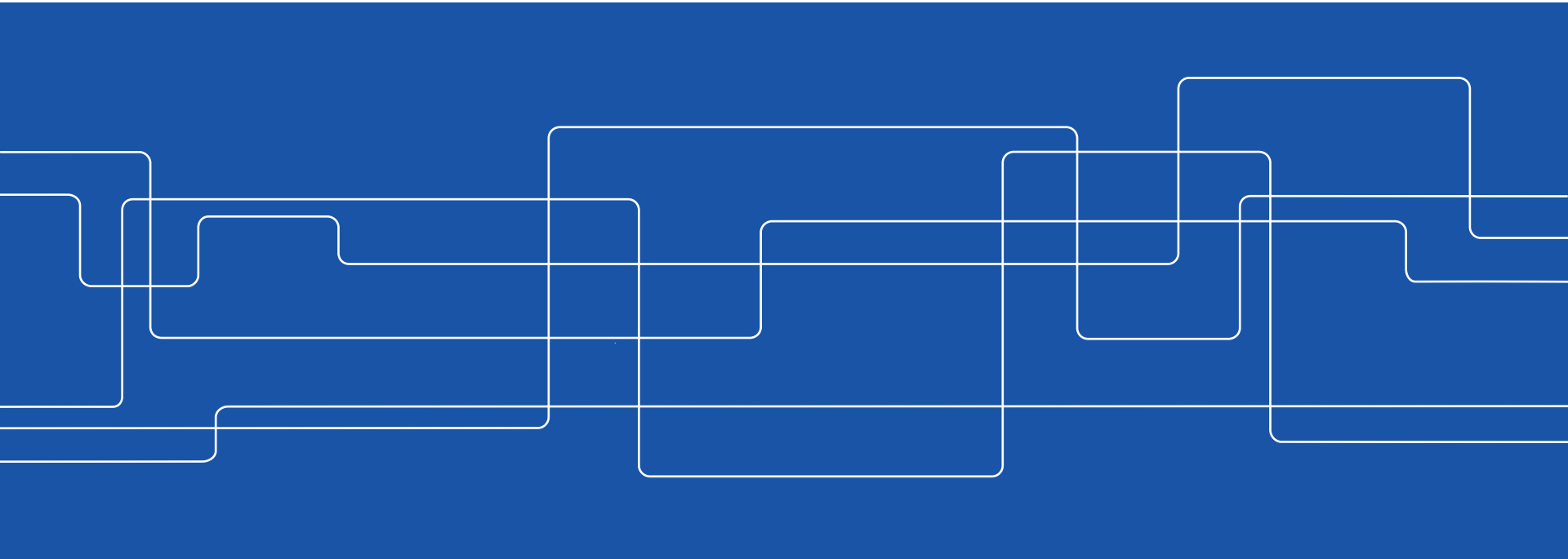




ROYAL INSTITUTE  
OF TECHNOLOGY

# Influence of ageing on polymeric components used in Nuclear power plants

Dr Payam Pourmand  
[pourmand@kth.se](mailto:pourmand@kth.se)



## Polymers in nuclear power plants

- Commonly found in cables, O-rings, seals, gaskets and hoses



- 1100 km of cable in Reactor O2 in Oskarshamn, Sweden.

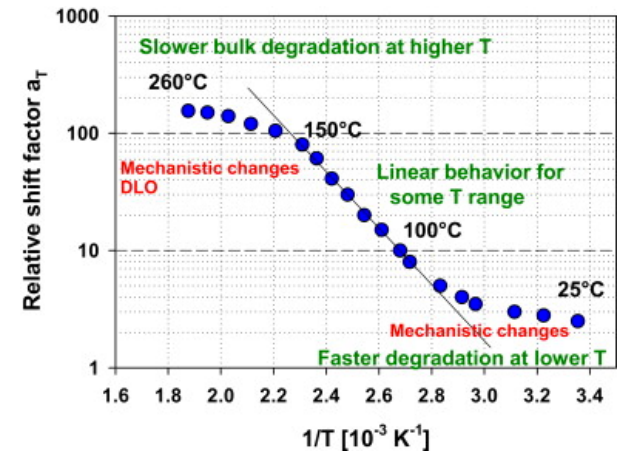
# Accelerated ageing



Source: <http://www.mctbrattberg.se/Products/InsertBlocks.aspx>

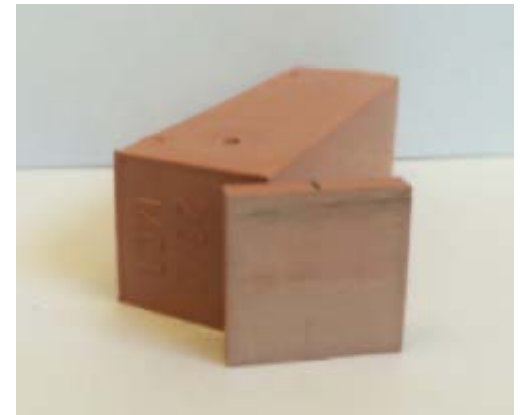
- Accelerated ageing is based on the assumption that the degradation mechanism is the same both at “operating conditions” e.g. room temperature and at high temperatures.

