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European Tools and
Methodologies for an
efficient ageing management
of nuclear power plant Cables



Ultrasound as a non-destructive tool to estimate polymer embrittlement

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Content

1. Background and the research question
2. Specimens and ageing process
3. Measurements and Results
4. Conclusions

Nuclear power and material degradation

- ▶ Nuclear power is the most important source of low-carbon electricity in the EU
 - 25 % of all electricity
 - 50 % of low-carbon electricity
- ▶ European nuclear reactor fleet is growing old
 - Most of the reactors were built in the 1970s and 1980s
- ▶ We must understand material degradation phenomena for safe long-term operation of nuclear power plants

Cables in a nuclear power plant

- ▶ In a single NPP, there is approximately 1 500 km of electric cables
 - Some of these cables are exposed to gamma irradiation
- ▶ Gamma irradiation brittles polymers such as polyethylene used as insulator in cables
- ▶ Planned life-time of a NPP is 60–80 year
- ▶ A low-cost non-destructive estimation method for the embrittlement is required.

Our research question

- ▶ While polymers brittle, they usually becomes harder
- ▶ Hardening increases Young's modulus, therefore it can be monitored with sound velocity

$$v = \sqrt{\frac{E}{\rho} \frac{1 - \nu}{(1 + \nu)(1 - 2\nu)}}$$

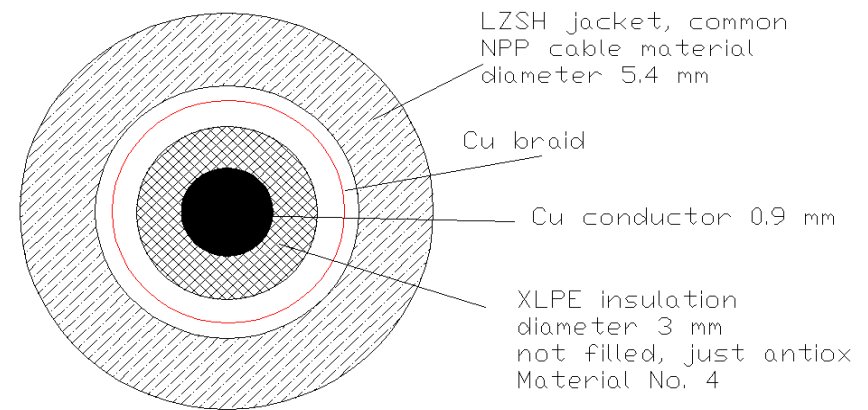
Does the Young's modulus increase enough to affect sound velocity?

Specimens and ageing process



Specimens

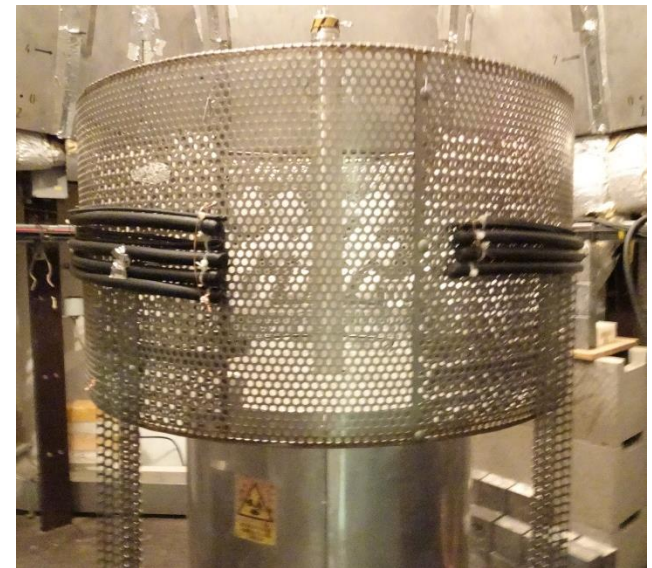
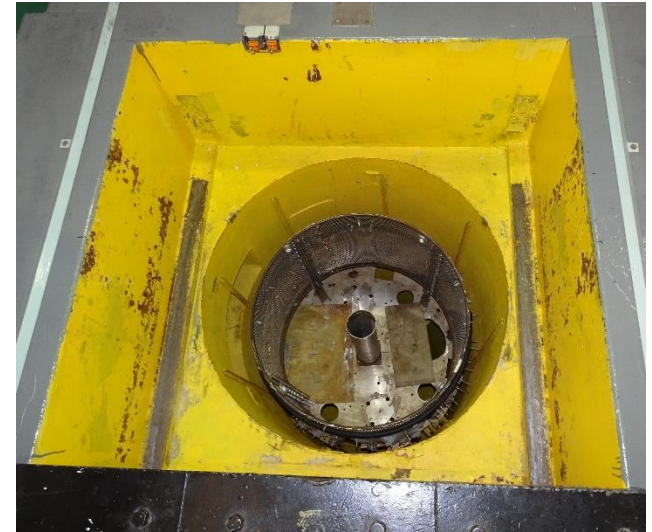
- ▶ Commercially available coaxial cable was used
- ▶ Industrial grade XLPE (with alumina trihydrate and antioxidants)



