Xenon pit duration in a pressurized water reactor

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1 Deviations from project proposal

2 Introduction to the problem

26 April 1986, 1:23 AM, Chernobyl's unit 4 core exploded, creating the worst nuclear disaster that ever happenend. One of the key factors that led to this accident is the lack of knowledge on the effects of Xenon, a radio-isotope with a large capture cross-section, which captures neutrons more frequently than uranium and effectively slows down the chain reaction.

Xenon comes principally from the decay of Iodine-135, Tellurium-135 and as a byproduct of the fission of Uranium. It then either decays into Cesium-135 or gets 'burned-up' by capturing a neutron and transmutating into Xenon-136. Both Cesium-135 and Xenon-136 have a much lower capture cross-section compared to Xenon-135.

When the neutron flux (positively related to the reactor power) is drastically lowered, the Xenon concentration rises because it is less burned-up by the neutron flux. This can cause the reactor to stall as Xenon builds up and if the concentration of Xenon is too high, the reactor operators cannot override its effect.

And so, as Chernobyl's unit 4 raised their control rods trying to compensate for a high xenon concentration and preventing a stall, they quickly experienced it's burn-up and a rapid augmentation of the neutron flux. Coupled to other effects, the reactor got out of hands and exploded.

Nowadays, Xenon effects are taken seriously and must be accounted in the design of every reactor. It is important to ensure a high enough reactivity margin (available control over the chain reaction) after each power reduction, and eventually shutdown the reactor for a long enough period of time if Xenon effects are too important.

For example, this is very important for reactor and grid operators to know when the plant will be back up after an outage. Or for planning a slow enough power reduction. Or even try to shorten the Xenon pit duration (timespan over which we observe this high concentration) to restart sooner after a short maintenance.

Definition of project scope

Processes to include

The basic process of Xenon production can be modelled as follows.

Processes to exclude

With this modelling, we exclude some processes by making the educated guess that they only play a minor role.

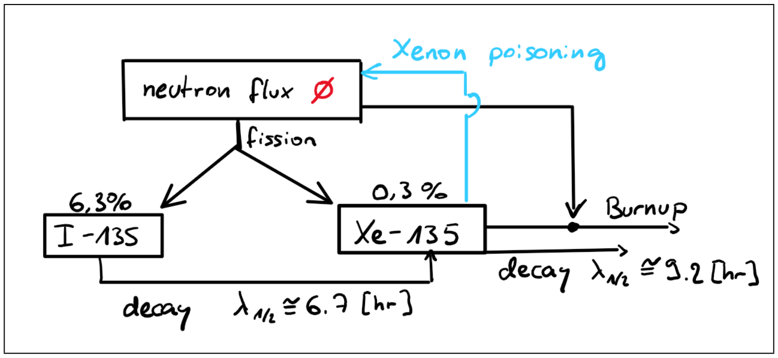

Figure 1: Schematic representation of the Xenon system

- **Effect of the other reactor poisons**
  - Samarium 149
    It can be considered a stable isotope, that will not decay. Due to its much lower capture cross-section (reflects the likelihood of a neutron capture).
  - Other accumulating fission products
    We will also neglect them as their effect is more long-term related.
- **Spatial variations**
  We consider a point reactor (no dimension) to make the computations easier and avoid the complexity of finite elements methods.
- **Decay of Tellurium-135**
  Iodine-135 comes from this fission product who's halftime is of 19 seconds. As our time resolution will be much larger (hours), we will assume that the production of Tellurium immediately results in Iodine. This is counted in the rate of production of Iodine-135.
- **Burnup of Iodine-135 by the reactor**
  It can be neglected due to its small microscopic absoption section (Module 3D, 2021).
- **Changes in neutron flux**
  We assume ϕ is perfectly controled and remains constant at the desired values, we will first consider instantaneous changes and, if we have time, allow for other profiles of neutron flux transients.

Scenarios considered

3 Approach used

Describe the approach taken to solve the problem. Include relevant mathematical relationships, models, algorithms, data, etc. Is the model mechanistic or empirical (e.g., conservation equation, or a parametrized relationship between input and output)? Do you use the program for forecasting/prediction, or inference (e.g., understand model parameters)?

Provide citation to literature where appropriate, particularly to compare your approach to existing work (whether it is similar or different).

4 Results

Describe the results. Give your assessment of whether they are reasonable - and how do you determine this?

5 Conclusion and outlook

Summarize the approach taken and the answer to the question set out in the problem statement. Describe limitations of the work (outlook) and how it could be improved.

6 References