But is that always right ?



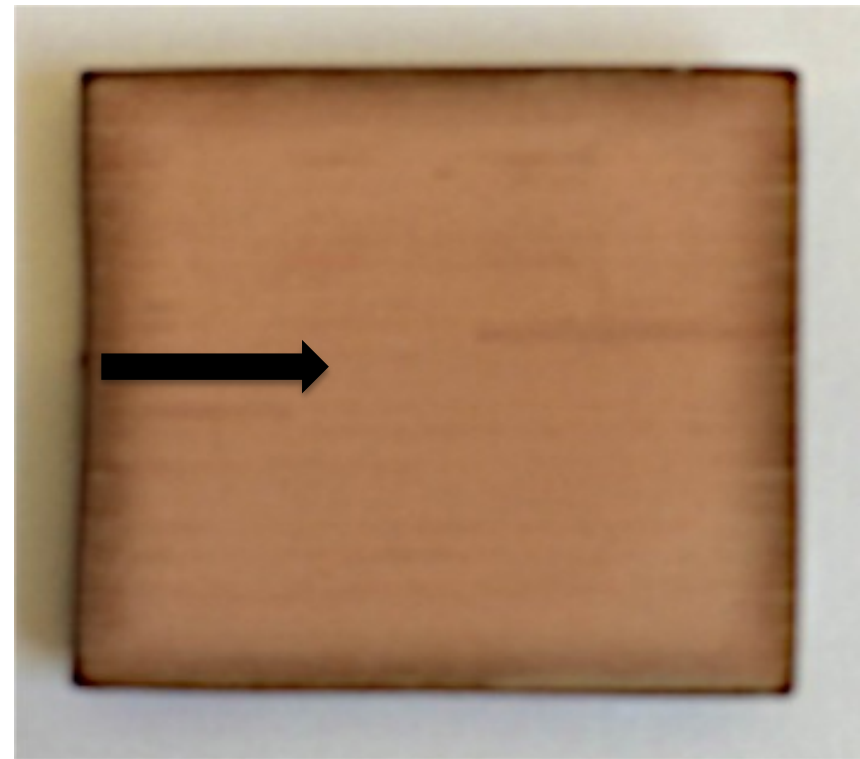
Celina, Mathew C. "Review of polymer oxidation and its relationship with materials performance and lifetime prediction." *Polymer Degradation and Stability* 98.12 (2013): 2419-2429.

# Profiling methods



## Some examples

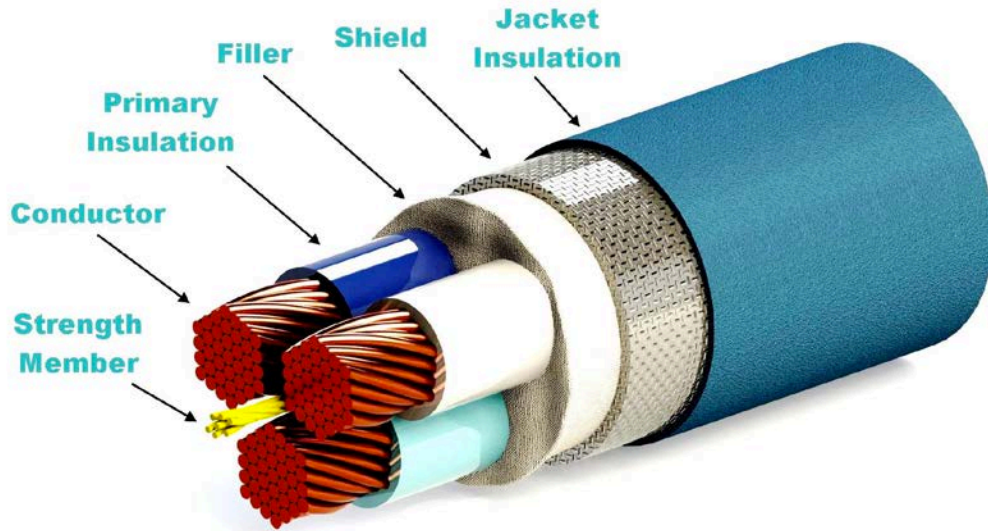
- Indenter modulus
- IR-profiling ( carbonyl index)
- Portable NMR
- Extraction profiles



