Knowledge Gaps in Toughness and Irradiation: Lessons of the Past, Prospects for the Future.

Tim Williams, UK

In over 50 years of commercial nuclear power, the understanding of the effects of irradiation damage on the through-life toughness of RPV steels has developed enormously. A key requirement, safe RPV operation, has been met. However, during this time there have been many examples of technical surprises that altered understanding or otherwise challenged existing safety cases. In many such cases substantial work was needed in order to be able to re-affirm that continued operation of the RPVs concerned was safe beyond all doubt. Mostly this was achieved through technical analysis, but in some, continuing operation was most readily justified by adopting engineering solutions, such as RPV annealing; in a very few cases early decommissioning was the only practicable or economic course.

During the same period there have been many technical developments, some the direct result of the above challenges. We now understand far more about materials behaviour, and we have much better tools at our disposal to investigate and model such behaviour and to perform structural integrity assessments (SIA). Furthermore, modern materials have better start of life toughness properties than those produced in the past and, thanks to control of copper and phosphorus, much reduced irradiation sensitivity. However, our experience is largely informed by work on the older materials and determined by the need to understand the irradiation shift of the transition region. We may need to review our priorities for the future.

The past 50 years have also brought incredible changes to reactor designs, steelmaking and fabrication processes, and to the ways in which the nuclear industry operates, as shaped by the changes to the society in which it functions. We cannot expect to predict the future with any accuracy, except to say that we will be probably be moving beyond current experience in one way or another.

It is sometimes claimed that engineering progresses through failure. Structures become lighter, faster, or cheaper until the point at which the hindsight that follows a failure results in a change to the design rules or materials specifications. Failure of an RPV is unthinkable and this demands that the probability of failures of foresight is reduced to a very low level, and that their effect is mitigated by forewarning through surveillance and development of knowledge.

But these requirements have to be met against the background that we are moving beyond current territory. Although we have large irradiation damage databases, there are regions of dataspace, in composition for example, that are relatively sparsely populated, even in two dimensions. But the biggest issue is in extrapolation in time and fluence.

So, what do we do?

First, the focus must remain on the development of mechanistic understanding and models. As Bob Odette emphasised in 1979, empiricism will not work. Instead, multi-scale multi physics(MS/MP) projects, such as PERFORM60, though perhaps some way yet from full fruition, have demonstrated that physical models are within our grasp.

Second, we must properly assess the risk of potential new phenomena. Sociological studies have shown what we all know, that credible and informed experts can often disagree over seemingly objective facts and that apparently established truths can be overturned. Where there is a disputed piece of information, the prime questions should be "What are the SIA implications?". Scientific resolution of the issue is important, but can follow.

The third essential, in the context of foresight and extrapolation, is to investigate gaps. A survey of paper titles from ASTM Radiation Damage Symposia and IGRDM meetings over the past few years reveals that about 90% of these are about 'hot topics', while certain other issues have received relatively small attention. This distribution may be because we have correctly identified the most concerning issues, but it is hard to be certain. A related requirement is to challenge current codes, procedures and assumptions to ensure that they take full advantage of current knowledge.

Finally we need to be prepared to meet the challenges of future unexpected issues, whether they are similar to those encountered in the past or different. The costs of unplanned outages or early decommissioning are potentially high in comparison to that of maintaining and developing the resource needed to minimize the effect of such arisings.