AREVA

forward-looking energy

TSP clogging and secondary side deposit: performance evaluation using simulation and site results

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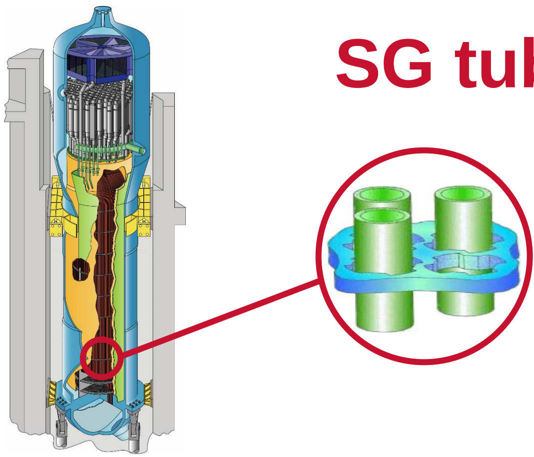
AREVA NDE Solutions

Summary

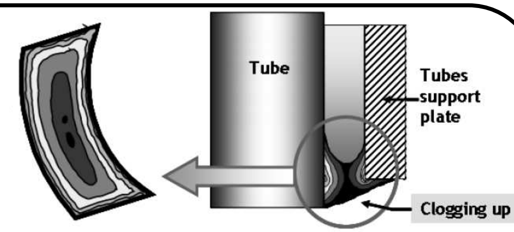
- Introduction
- Secondary side deposit
- Clogging of TSP
- Conclusion

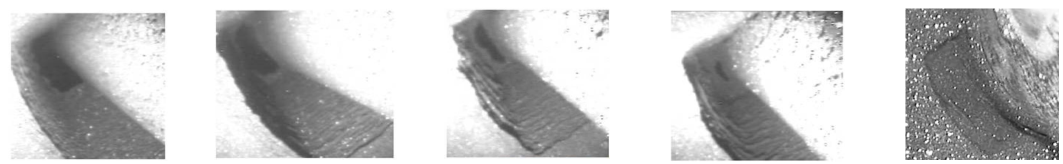
Introduction
SG tubes deposit and TSP clogging



▶ TSP clogging

- Mainly magnetite
- Located on down side of TSP
- Diaphragm shape





▶ Secondary side tube deposit

- Mainly magnetite
- Adhering to the wall of the tubes

▶ Clogging affects

- **Performance: secondary water flow rate is reduced**
- **Safety[1]:**
  - possible secondary water-steam flow instability which induces stresses on the tubes then risk of fatigue cracking
  - excessive stress on tie rods and TSP
  - stability of water level in secondary
  - mass of water in the secondary is reduced

▶ Deposit affects

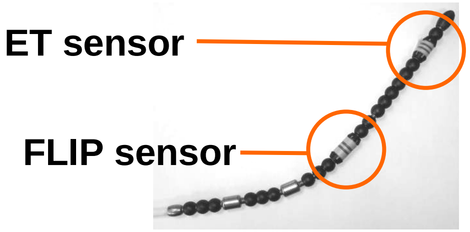
- **Performance: reduces heat transfer**
- **Safety: magnetic deposit interacts with eddy current techniques used to examine the tubes**

» **Chemical cleaning to remove clogging and deposit material**

[1] H. Bodineau and T. Sollier, "Tube support plate clogging of french PWR steam generators", Eurosafe, 2008

Introduction
Industrial solution

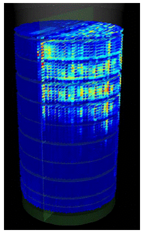
- **Technical objectives**
  - **Monitor deposit level and progress speed**
  - **Provide data to define chemical cleaning parameters**
  - **Verify chemical cleaning efficiency**