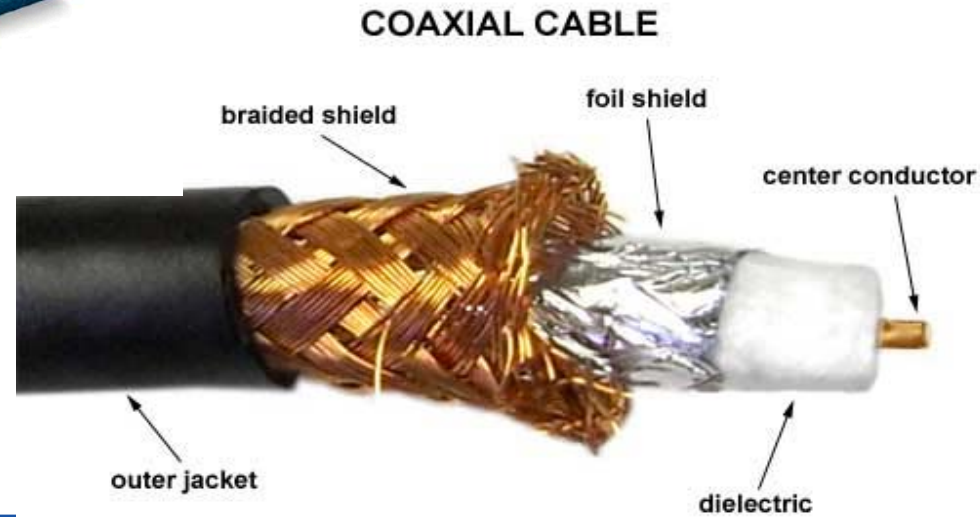
Brattberg seals aged at 170C for 100 h

# How about cables ?

- Large variety of cables – complex structures!



Insulation & fillers are of interest!





## Traditional testing methods

- Mechanical assessments: Tensile testing
  - Strain at break, Young's modulus
- Indenter modulus (Surface hardness)
- Swelling or thermo-gravimetry....works for some polymers.
- LIRA – EU project (online monitoring system).

All require sample removal and preparation!

## Portable NMR (Low-field NMR)

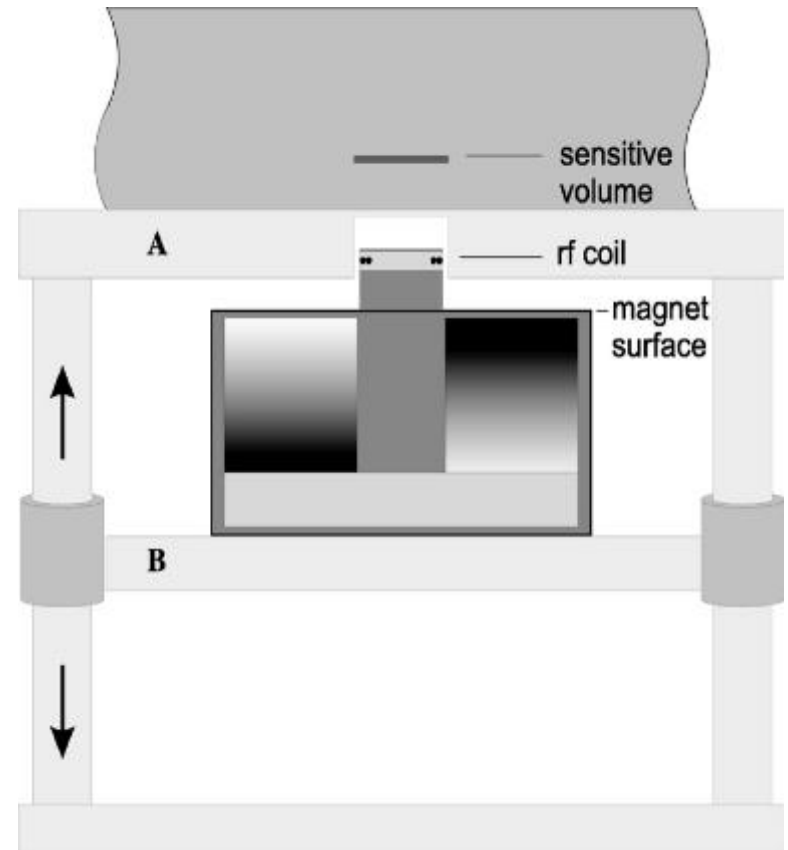
- Rubber aging:

Molecular mobility change due to crosslinking, scission and migration of low molar mass components

- NMR can be used to measure  $^1\text{H}$ -relaxation, transverse relaxation  $T_2$

