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THE IMPACT OF NUCLEAR PHASE-OUT ON REACTOR SAFETY IN GERMANY

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Overview

After the Fukushima accident, Germany decided to phase-out nuclear energy by 2022. Eight nuclear power plants were shut down immediately in 2011, while nine others will follow a graduated phase-out scheme. Thus, it becomes obvious that the operation characteristics of the remaining plants will be changing, with more frequent load changes. These changing conditions raise the question, whether the nuclear phase-out has an impact on reactor safety. Investigations on the learning hypothesis give a detail insight in the development of systemic risk with growing experience.

Methods

The learning hypothesis is a physical model for human behavior when working in conjunction with a technological system. The hypothesis is based on the assumption that humans learn from events occurring due to mistakes. The failure rate of a homo technological system (HTS) λ therefore declines with growing experience ε when learning occurs proportional to the rate of learning k (Duffey, 2008):

$$\lambda(\varepsilon) = \lambda_m + \left(\lambda_0 - \lambda_m\right) e^{-k\left(\varepsilon - \varepsilon_0\right)} \qquad (1).$$

In the Duffey–Saull Method (DSM) approach, a set of rules for analyzing error data based on the learning hypothesis (Duffey, 2008), is used to determine past learning trends in reportable event data of German nuclear reactors. The knowledge acquisition obtained by the humans embedded in a homo technological system reflects its learning trends (Duffey, 2011). Thus, calculating Germany's cumulative knowledge stock *(KS)* of nuclear power is used for explanation of past and estimation of future German nuclear reactor event rates *(ER)*. The cumulative knowledge stock of energy technologies from 1974 to 2013 in IEA-countries *i* can be broken-down among seven groups *k* defined by IEA (2012). This comprises the depreciated cumulative knowledge stock of the last period $(1 - \delta) \times KS_{(t-1)}$ and the R&D expenditures in period *t-x*. So, the cumulative knowledge stock *(KS)* is as follows

$$KS_{(t)\,i,k} = (1 - \delta) \times KS_{(t-1)\,i,k} + RD_{(t-x)\,i,k} \qquad (2).$$

Klaassen et al. (2005) and Kobos et al. (2006) give a comprehensive overview of this methodology. In this study, *i* is limited to Germany and *k* to nuclear power. However, the dataset does not include private R&D expenditures yet, which play an important role; see Breyer et al. (2010). Wiesenthal et al. (2012) estimate that 44% of Europe's 1.25 billion EUR nuclear fission R&D investments in 2007 were financed by private companies, largely concentrated in France.

Results

Past reactor event rate development shows an overall decreasing trend that indicates learning efforts with growing experience (Fig. 1). However, it can be seen that learning is partly insufficient. Five phases of different rates of learning are determined.

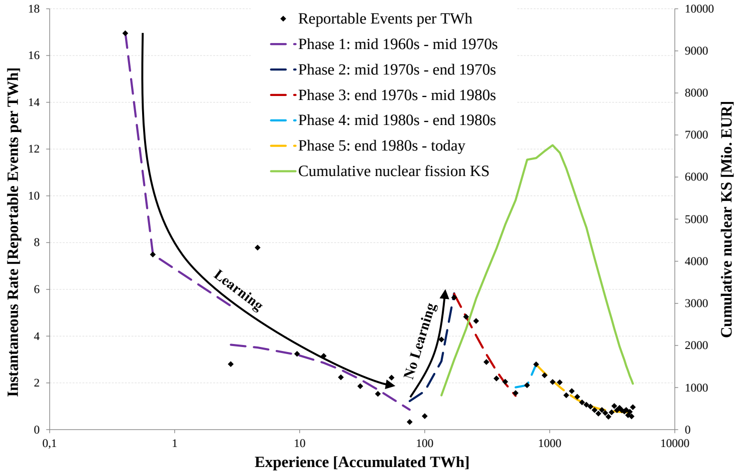

Fig. 1: *Instantaneous Rate of Reportable Events in German nuclear power plants and cumulative nuclear fission Knowledge Stock of Germany induced by R&D expenditures (mil. €; 2011 prices and exc. rates; knowledge depreciation 10%, time lag 3 yrs) [Own illustration based on BfS (2013), IEA (2012), VGB (2011)]*

According to Duffey et al. (2008) learning is significant for three phases (negative gradient) but insufficient for the others (positive gradient). Putting the first commercial reactors into operation at low diffusion rates offered good opportunities to learn from errors since the mid-1960s (Phase 1). Insufficient learning since early mid-1970s seems to result from five light water reactor units with a cumulated capacity of more than 5500 MW, which started commercial power operation, and the activation of the first German fast breeder research reactor (Phase 2). The large increase of the nuclear fission knowledge stock due to higher R&D expenditures since the late 1970s as a consequence of the oil prices shocks ensured an event rate reduction (Phase 3). With growing experience, less R&D expenditures were necessary to keep the event rate low, even though the tremendous decline of knowledge since 1988 seems to cause a lower learning rate (Phase 5). However, a remarkable decline of knowledge per event, indicating the reliability of controlling incidents and thus avoiding severe accidents, can be identified since 2000 (Fig. 2).

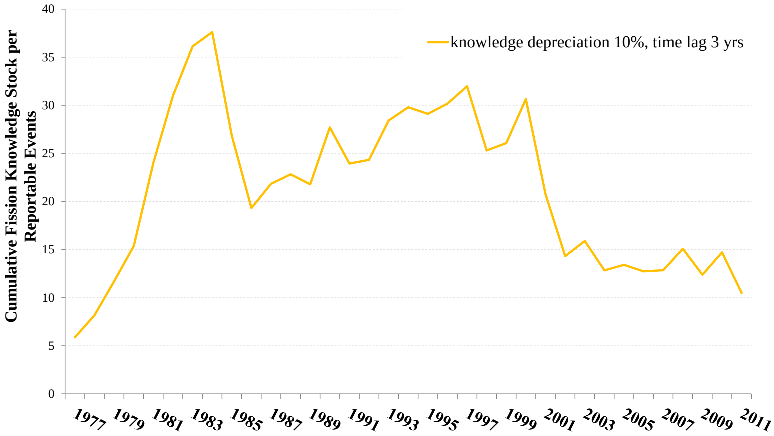

Fig. 2: *Cumulative nuclear fission Knowledge Stock of Germany induced by public R&D expenditures (mil. €; 2011 prices and exc. rates; knowledge depreciation 10%, time lag 3 yrs) per number of Reportable Events in Germany's nuclear power plants [Own illustration based on BfS (2013), IEA (2012)]*

Conclusions

As shown above, increasing knowledge and experience secure decreasing reactor event rates. Thus, rapid changes in the circumstances of nuclear power generation in Germany could have negative impacts on learning opportunities and thus may cause increasing failure rates. Particularly, the energy turnaround and the nuclear phase-out require load cycling operation and standstills of the remaining nuclear power plants, while there is little experience and knowledge in this kind of operation. Therefore, it can be assumed that the nuclear phase-out may affect future reactor event rates. This shall be subject to further research. Further, determining the mathematical relationship between knowledge and reactor event rates requires investigations on private R&D expenditures. Finally, due to the shortage of skilled professionals in nuclear technology in Germany and overaged workforce (Mez, 2011) the branch is in danger of a tremendous loss of knowledge in the next years with a potential impact on nuclear safety, which needs to be taken into account additionally.

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