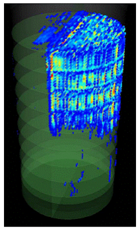


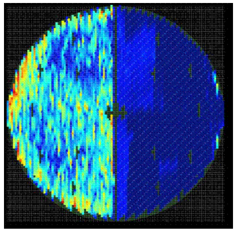
- **Development of a specific combined probe:**
  - **eddy current (ET) axial sensor to measure free span deposit and usual tube examination**
  - **FLIP sensor to measure TSP clogging**

- **Signal processing and visualization with Aida G3 software**
  - **Automatic analysis**
    - Signal to clogging/deposit transfer function
  - **Graphical representation**
    - 2D/3D view of clogging/deposit mapping

AIDA



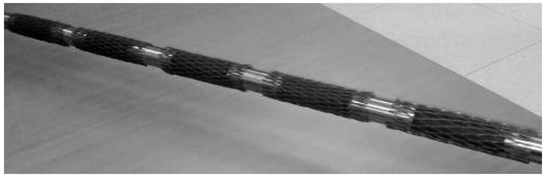




Inspections of usual tube examination (bobbin), free span deposit evaluation and TSP clogging at the same time

- **Performance evaluation required, 3 sources of signals:**
  - **Mock-up measurements**
  - **Modeling and simulation**
  - **Site results**

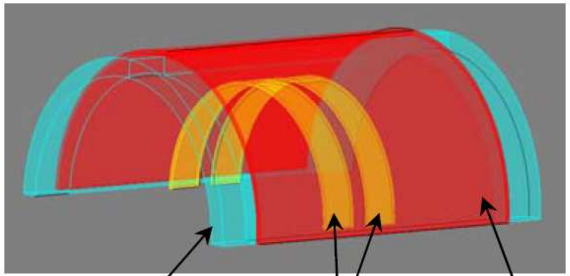
Secondary side deposit
Technical approach

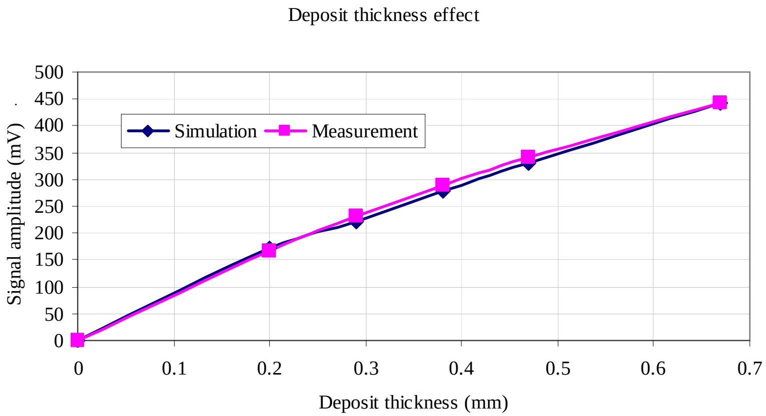


- **Deposit reference tubes manufacturing**
  - **1 tube with varying thickness of deposit**
  - **1 tube with varying composition (Fe_3O_4 mass percentage)**
- **Theoretical formulation of the magnetic permeability of the deposit**
  - **Relative permeability μ_r as an analytic function of the Fe_3O_4 rate**
- **FE simulation, reference tubes measurement versus simulation results**
  - **Model validation**
  - **Magnetic permeability theoretical formulation validation**
- **Performance evaluation**
  - **Identification of influent parameters (geometry and material properties)**
  - **Parametric study**
- **On-site implementation**

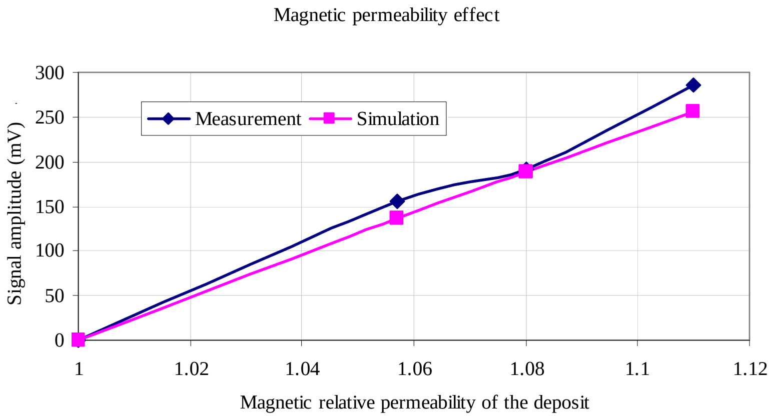
Secondary side deposit
Model validation

- **FE modeling using Flux3D**
- **Model validation**
  - **Cross verification between theoretical formulation, simulation and experimental results**