Size for connectors N 50 Ω m
e.g. Rosenberger 53S114-006N5
dimensions as RG400, RG223

Radiation ageing in UJV

- ▶ High dose rate radiation ageing:
 - Average temperature 20 °C
 - Dose rate 400 Gy/h
 - Total doses of withdrawals: 67 kGy / 134 kGy / 202 kGy / 269 kGy / 336 kGy
- ▶ Medium dose rate radiation ageing:
 - Average temperature 46.6 °C
 - Dose rate 59.4 Gy/h
 - Total doses of withdrawals: 51.2 kGy / 110 kGy / 168 kGy / 227 kGy / 286 kGy



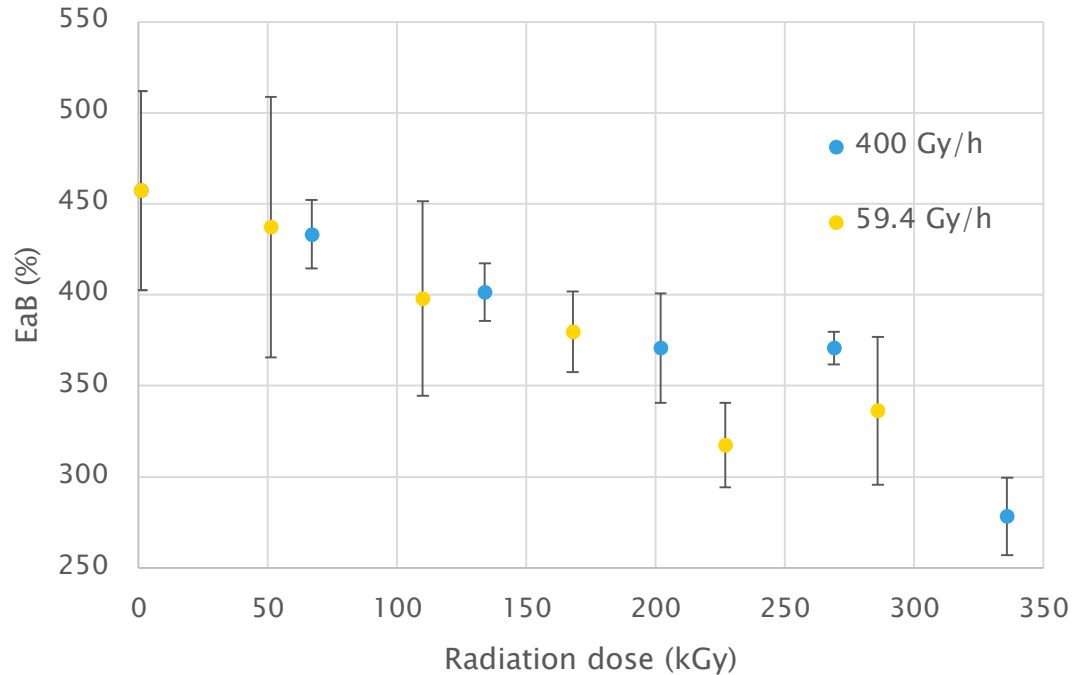
Measurements and results



Tensile properties measurement



Instron 3366, software Bluehill 3
Tubes: without extensometer,
 50 mm/min, L= 30 mm, 20
 pts/s, smooth steel grips
 12.5(h)x38(w)mm