- Portable NMR:  
Small and non-destructive test method

- Signal can be distorted  
Ferro magnetic steel – affecting the magnetic flux



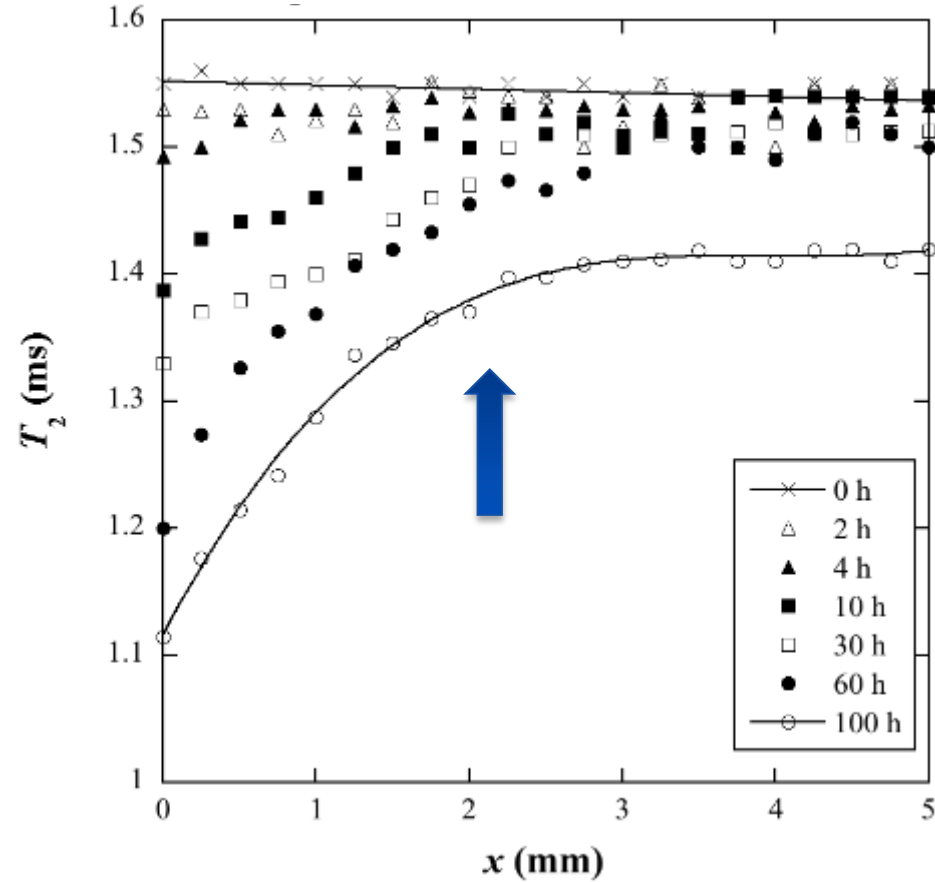
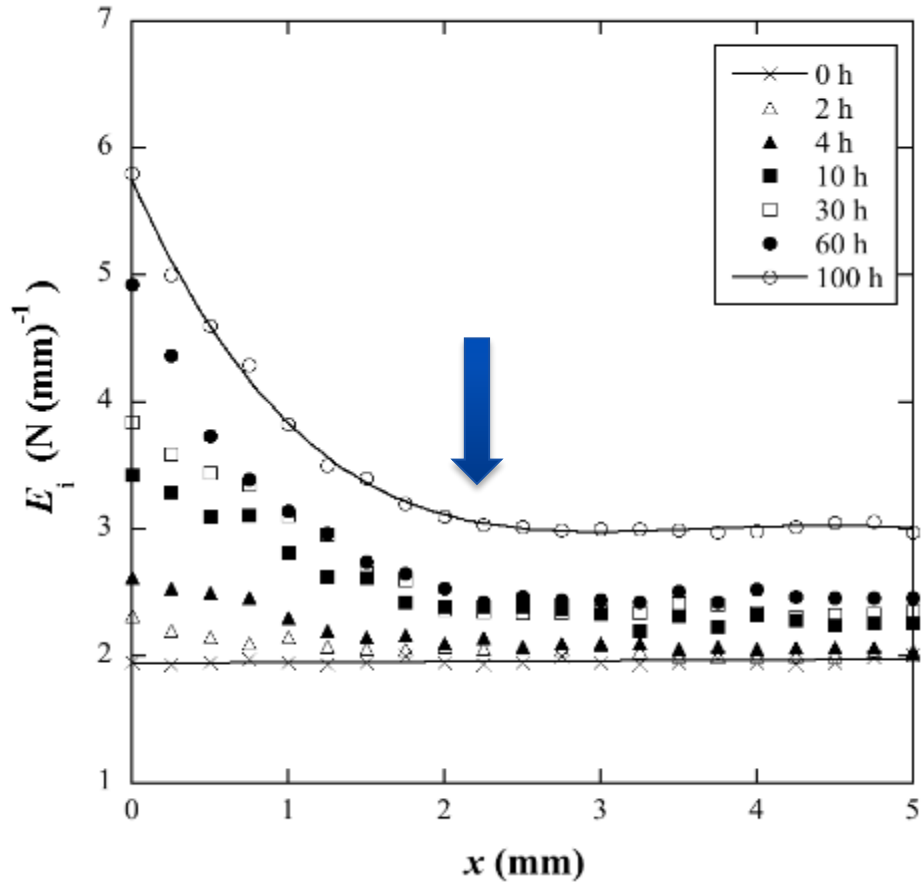
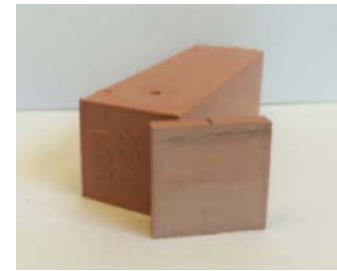
0.5 Tesla

