Resilience and the Training of Nuclear Operators – A View from the Shop Floor

Michael Hildebrandt[1], Helena Broberg, Salvatore Massaiu,
Beant Kaur Dhillon and Malgorzata Tarasewicz
OECD Halden Reactor Project, PO Box 173, 1751 Halden, Norway
[1]Michael.Hildebrandt@hrp.no

Abstract. The paper reports results from an interview about resilience with a practitioner from the nuclear industry. The aim of the interview was to understand how a practitioner construes of resilience, where and how it may be relevant for his/her everyday work, and what the practical constraints and limitations of RE may be when applied to the nuclear domain. The interview produced interesting results on how resilience may be improved through training on beyond-design-base scenarios, and where there are practical limitations to flexibility and adaptability of work practices and work environments. To facilitate discussion with the practitioner, a timeline representation of resilience was developed and is reported in the paper.

1 INTRODUCTION

"*What* Engineering?" – "Resilience Engineering. You know, as in resilience against disease, or against depression. Just applied to complex socio-technical systems." – "Hm OK. So it's a bit like safety engineering." – "Uh, well, ... It's the ability of a system to return to a stable state after disturbance" – "As in...?" – "As in... Well, take 9/11 for example, or the Asian Tsunami" – "Yes, but..."

Many conversations among researchers in the safety world and in Human Factors may have taken a similar course over the past few years. As researchers explored the semantics of the concept of resilience, metaphors from other domains, such as ecology and epidemiology, entered the thinking of the Resilience Engineering community. In addition to conceptual work, attempts to identify resilience markers in observational and experimental data led to a better understanding of resilience at an operational level (e.g. Back et al., 2008). Building on this work, we believe additional insights can be gained from discussing the concept of resilience with practitioners (see Perin, 2004, for examples of interview studies in the nuclear domain). Questions to be answered by such an approach include: how does a practitioner construe of resilience? What examples of resilience does he/she generate from his/her experience? Does he/she consider the organisation they work in as sufficiently resilient? Is resilience something new, or is it 'old wine in new bottles' to them? What is the cost of resilience, what are the risks involved in trying to make a system more resilient? What are the practical constraints that may limit the scope of resilience engineering? Will resilience introduce new expectations and responsibilities for operators, and how will they cope with these expectations?

This paper presents results from an initial interview where some of these questions were explored with a practitioner from the nuclear industry. The aim was to understand the practitioner's perspective on resilience and its relevance for nuclear operations. Is resilience and the associated concepts of flexibility, adaptivity, buffering and creativity (Woods, 2006) relevant and meaningful from the point of view of someone at the sharp end of operations?

During the preparations for the interview, it became obvious that a clear and comprehensive representation was needed to facilitate and ground the discussions about resilience. These considerations led to the 'resilience timeline' described in the next section. Section 3 presents some results from the interview. Preliminary conclusions are drawn in section 4.

2 THE RESILIENCE TIMELINE: A BOUNDARY OBJECT

Talking about resilience is not easy. As preparations for the interview proceeded, it became clear that a strategy was needed to convey the main ideas of resilience, and some indications of the relevance and expected benefits of Resilience Engineering, to a practitioner within a limited amount of time. Several options were considered: describe the theory, give examples, explain differences to other approaches, or a combination thereof. However, none of the attempts to combine elements from the existing literature produced a result that fulfilled the requirements for the interview: to generate a representation that actively and systematically encourages concrete discussions about resilience markers, mechanisms and threats at different levels of abstraction, from technical/operational to organisational and regulatory. The problem was that functional definitions of resilience, e.g. resilience as the ability of a system to return to a stable state after disturbance, potentially cover any and all activities at any and all levels of an organisation. This degree of comprehensiveness and generality can make it difficult to systematically discuss concrete manifestations of and interactions between resilience mechanisms at these different levels. With concrete examples such as 9/11, on the other hand, there is a risk of focussing too closely on certain aspects of resilience (e.g. creativity) and losing sight of the multitude of resilience mechanisms in other parts of the system.

