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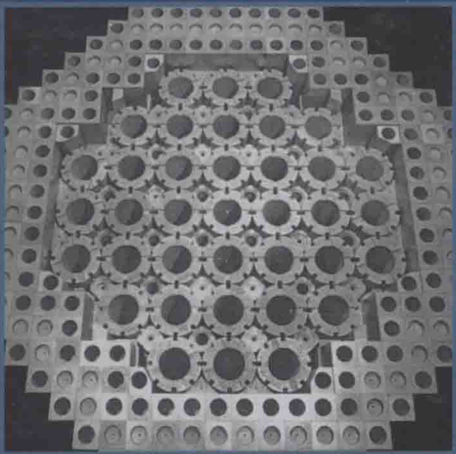

Understanding and mitigating ageing in nuclear power plants

Materials and operational aspects of plant life management (PLiM)

Edited by Philip G. Tipping

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Foreword

Y. DOU, Shanghai Nuclear Energy Research and Development Institute (SNERDI), P. R. China

The development and commercial use of nuclear energy in the form of cost-competitive electricity and district heating was one of the most significant industrial achievements of the 20th century. The 21st century is now approaching its second decade, and global energy consumption continues to grow rapidly, and projections show a doubling of world electricity demand by 2030, creating the need for considerable amounts of newly installed generating capacity (of all origins) in the next 25 years. The current global nuclear energy capacity is about 367 GWe, and between 524 GWe and 740 GWe is expected to be needed before 2050. This will necessitate building between 200 and 400 new nuclear power plants (NPPs) worldwide to just replace the lost capacity of electrical power from decommissioned NPPs and to provide the new capacity that will be necessary by 2050, not only to satisfy the needs of growing energy consumption, but also to ease environmental pressure by reducing dependence on fossil-based energy. For example, in China, where the economy has continuously increased by 9% per year, on average, over the past 30 years, the current portion of nuclear-generated energy is only around 2%, which is a relatively small percentage in comparison with the world's current nuclear-generated energy portion of about 16%. To satisfy the demand for energy in an environmentally friendly way, free from greenhouse gas emissions, China is thus launching an ambitious nuclear power plan to raise the portion of nuclear energy by 4–5% by the year 2020. That means that 40–60 new NPPs of 1000 MWe should be built in a decade or more. Such ambitions for new-build requirements for NPPs create considerable logistics and planning tasks, having due regard for the industry's overall current and projected ability to supply the heavy equipment required for NPPs (e.g. pressure vessels, quality alloys for piping, steam generators, core shrouds, pumps, high quality cement for containment buildings and cooling towers, etc.). Furthermore, action must be taken now to ensure that sufficiently trained, educated and experienced personnel are available to operate the plants and to regulate them. Also, the need to have fossil-fuel free low 'greenhouse gas' energy sources puts the focus squarely on the nuclear option, as long as it can remain safe.

Two crucial and decisive factors to sustain long-term operation of nuclear power plants are their safety and profitability, which can be achieved through a combination of applying optimum management strategies with an understanding of the ways in which the safety-related systems, structures and components (SSCs) perform and interact in their respective operating environments. The SSCs are made of various materials (e.g. metals, alloys, concrete, plastics) and it is the behaviour of materials due to their operational conditions (e.g. temperature, pressure, loading, irradiation, coolant chemistry) that can lead to ageing degradation with attendant impact on NPP availability, SSC reliability, or a lessening of safety margins and possible attendant operational constraints. It is the duty of NPP operators to ensure that their NPPs are safe as well as profitable. Operators can be assisted in achieving these goals by using ageing management and plant-life management approaches, based on science and technology and global experience. Ageing management and plant-life management covers various aspects of knowledge on SSCs, such as information on requirements of design basis, manufacture, installation, commissioning and operation, understanding of material degradation mechanisms, inspection programmes, evaluation and robust implementation of associated methodologies for assessing SSC fitness-for-service, use of database techniques, etc. For those countries having various designs and types of NPP, the available experts and plant personnel may need information or have to deal with tasks or problems from the different units synchronously. It is therefore extremely useful to have a single book which provides a wide range of the most recent information covering all types of NPPs on ageing and plant-life management techniques and also gives insights and guidance on how to keep NPPs operating safely and reliably. This is facilitated by understanding how ageing degradation occurs in SSCs and then by using this knowledge to develop scientifically based methods to mitigate or eliminate it.

This book has been produced through a multinational team of globally recognized experts in their respective fields. The scope of this modern book is therefore immense and records the knowledge and experience gained with materials in NPPs over the last 50 or so years of nuclear power development. The suggestions for further reading and the references provided give the reader access to even more information. Accordingly, this book is a practical and technical manual for engineers, technologists and specialists involved in all aspects of NPP operation. Students and younger technologists studying nuclear technology, or those just embarking on their careers in nuclear power, will find here a source of inspiration and current information to help them achieve their academic and career goals. Furthermore, this book is a record of the current knowledge and experience that needs to be kept for future generations. This is even more so now, due to the gradual but steady loss of the “pioneer” generation of nuclear technologists and researchers, as they go into retirement. External organizations, including design institutes, technical supporters, sub-contractors of nuclear steam supply systems, materials suppliers and regulators will also find valuable information in this book to enable them to carry out their respective tasks. In a word, this book is essential reading for anyone associated with nuclear power.