Simulation model validation vs experimental results (50% magnetite)

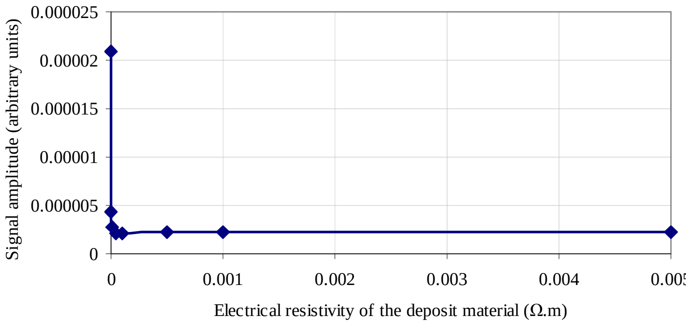


Relative permeability analytic formula validation vs correlation modelling/experimental results (0.23mm deposit)

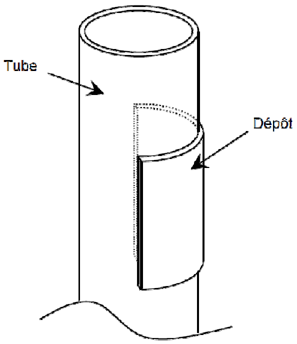
Calculation of the relative permeability for any deposit composition

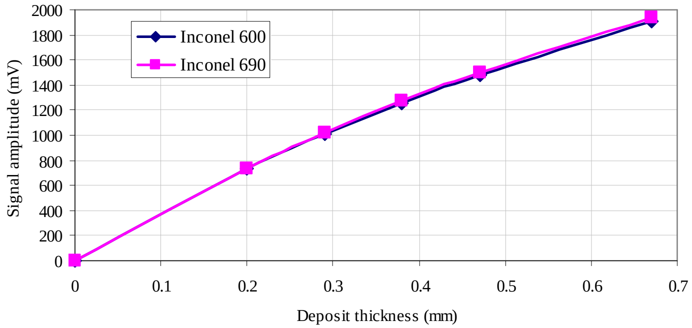
Secondary side deposit
Parametric study

- **Electrical resistivity**
  - **No influence for $\rho > 10^{-4}$ Ω.m**



- **Tube material (Inconel 600 and Inconel 690)**
  - **Difference of 1.3% in amplitude and 2.2° in phase ➔ Limitation of the number of reference tubes**

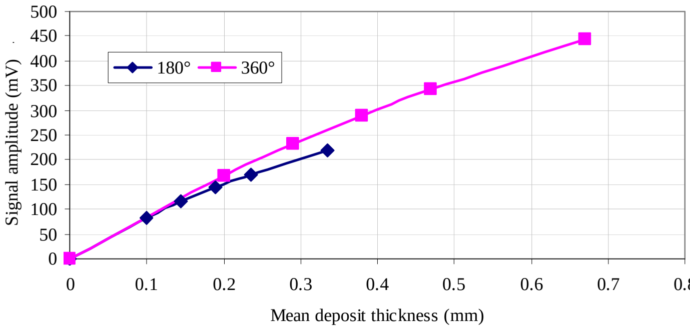




- **Deposit configuration**
  - **23% under estimate of deposit thickness for 0.67mm thickness when 180° deposit instead of 360° deposit**

- **Deposit density and composition**
  - **Variation of the deposit relative permeability from 1.37 to 1.41 for Fe_3O_4 mass percentage from 88% to 95%**