What was required was a grounded, conversational model of resilience that would act as a boundary object between practitioner and researcher (Bowker and Star, 1999). The solution that emerged for this problem was the idea of a *resilience timeline* (Fig. 1). A timeline provides a generic framework for anchoring phenomena across different levels of granularity. Activities at the sharp end and at the blunt end can be conveniently allocated onto a timeline (Westrum, 2006). Synchronicity and persistence can be represented by adding different layers to the timeline. Operational and organisational phenomena often fall into different sections of the timeline. Where they do not, interactions and overlaps can be represented as well. A linear representation of time can easily be extended into a cyclical model to represent iterative processes and feedback loops.

In order to facilitate discussion about preventive resilience and recovery resilience, the timeline was organised around a hypothetical *initiating event*, i.e. an incident or accident. Either side of this initiator, the timescale stretches from seconds and minutes to days, months and years. Note that the inclusion of an initiating event in the timeline is not meant to imply that all actions on the pre-initiator time scale are focussed on the event (in the sense of anticipating or preparing for a particular accident scenario). Instead the timeline can also be used to discuss day-to-day resilience, adaptation to everyday stressors and constraints, as well as anticipation and adaptation to changes in the environment and in the organisation.

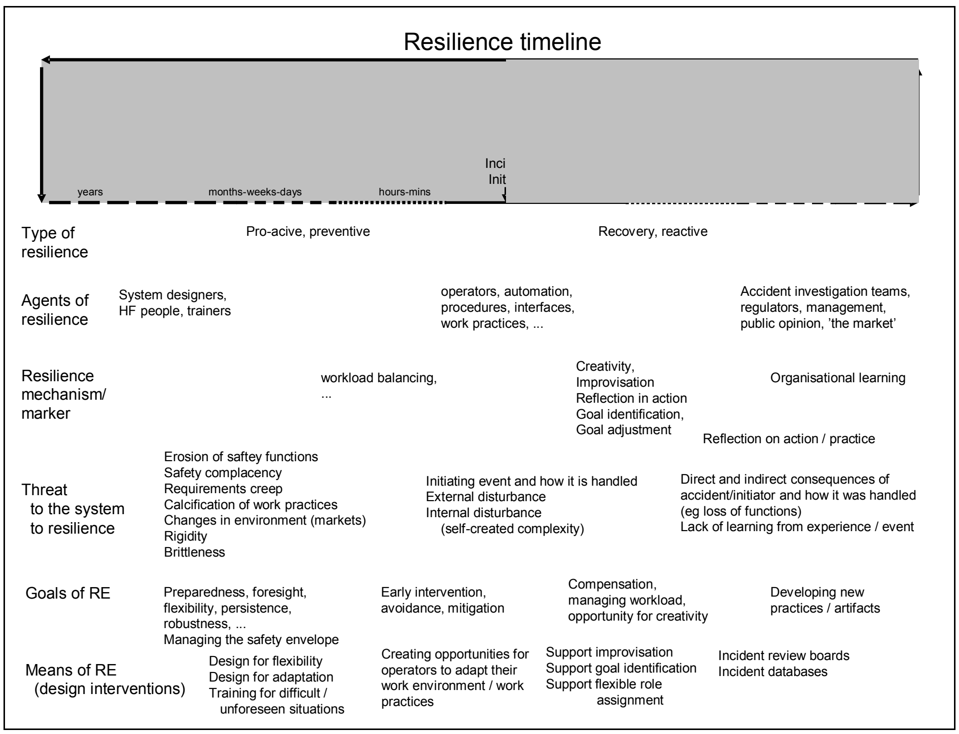

Fig. 1. *Resilience timeline* – A representation for discussing resilience mechanisms and threats to resilience at different organisational levels and temporal granularities.

However, the imitating event as focal point of the timeline becomes useful when talking about the resilience mechanisms relevant for handling unforeseen or unexampled events.

What conditions or system properties have to be put in place months and years before an event, so that resilient work practices can emerge, either over long periods of time or spontaneously as a reaction to an unforeseen event? How can the foundations for resilience be laid in system design, staffing and training? The agents of resilience and the means and mechanisms for creating resilience on the long pre-initiator time scale are very different from how resilience is created and enacted just before and just after an initiating event. At the sharp end, active deviation monitoring and workload balancing may be a means of enacting preventive resilience. Just after the initiating event, resilient recovery may be created by reflection-in-action, creativity and improvisation. These activities are again very different from the resilience mechanisms that may act months and years after an incident. This is the realm of reflection-on-action, of learning from experience, and long-term adaptation to new operational and organisational realities. The agents of resilience at this time scale are operators, management, but also, for example, accident investigation teams and regulators. As changes get absorbed into everyday practice, the cycle closes.