Initial properties



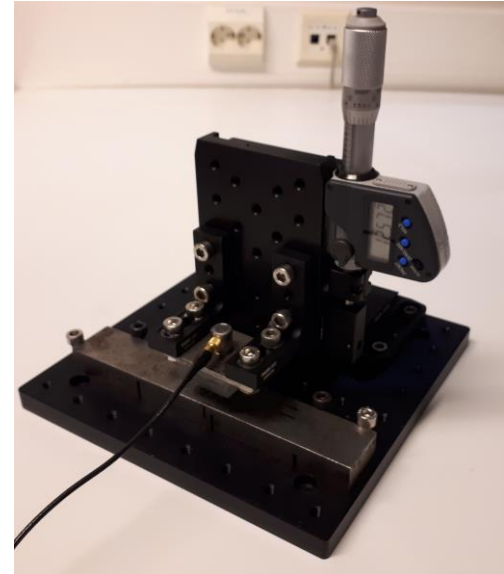
400 Gy/h - 336 kGy



59.4 Gy/h - 286 kGy

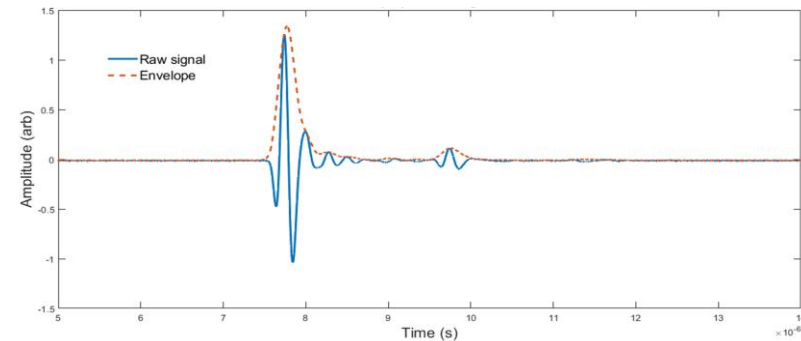
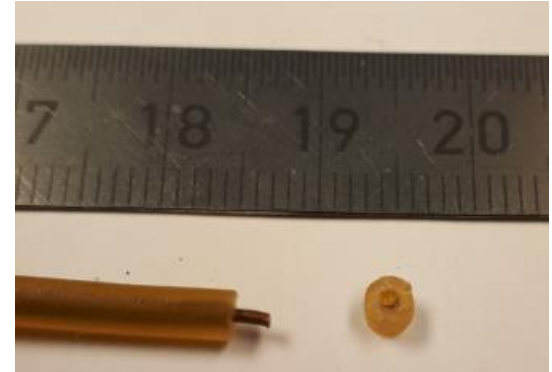
Sound velocity setup

- ▶ Ultrasound transducer with 10 mm delay line (5 MHz, GE)
 - ▶ Digital micrometer (Mitutoyo)
 - ▶ Panametric Model 5077PR pulser-receiver
 - ▶ Tektronix TDS 5034 B oscilloscope (sampling rate 5 Gs/s)
 - ▶ Off-the-shelf fine mechanics from Thorlab
-
- ▶ The distance between the transducer and steel back plate is freely adjustable.