- **Copper**
  - **Important effect on the signal**
  - **Necessity to manufacture reference tube with representative composition**



Secondary side deposit
On-site implementation

- **Since 2009, 3 SG secondary side deposit analysis**
  - **3/4" and 7/8" tubes**
  - **25% or 50% of the tube bundle**
  - **Three more steam generators to be inspected**
- **Results**

<table>
<tr><th></th><th>SG 1</th><th>SG 2</th><th>SG 3</th></tr>
<tr><td>AREVA Deposit mapping</td>
<td>
<table>
<tr><th colspan="2">Partie libre</th><th>Nombre de segments</th><th>Branche chaude (kg)</th><th>Branche froide (kg)</th></tr>
<tr><td>PT</td><td>PE1</td><td>12</td><td>34.4</td><td>25.4</td></tr>
<tr><td>PE1</td><td>PE2</td><td>14</td><td>39.5</td><td>17.1</td></tr>
<tr><td>PE2</td><td>PE3</td><td>14</td><td>116.3</td><td>5.5</td></tr>
<tr><td>PE3</td><td>PE4</td><td>14</td><td>158.8</td><td>11.3</td></tr>
<tr><td>PE4</td><td>PE5</td><td>14</td><td>152.8</td><td>8.7</td></tr>
<tr><td>PE5</td><td>PE6</td><td>14</td><td>133.1</td><td>2.7</td></tr>
<tr><td>PE6</td><td>PE7</td><td>14</td><td>126.6</td><td>6.6</td></tr>
<tr><td>PE7</td><td>PE8</td><td>14</td><td>109.0</td><td>25.7</td></tr>
<tr><td>PE8</td><td>PE9</td><td>14</td><td>68.2</td><td>62.0</td></tr>
<tr><td colspan="3">Total par branche (en kg)</td><td>939</td><td>165</td></tr>
<tr><td colspan="3">Total (en kg)</td><td colspan="2">1104</td></tr>
</table>
</td>
<td>
<table>
<tr><th colspan="2">Partie libre</th><th>Nombre de segments</th><th>Branche chaude (kg)</th><th>Branche froide (kg)</th></tr>
<tr><td>PT</td><td>PE1</td><td>12</td><td>7.7</td><td>1.5</td></tr>
<tr><td>PE1</td><td>PE2</td><td>14</td><td>1.0</td><td>1.2</td></tr>
<tr><td>PE2</td><td>PE3</td><td>14</td><td>1.0</td><td>0.1</td></tr>
<tr><td>PE3</td><td>PE4</td><td>14</td><td>1.5</td><td>0.4</td></tr>
<tr><td>PE4</td><td>PE5</td><td>14</td><td>5.8</td><td>0.5</td></tr>
<tr><td>PE5</td><td>PE6</td><td>14</td><td>58.6</td><td>0.7</td></tr>
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<tr><td>PE8</td><td>PE9</td><td>14</td><td>149.9</td><td>5.7</td></tr>
<tr><td colspan="3">Total par branche (kg)</td><td>564.0</td><td>12.4</td></tr>
<tr><td colspan="3">Total parties droites (kg)</td><td colspan="2">576</td></tr>
<tr><td colspan="3">Estimation cintre (kg)</td><td colspan="2">157</td></tr>
<tr><td colspan="3">Total tubes (kg)</td><td colspan="2">733</td></tr>
</table>
</td>
<td>
<table>
<tr><th colspan="2">Partie libre</th><th>Nombre de segments</th><th>Branche chaude (kg)</th><th>Branche froide (kg)</th></tr>
<tr><td>PT</td><td>PE1</td><td>12</td><td>3.8</td><td>6.1</td></tr>
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<tr><td>PE3</td><td>PE4</td><td>14</td><td>1.9</td><td>5.9</td></tr>
<tr><td>PE4</td><td>PE5</td><td>14</td><td>6.5</td><td>7.4</td></tr>
<tr><td>PE5</td><td>PE6</td><td>14</td><td>40.6</td><td>8.3</td></tr>
<tr><td>PE6</td><td>PE7</td><td>14</td><td>99.8</td><td>9.5</td></tr>
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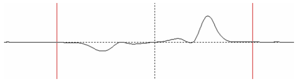
<tr><td colspan="3">Total par branche (kg)</td><td>363.6</td><td>73.3</td></tr>
<tr><td colspan="3">Total parties droites (kg)</td><td colspan="2">436.9</td></tr>
<tr><td colspan="3">Estimation cintre (kg)</td><td colspan="2">76.5</td></tr>
<tr><td colspan="3">Total tubes (kg)</td><td colspan="2">513.4</td></tr>
</table>
</td></tr>
<tr><td>EDF reference</td><td>1250kg</td><td>1000kg (±30%)</td><td>500kg (±40%)</td></tr>
</table>