# NMR MOUSE



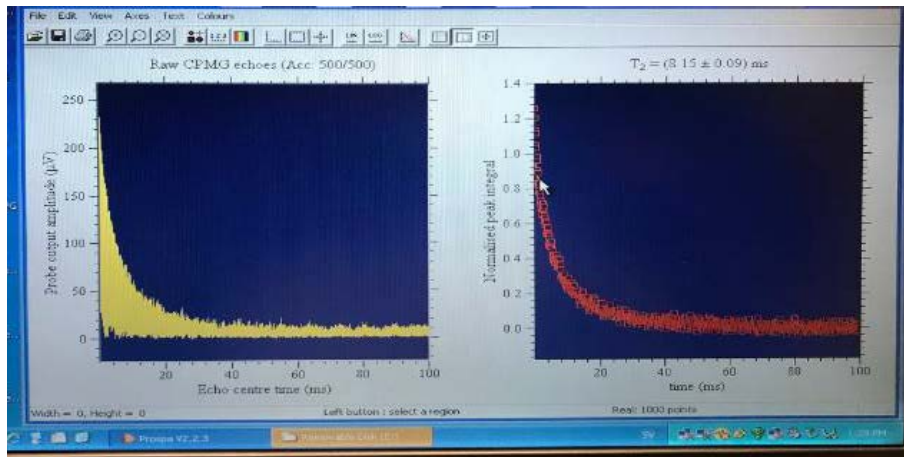


### Modulus profile – Brattberg sealant aged at 170 °C

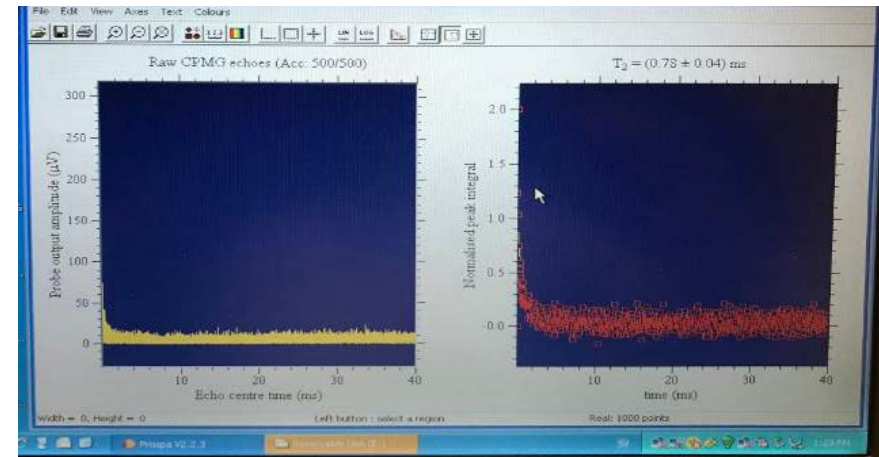


# Commercial NMR MOUSE

- Signal distorted by cable shielding
- Ferro magnetic material affects the field strength
- How can we increase the field strengths ? Suppress effects from shielding materials ?



