Modelling cross-talk in Cherenkov light production of irradiated nuclear fuel assemblies in wet storage

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Uppsala University, 11 October 2017
Outline

1. The Digital Cherenkov Viewing Device (DCVD).
2. The near-neighbour effect (cross-talk) in quantitative measurements.
3. Simulations of the near-neighbour effect.
5. Experimental validation of simulations.
6. Conclusions.
1. The Digital Cherenkov Viewing Device

- Portable system.
- Easy setup
- Non-intrusive
- Quick measurements
- No fuel movement required

Image courtesy of Channel Systems
2. The near-neighbour effect in quantitative measurements.

- A 50% partial defect is expected to reduce the measured intensity by at least 30%.

- Partial defect verification compares measured and expected Cherenkov intensities.

- Good predictions of the measured intensity is required for accurate assessment.
2. The near-neighbour effect in quantitative measurements.

With fuels stored closely, radiation from one assembly can enter a neighbour to create Cherenkov light.

If not compensated for, this introduces systematic errors in the current analysis.

The result may be that normal fuels is flagged as an outlier and that partial defects are not accurately detected.

Image courtesy of Clab.
3. Simulations of the near-neighbour effect.

The near-neighbour effect was studied through Monte-Carlo simulations.

A BWR 8x8 and a PWR 17x17 fuel was simulated, for a close packed (a few mm of steel separates the fuels) and for sparsely packed (60 resp. 100 mm of water separates fuels).

Simulations were done for various gamma energies, allowing combination with ORIGEN-calculated spectra.
3. Simulations of the near-neighbour effect.

Simulations results for tight-packed BWR fuels

Closest neighbours (N1 and N2) most strongly affected by the near-neighbour effect.

The intensity at the N2 position is affected by the presence or absence of N1 neighbours.
3. Simulations of the near-neighbour effect.

Simulations results for tight-packed BWR fuels

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The intensity at the N2 position is affected by the presence or absence of N1 neighbours

<table>
<thead>
<tr>
<th>Neighbour</th>
<th>Intensity</th>
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<tbody>
<tr>
<td>N1</td>
<td>0.4 – 0.9%</td>
</tr>
<tr>
<td>N2</td>
<td>2.8%</td>
</tr>
<tr>
<td>Main</td>
<td>100%</td>
</tr>
</tbody>
</table>
3. Simulations of the near-neighbour effect.

Simulations results for tight-packed BWR fuels

The N3 position only needs to be considered if the N1 position is empty.

N4 and N5 are low enough that they can be neglected in any realistic scenario.
3. Simulations of the near-neighbour effect.

For close-packed BWR fuels of the same intensity, up to 14% of the measured intensity may be due to its neighbours. For PWR fuels, up to 12% may be due to its neighbours.

The near-neighbour intensity is affected by:
- Fuel type
- Gamma spectrum (burnup/cooling time)
- Fuel spacing
- Storage rack material
4. Proposed method for compensating for the near-neighbour effect

It is possible to simulate and parameterize the near-neighbour contribution as a function of:

- Gamma-ray energy. Allows estimating the near-neighbour effect for any gamma-ray spectrum, as calculated by e.g. ORIGEN.

- Fuel type. Some fuel types may behave similarly, e.g. different BWR fuels of comparable size.

- Fuel spacing. Can differ from facility to facility.
4. Proposed method for compensating for the near-neighbour effect

It is possible to simulate and parameterize it as a function of:

- Presence or absence of N1
  Required for accurate N2 and N3 assessments
- Amount of storage rack material
  Differ from facility to facility

With such a parameterization, the near-neighbour intensity can be calculated quickly on modest hardware, and therefore compensated for.
5. Simulations of the near-neighbour effect.

In 2012 a dedicated measurement campaign was made at Forsmark NPP, which has also been simulated. The measurements featured one fresh assembly and one irradiated one being moved to the neighbouring positions.

<table>
<thead>
<tr>
<th></th>
<th>Simulated</th>
<th>Measured</th>
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<tbody>
<tr>
<td>N1</td>
<td>1.16 ± 0.02%</td>
<td>1.25%</td>
</tr>
<tr>
<td>N2</td>
<td>0.43 ± 0.01%</td>
<td>0.36%</td>
</tr>
<tr>
<td>N3</td>
<td>0.18 ± 0.01%</td>
<td>0.12%</td>
</tr>
</tbody>
</table>

Good agreement, especially for N1, despite some differences between measured and simulated situation.
5. Simulations of the near-neighbour effect.

A measurement campaign was also carried out at a PWR, for short-cooled fuels.

Standard deviation between predictions and measurements:

<table>
<thead>
<tr>
<th>No NN compensation</th>
<th>With NN compensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1 %</td>
<td>7.8 %</td>
</tr>
</tbody>
</table>

Due to the storage situation, the near-neighbour effect was low. An average of 1.5 % and a maximum of 6 % of the Cherenkov light was caused by neighbours.
6. Conclusions

The near-neighbour effect introduces systematic errors in the measurements.

Compensating for it requires taking into account fuel type, gamma spectrum and storage situation.

Through simulations, the near-neighbour effect may be parameterized, allowing for quick estimates of its intensity during an inspection.

Making predictions including the near-neighbour effect improves the situation, but verification against situations with a stronger near-neighbour intensity is required.
Thank you for your attention!

Questions?

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