Good correlation between AREVA deposit mapping and EDF reference (mass balance method)

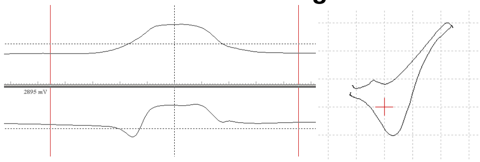
TSP clogging
Technical approach

- **Performance evaluation using finite element simulation**
  - **Step 1: validation of SAX and FLIP models**
    - EDF Clogging mock-ups: 0 - 25 - 50 - 75 -100% clogging rate
    - Finite element simulation
    - Simulated versus experimental signals

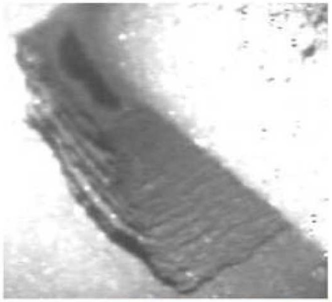
FLIP signal



SAX signal



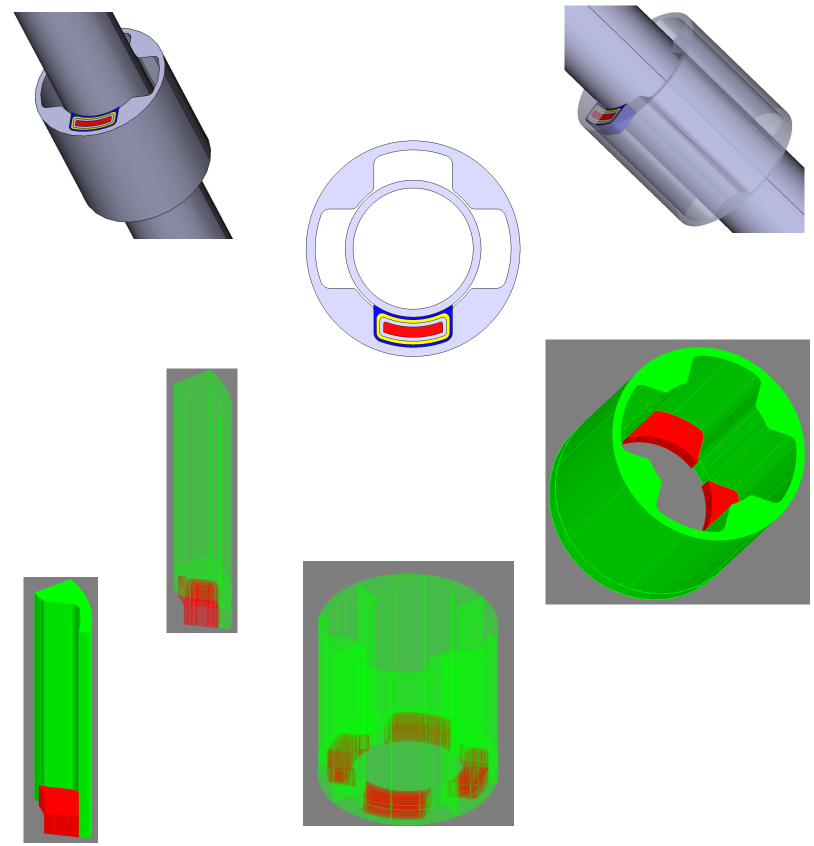
  - **Step 2: use models to determine influent parameters of real deposit/clogging configuration**
    - Real deposit/clogging configuration parameters
    - Finite element simulation with variable parameters, determining influent parameters
    - Comparison to site measurements to find correct parameters value