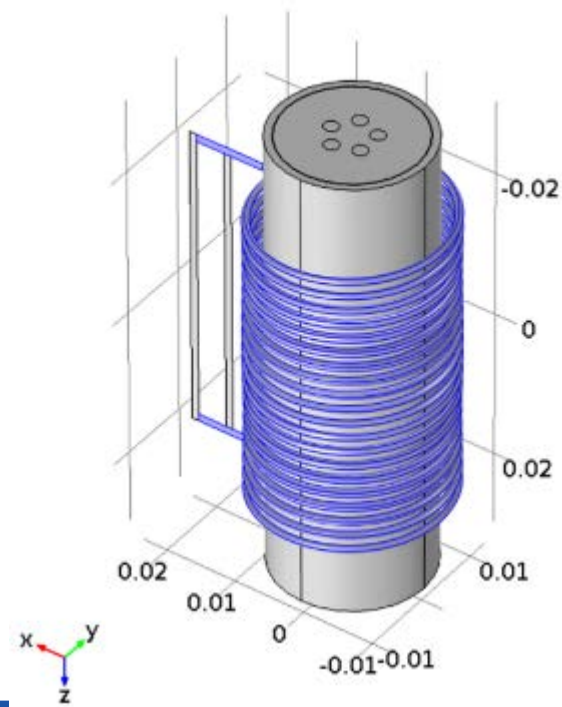
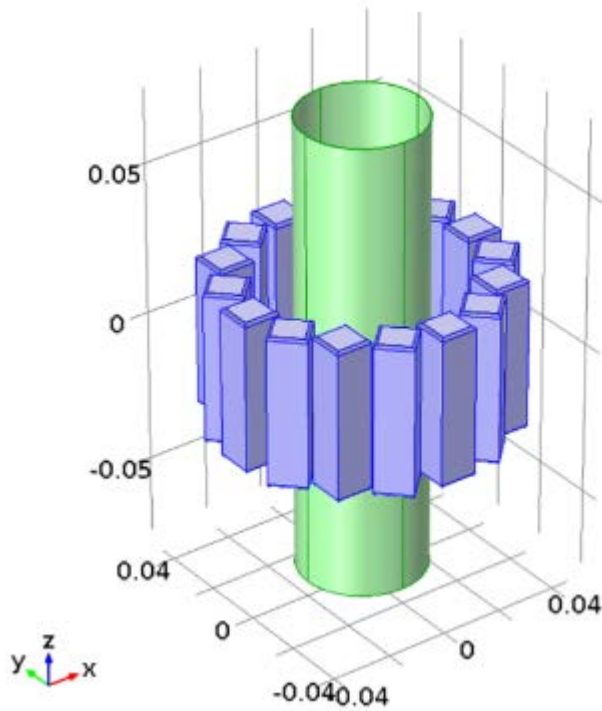
Cable insulation without shielding



Cable insulation with shielding

## NMR sensor for cables

- All simulations were made in Comsol Multiphysics.
- Single sided NMR magnet sensor – signal to weak!



## Prototype N1

1. High strength circular magnet Halbach Array
2. Transmitting/Receiving RF coil
3. The matching electronic circuit assembled in shielded case
4. Teflon case
5. Non-magnetic aluminum stands

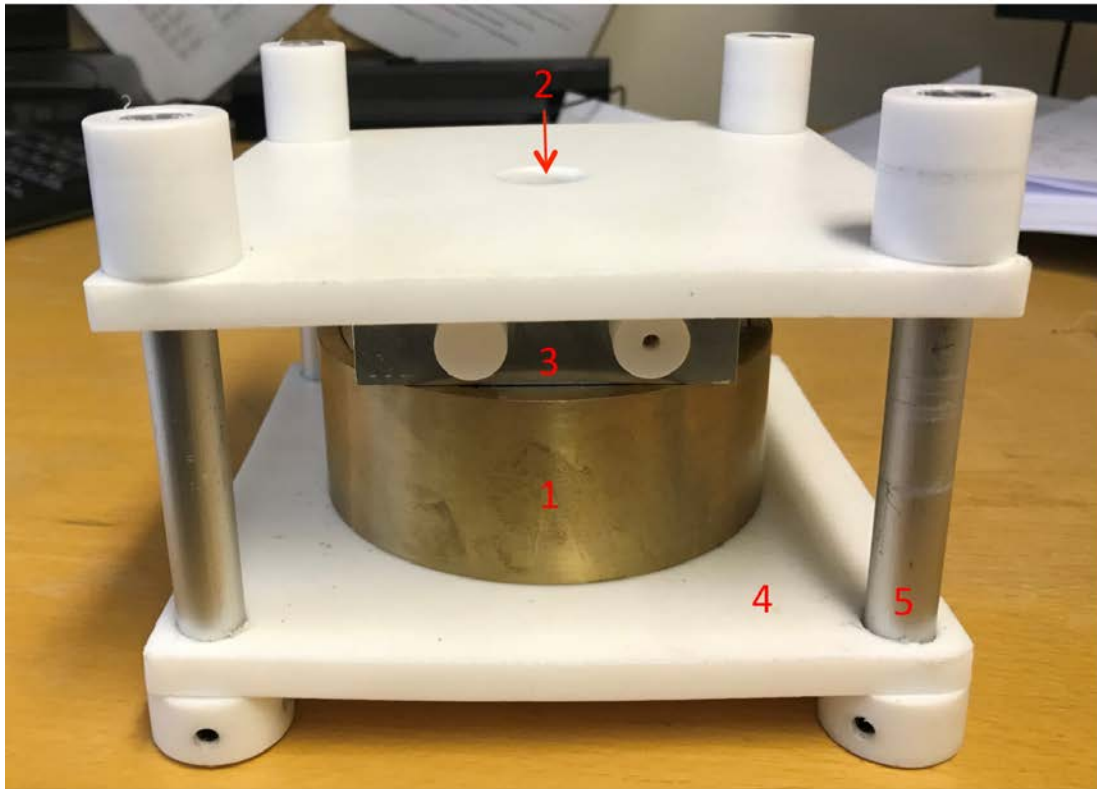
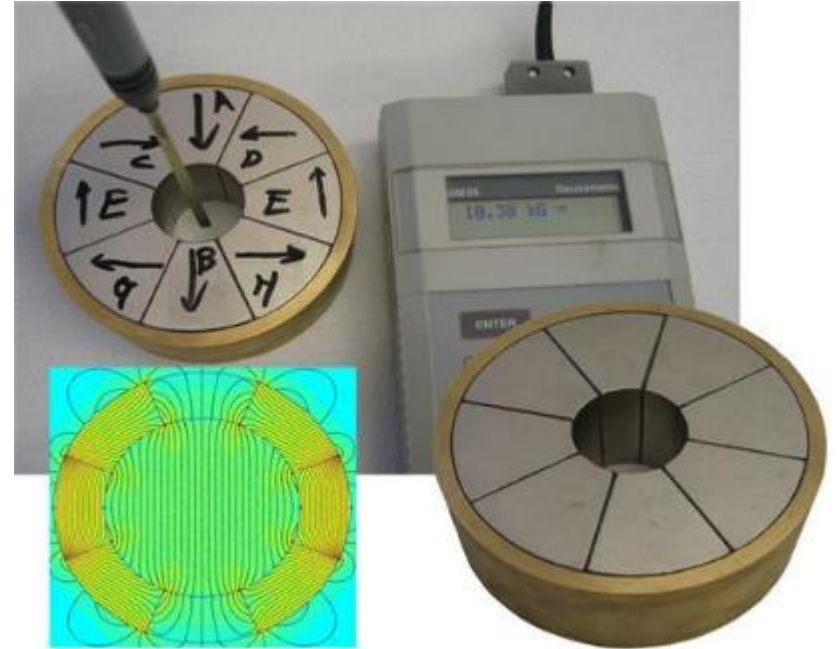