Several dimensions of resilience were added to the timeline representation in order to systematically explore opportunities for resilience engineering. These are: types of resilience; agents of resilience; resilience mechanism; resilience markers; threats to resilience and to the system; goals of resilience engineering; and means or RE. This created a 'resilience map' where almost any aspect and example of resilience can be anchored, constraints can be identified and explored, the scope of discussion for any particular example of resilience can be widened, and *what if...* questions can be asked. It was expected that this representation would make it much easier to convey the core ideas of resilience and of RE to someone unfamiliar with the concept.

3 RESULTS FROM THE INTERVIEW

The interview was conducted over a period of approximately 2 hours. It started with a presentation of the main ideas of resilience, based on the resilience timeline discussed above. The interview partner, John (not his real name), was a shift supervisor and simulator trainer with many years of experience operating pressurized water reactors (PWRs).

The first topic we discussed in the interview was resilience during unforeseen and unexpected situations. In the nuclear domain these situations are often called *beyond design-base scenarios*. Design-base scenarios are those situations which were considered during system design, and modelled in the plant's Probabilistic Risk Assessment. Examples are loss of feedwater scenarios or steam generator tube ruptures in PWRs. Design-base scenarios are rehearsed regularly during simulator training. They are also considered in detail when Emergency Operating Procedures (EOPs) are compiled and revised. In *beyond* design-base incidents, on the other hand, there is added complexity that may not be fully covered by the EOPs and automatic safety functions. Such scenarios require interpretation, intelligence and flexibility from the operating crews. Examples are fire incidents (which may disable many systems in the plant), large-scale loss of functionality (e.g. loss of electrical power and backup diesels), or mis-aligned, mis-reading or broken sensors, indicators and alarms. Incomplete, incorrect or non-applicable EOPs may exacerbate beyond design-base situations. Recent simulator studies on beyond design-base scenarios, where EOP-based problem solving was challenged by additional complications such as masked indicators, have shown that work practices, team dynamics, communication and leadership style are all important factors for success in these situations (HWR-844). One may argue that these unusual circumstances require resilience from the operating crew, or more precisely from the joint crew – control room system.

John shared this assessment and thought that resilience is a useful concept for describing success factors in such situations. He believed that beyond design-base scenarios (and the complexities they generate) are inadequately addressed in existing safety approaches, and that this is reflected in the training of nuclear operators. He believes that beyond design-base scenarios, and the resilient crew response they require, should be a much stronger emphasis during simulator training in plants. Instead there seems to be an emphasis on rehearsing well-known accident scenarios, where success is almost guaranteed by closely following the EOPs. Such training may over-emphasise the importance of thorough procedure reading at the expense of a more insight-oriented approach, where operators are constantly aware of the goals of the procedures and the expected plant response for a particular control action. John believes that both an understanding of the goals of the procedure *and* thorough work practices in procedure reading are necessary to create resilience. He associates lack of resilience in unfamiliar situations with loss of control by the operators. Such problems have been observed repeatedly in simulator runs, and can be triggered by even minor confusion caused by mismatches between expected plant state (as inferred from the EOPs) and actual or indicated plant state. Some crews have difficulty resolving such conflicting information. This can trigger a succession of minor errors and erratic work styles that can add considerable complexity to the scenario. John believes that generic strategies and training on how to manage such problems are essential for creating resilience. He was cautious to use the term 'creativity' in this context. He thought it was unrealistic to consider scenarios where operators would completely step outside the EOPs, or situations where they would generate a completely novel solution. Rather they will use and adapt resources, including procedures, in new and unforeseen ways. This flexibility to interpret procedures and to match them to the operational context is essential for success, as no amount of foresight and modelling during the design stage can cover all possible accident scenarios. For him, resilience seemed a useful concept to capture and promote this essential aspect of nuclear operations.