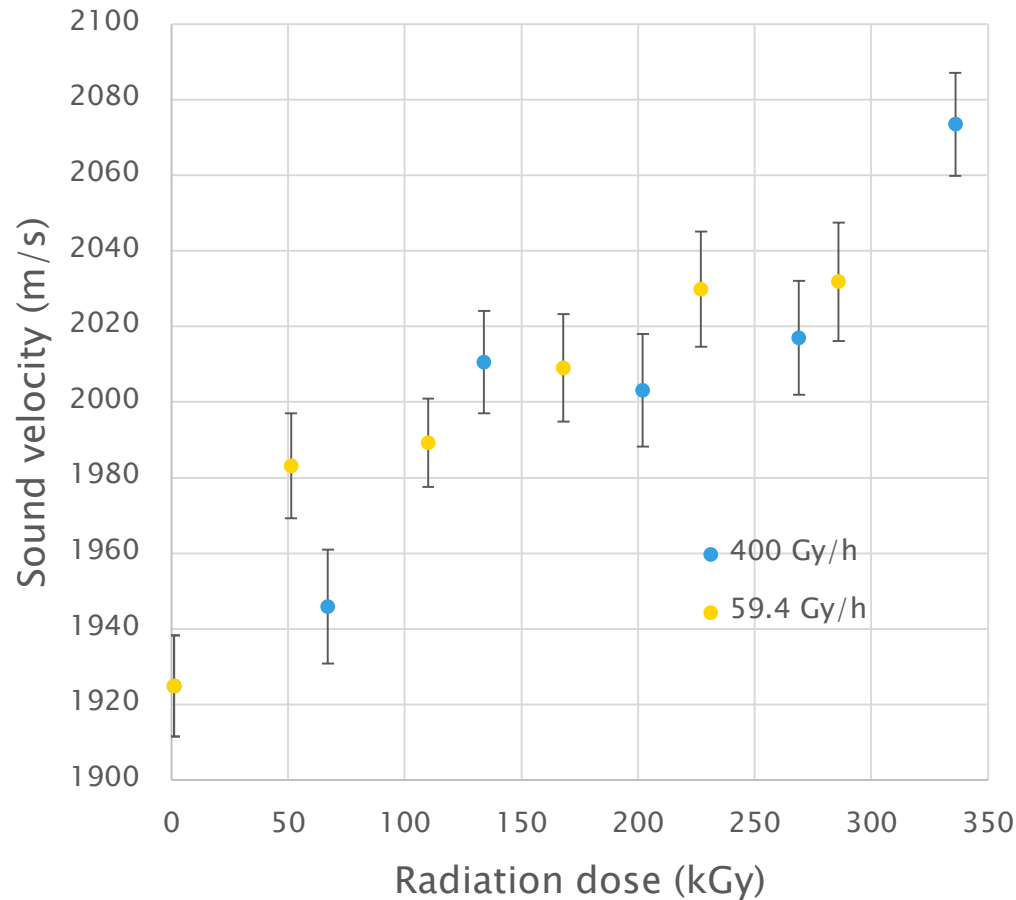


Sound velocity measurement

- ▶ A short (~2 mm) cylindrical piece of the insulator with a scalpel
- ▶ The specimen was placed on the measurement setup in standing position
 - Honey was used as a contact agent
- ▶ The sound signals were recorded and specimen length measured simultaneously
- ▶ Sound velocity is $v = \frac{2l}{t}$

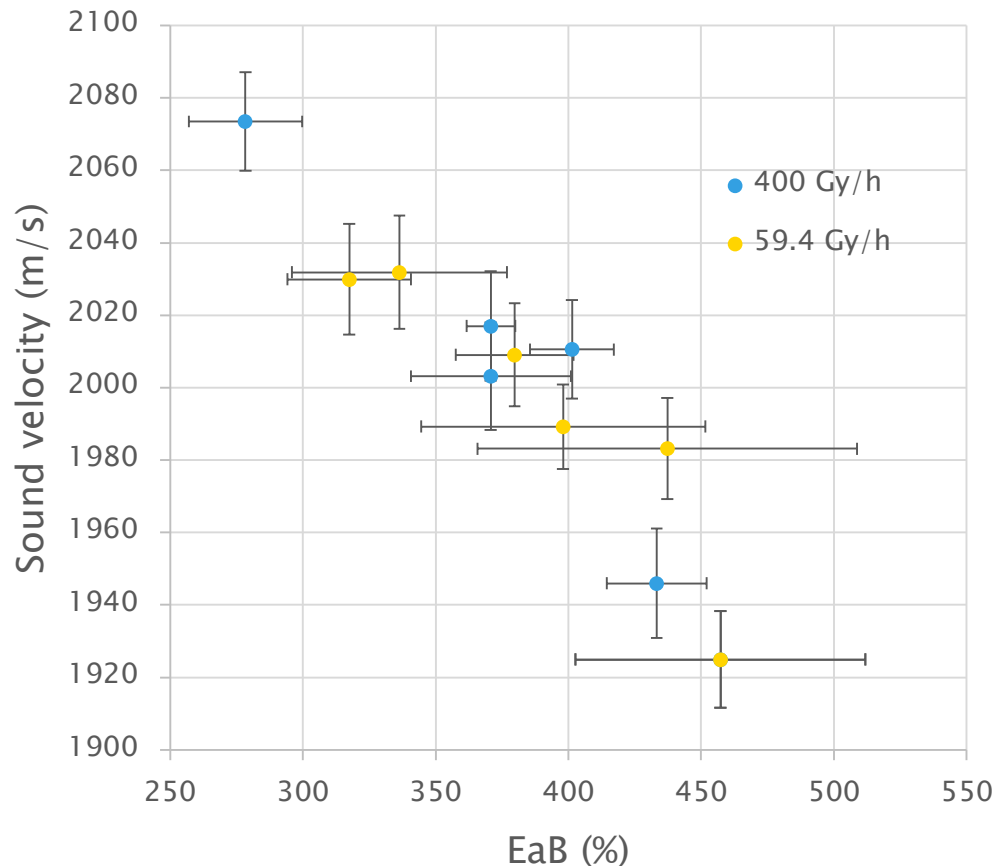


Radiation dose and sound velocity



- Sound velocity clearly increases while material is irradiated
- Dose rate seems to have no effect on the sound velocity

Sound velocity and EaB



- Clear negative correlation between sound velocity and EaB
- No clear effect caused by dose rate

Conclusions

- ▶ Polyethylene brittles while it is exposed to gamma radiation
 - The dose rate seems to have no effect.
- ▶ Irradiation increases Young's modulus
 - This increases the sound velocity
- ▶ There is a clear correlation between the sound velocity and embrittlement

Ultrasound can be used as a low-cost method to estimate embrittlement non-destructively

Thank you!

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