Figure 1. Design outline of the prototype N1.

# RF-Coils



- Three types of coils were designed N1-N3.

# Cables studied

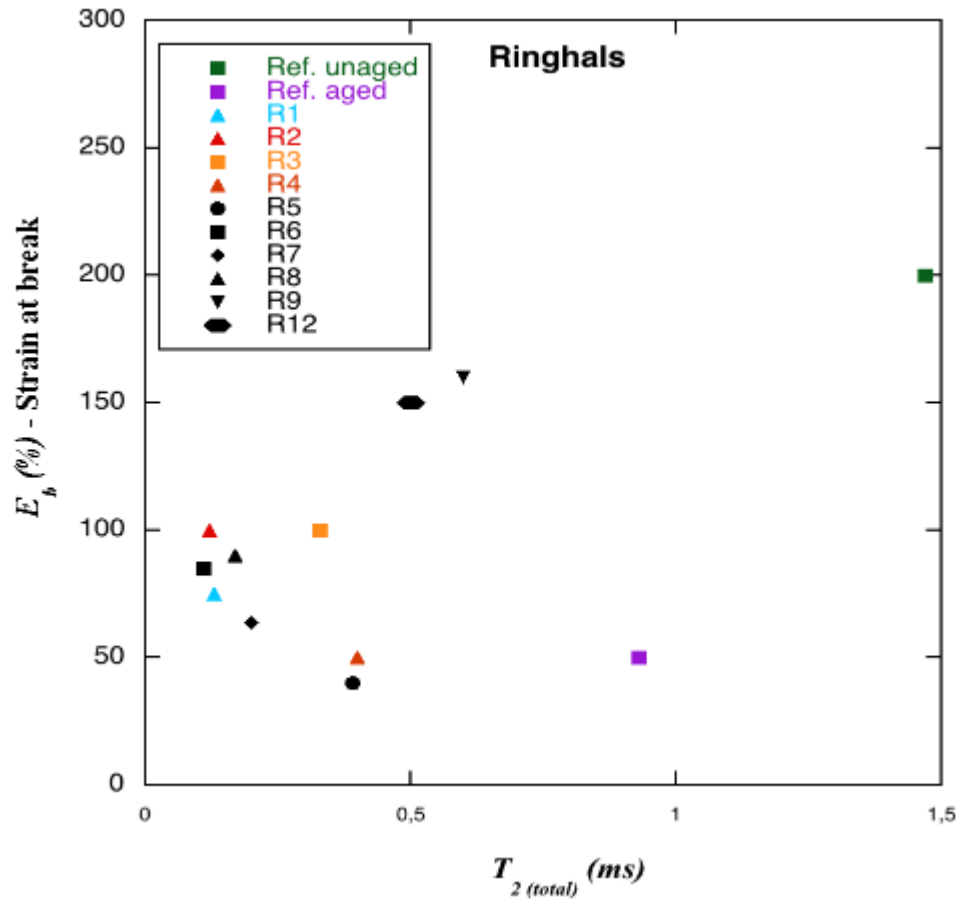
Cables from Ringhals AB – 12 cables.