Discussion then moved on to the topic of compensation mechanism. For John, the multitude of compensation mechanism that exist among a crew of nuclear operator are an important condition for the emergence of resilience during unforeseen situations. They are also responsible for much of the buffering that keeps the many minor slips, lapses and mistakes that occur during operations from having disastrous consequences. Many examples of compensation mechanisms can be identified. For instance, the shift supervisor's (SS) monitoring of reactor operator's (RO) procedure reading can capture and correct RO's procedure reading problems, such as missing steps in the procedure or neglecting to read notes and warnings. The RO, on the other hand, can alert the SS to unusual indications that can help the SS to update or correct his assessment of the situation. On a larger scale, the crew can compensate for deficiencies in system design, particularly during beyond design-base incidents. Conversely, automatic safety functions, procedures and control room instrumentation can to some extent help compensate for a crew's erratic work style. Certain aspects of how work is organised, such as structured short meetings for assessing the situation and forming a plan, can amplify compensation mechanisms. For John, resilience and compensation mechanisms are closely related.

One aspect we wished to discuss was flexibility and rigidity, and how they affect resilience in nuclear operations. We expected to obtain examples where rigidity, e.g. in role allocation, would stifle resilience. However, when we discussed this topic, some interesting insights emerged. John mentioned several examples where flexibility in role assignment led to problems. Specifically, he mentioned instances where an SS became too involved in the work of the RO and almost acted as an additional RO. At the same time, he neglected his responsibility as a SS to keep an overview of the situation and to direct the crew. This problem seemed to be more pronounced in SSs who had only recently moved to this role and were previously working as ROs. Thus, even though some degree of flexibility of roles appears useful for managing workload peaks and for enabling compensation mechanisms, it is equally important that all roles are filled at all times. In particular, that one member of the crew is responsible for keeping an overview of the situation and to step back from the actual running of the plant when necessary. Resilience in this sense may refer to the crew's ability to resist corrosion of roles and responsibilities during unusual, high-complexity situations.

One final aspect of resilience we discussed with John was the operators' ability to adapt their working environment and work practices to cope with everyday stressors and constraints. We suggested to him that resilience may be created by giving operators the freedom to generate local solutions to compensate for design deficiencies and to adapt to gradual changes in demands and context. He was very cautious about such bottom-up changes to work practices and the work environment. He stated that it is each operator's responsibility to bring any problems to the attention of plant management, and that any proposed solution should be subject to a review before being implemented. He did, however, concede that rising demands on operators, e.g. through increased power output, create additional pressures and may erode safety margins.

4 CONCLUSION

One of the challenges for Resilience Engineering is to move from the research domain into plants and organisations. One way of facilitating this transition is to discuss resilience with practitioners. Such exercises can help researchers understand where more work is needed to make the ideas and concepts behind RE more explicit, and how RE can be made relevant for everyday work throughout all levels of the organisation. Discussions with practitioners can also highlight practical constraints, limitations, costs and risks of RE.

The interview reported in this paper was a pilot exercise. More work is needed to understand resilience in practical terms. Nonetheless, interesting insights emerged from the interview. First and foremost, resilience was considered by our interview partner as an important approach for improving plant safety. In concrete terms, resilience was seen as an important factor for handling situations where strict adherence to emergency operating procedures would not guarantee a successful handling of the event. The ability to interpret and adapt emergency procedures to the operational context was considered an important resilience mechanisms. These skills may not be sufficiently trained in the simulator. RE was seen by the practitioner as an approach that can help promote this much-needed training on out-of-the-box thinking. On the other hand, there may be a limit to what can be achieved through flexibility and creativity. Additional complexities may be introduced when operators move too far away from the procedures. From his point of view, what creates resilience is thorough work practices in procedure use, combined with insight, foresight and reflection.

The interview was limited to operational aspects of resilience. We recognize that many of the characteristics of resilience, and the conditions for the emergence of resilience, may not be identified from such data. More information is needed, for example, on resilience mechanisms and manifestations at an organizational level, or in safety management practices. However, operational data is a useful starting point for exploring these other levels.

The 'resilience timeline' proved a useful approach for stimulating discussion and anchoring examples of resilience in a comprehensive representation. We plan to explore further applications of this representation, e.g. how it can be used for generating and analysing concrete Resilience Engineering solutions at a plant level.

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