In China we have a proverb, namely, 'Experience is the best teacher'. I believe that this book will act as one of the best teachers currently available, since it is based on the cumulative experience of more than 750 person-years when the career years of all the contributing authors are taken into consideration. It remains to be seen what the next generation of NPPs will demand in terms of specialist knowledge and operational practices. One thing is certain: as new knowledge is obtained, it must also be recorded in a book such as this.

Executive summary

PH. G. TIPPING, Nuclear Energy and Materials Consultant, Switzerland

Overview of the book

This reference book is a comprehensive state-of-the-art, science and technology record of the current knowledge base concerning materials ageing degradation (AD), and its mitigation and elimination in systems, structures and components (SSCs) used in commercially operated nuclear power plants (NPPs). Accordingly, it covers a wide range of subjects relating to NPP SSC-AD, and so the phrase 'from atoms to zirconium' could be a fitting one when attempting to capture the very essence of this book. It traces the historical development of commercial nuclear power, while illustrating the way our understanding and mitigation of SSC-AD has continually increased through basic and applied research approaches. The effectiveness and integration of validated SSC-AD mitigation methods (which have been largely furnished by basic research efforts) into the daily operation of NPPs is exemplified throughout.

The necessity for always keeping SSCs 'fit-for-service' is a vital safety-related aspect, but it is also an important commercial requirement as well, since NPPs may thereby retain the technological basis, and thus the regulatory possibility (in satisfying licence requirements), to continue safe and reliable operation, even in excess of their original design life. The chance that this 'long-term operation' (LTO) can be realized is significantly enhanced when NPP plant life management (PLiM), ageing management (AM), ageing surveillance programmes (ASPs) and standard operational practices (OPs) are optimized, and when plant-specific and worldwide lessons learned are continually and robustly integrated into the operational management of NPPs. The effectiveness of PLiM, AM, ASPs and OPs is also shown to depend significantly on the level of safety culture prevailing in the NPP's workforce, as well as on efficient plant knowledge management (KM) and associated job succession and training strategies for personnel. These essential themes are discussed throughout the book.

Each chapter may be regarded as a 'stand-alone' contribution, providing in-depth information concerning the specific subject matter dealt with. The authors responsible have provided concise abstracts, summaries, conclusions, references and further information sources regarding SSC-AD, PLiM, AM and ASPs from their perspectives. The book is structured to allow the reader to select specific subject areas on the topic of interest in order to provide detailed information on SSC-AD, and also to give a perspective on the commercial nuclear power industry as a whole.

Overview of Part I

Part I reviews the role of nuclear power in the global energy mix, and the importance and relevance of plant life management (PLiM) for the safety regulation and economics of nuclear power plants.

In **Chapter 1,** by **Tipping**, a strong argument for the use of commercial nuclear power is provided with respect to its role as a non-fossil based energy source. Accordingly, aspects concerning the world's climate, and the part nuclear power has in providing safe, cost-effective, and low environmental impact energy, are presented. Owing to climate and carbon dioxide emission issues, current and future use of nuclear power is considered to be a vital factor in the global effort to improve on the Earth's environmental 'balance of health'. (Viewed relatively, the carbon dioxide content of the atmosphere is currently about 70% more than it was 40 years ago, and this trend is continuing.) Comparison is made between nuclear and other forms of energy, not only in terms of carbon footprint and greenhouse gas aspects, but also in terms of costs and availability of fuels. Attention is brought to the finite nature of fossil-based fuel resources compared to nuclear fuel cycles that can 'breed' further fuel. Cost-competitive fissionable materials suitable for fuel in current and future fission-based nuclear technology are conservatively estimated to be sufficient for at least the next 500 years at projected usage rates/requirements estimates. Features and characteristics of next generation NPPs have also been provided to introduce the reader to this evolving aspect of commercial NPP development, and fusion-based nuclear power, although beyond the scope of this book, is also briefly addressed in terms of a future fossil-fuel free energy source.

The key elements, principles and approaches to NPP-PLiM for plant designs most commonly in current use are explained in **Chapter 2,** by **Tipping**. Goals and essential features of PLiM, AM, ASPs and standard OPs are shown to be the result of logical and safety-based approaches to ensure that resources are primarily invested into the most important SSCs to maintain adequate safety margins and to continuously increase safety levels. Common NPP SSC-AD terminology and definitions are listed. Many SSCs can be routinely maintained or replaced, but it is the condition of the large, passive SSCs, which are deemed irreplaceable (due to practical and cost issues), that will ultimately decide the operational life of a NPP. Failures in