  - **Step 3: predict signal from specific deposit/clogging configuration**
  - **Conclusion on FLIP and SAX probe performances**

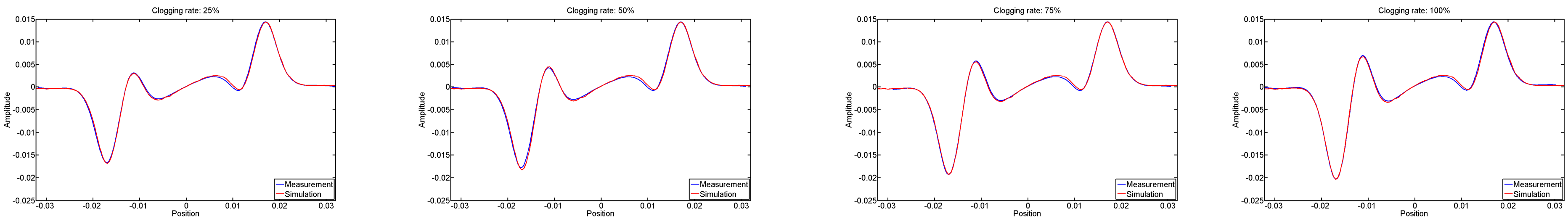
TSP clogging
FLIP model validation

- **Mock-up model from CAD**
  - **Limited plate radius**
  - **4 volumes for the different clogging rates**
- **Mock-up model for FE simulation**
  - **No tube because no effect on probe signal**
  - **1/8 geometry + symmetry/periodic conditions**
- **Unknown material properties**
  - **TSP magnetic permeability**
  - **Clogging material magnetic permeability**
- **2D parametric study fo validation / material properties identification**



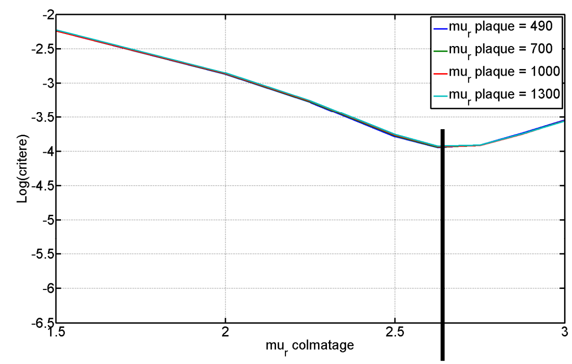
TSP clogging
FLIP model validation

- **Measured and simulated probe signals**

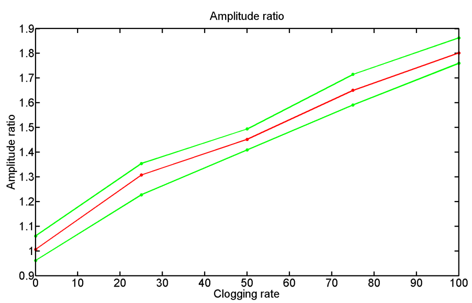


  - **Good agreement but …**
  - **… multiple 'visible' solutions…**
  - **… anyway model is validated.**

Best objective solution:



- **Transfer function for operational use:**



But depends on material properties

Conclusion

- **Operational solution for tube deposit and TSP clogging with positive results**

- **Deposit and clogging probes performance study in progress**
  - **FE modeling vs mock-up**
  - **Validation of FE models**
  - **Determination of influent parameters**
  - **Fine tuning of transfer functions**

» **Update transfer functions used for deposit/clogging mapping in AIDA software**

- **Perspective: comparison with real site deposit/clogging mass measurements from Sherlock program**

Note