continuum' based on measurements collected throughout the life-cycle of an engineering system that would allow its condition to be monitored and compared to the intended design state.

The aerospace and nuclear industries could both be described as operating with the over-riding requirement for safe operation of high-cost capital equipment within a strong regulatory framework and in the spotlight of public opinion. Noting these similarities this paper discusses the benefits that the translation of the digital twin concept from the aerospace to the nuclear industry could realise. In this case the life-cycle starts from the prototype tests required to support the development of a nuclear plant and extends to the storage and disposal of the waste material when the plant is decommissioned. The term 'nuclear plant' is used as a generic term to include all nuclear infrastructure including power, fuel processing and waste plants.

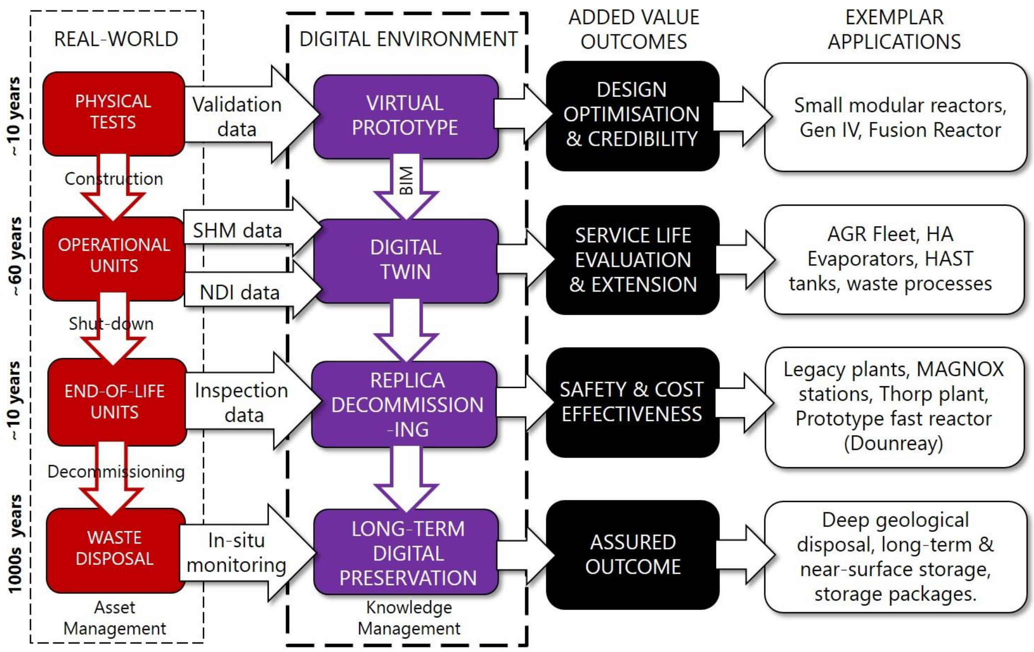

Figure 1: Schematic diagram of the 'Integrated Nuclear Digital Environment' (INDE).

2: Integrated digital environment

Figure 1 shows a schematic diagram of the ‘Integrated Nuclear Digital Environment’ as the second column from the left, its relationship to the real-world in the left column as well as the potential benefits and exemplar applications in the two right-hand columns. The ‘life-cycle’ flows downward with a non-uniform time-scale on the extreme left.

Real-life in the nuclear industry has been idealised into four stages: (i) physical tests that are performed during the design stages of a nuclear plant which might extend over about ten years; (ii) an operational period for the plant that extends over decades and is connected to the prior stage by a construction process; (iii) an end-of-life stage lasting about ten years which is connected to the prior stage by a shut-down process; and (iv) waste disposal or storage which lasts for thousands of years and is connected to the prior stage by a decommissioning process. This real-world sequence is characterised by asset management.

A corresponding digital world or environment is proposed with four stages. First, a virtual prototype in the form of a computational model of the proposed plant that can be used to simulate all aspects of its performance. Such computational models require validation to establish the ‘extent to which they represent the real-world with respect to their intended uses’ [AIAA, 1998] and the transfer of data measured in the real-world physical tests represents the first connection between the real-world and the digital environment. In assessing structural integrity, these data could be maps of surface strain acquired using digital image correlation and a methodology for efficient quantitative comparison of large fields of strain data is available [CEN, 2014]. The second stage in the digital environment is a ‘digital twin’ of the operating unit which is created from the virtual prototype by combining it with Building Information Modelling (BIM) data collected during construction of the plant. The connection to the real-world for the digital twin is provided by the input of monitoring data, such as structural health monitoring (SHM), and inspection data acquired during maintenance periods, such as non-destructive inspection (NDI) data. The combination of the design or prototype model, BIM, SHM and NDI data probably turns the digital twin into an interconnected CAE model and database which, when transported into the third stage of the digital environment provides a complete description and service history of the plant that can be used to plan its decommissioning. In other words, replica decommissioning procedures can be performed in the digital environment, for instance using immersive four-dimensional virtual reality facilities. Inspections of the real-world end-of-life plant will provide additional information for the replica decommissioning and could allow validation of the condition of parts of the plant that were impossible to monitor or inspect during operation. The fourth stage of the digital environment is the long-term digital preservation of the data describing the nuclear waste. This stage will last thousands of years and should have continuous input from in-situ monitoring of the real-world waste. All four stages in the digital environment can be characterised as knowledge management, i.e. they go further than simply management of data, because the data must be handled in way that adds value by enhancing safety and lowering costs.

3: Concluding Remarks

Some of the stages in the digital environment exist already and many of data acquisition techniques are used routinely; however the interconnections are problematic. ISO standards exist for the exchange of digital engineering data but the nuclear industry has been slow to accept them [Swindells, 2014] and they probably are not sufficiently comprehensive to handle to the diversity and quantities of data envisaged here which would require the use of supercomputers to process it effectively. Most software used in the nuclear industry is not optimised for supercomputers and so considerable optimisation of data and software protocols and packages will be required to allow this enabling technology to be exploited.

Acknowledgements

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