Nr	Typ	Ledare	Använd/ny	Insida/utsida	Block	Mantel	Part	Tillverkare
1	FSFR	2x1	använd	insida	R3	CSPE	EPDM+Lipalon	ASEA kabel/ Liljeholmen
2	FSAR	3x1	använd	insida	R3	CSPE	EPDM+Lipalon	ASEA kabel/ Liljeholmen
3	ESSJ	3x2,5	använd	insida	R4	CSPE	EPDM+Lipalon	ASEA kabel/ Liljeholmen
4	FSFR	7x1	använd	insida		CSPE	EPDM+Lipalon	ASEA kabel/ Liljeholmen
5	FSFR	4x1	använd	insida		CSPE	EPDM+Lipalon	ASEA kabel/ Liljeholmen
6	FSFR	3x1	använd	insida		CSPE	EPDM+Lipalon	ASEA kabel/ Liljeholmen
7	FSFR	7x1	använd	insida		CSPE	EPDM+Lipalon	ASEA kabel/ Liljeholmen
8	MXS	4/C 12 AWG	använd	insida		CSPE	XLPE	Rockbestos Suprenant Cable Corp.
9	NU- SmHXHXCHX	2x2,5	Ny			FRNH Crosslink	EPR/FRNH	EUPEN
10	RSS		använd	insida	R3	CSPE	EPDM+Lipalon	ASEA kabel/ Liljeholmen
11	RSAR	48x1	använd	insida		CSPE	EPDM+Lipalon	ASEA kabel/ Liljeholmen
12	RSSR	14x1	NY			CSPE	EPDM+Lipalon	ASEA kabel/ Liljeholmen



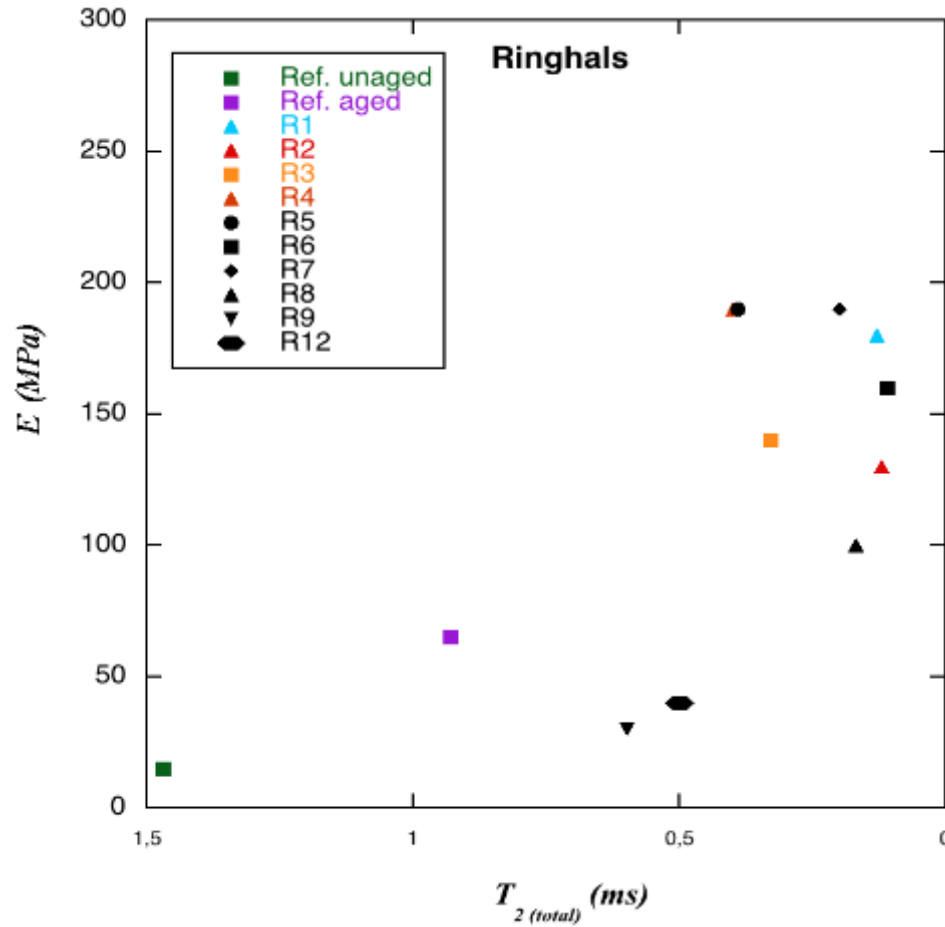
Cables were provided by Ringhals and Forsmark

## T2 and strain at break



- Less aged showed longer  $T_2$
- Aged samples showed lower strain at break and shorter  $T_2$

# T2 and Young's modulus







## Conclusions

- Custom designed portable NMR sensor (prototype N1) provides superior (> 10 times higher) NMR signal compared to the commercially available NMR mouse system.
- The NMR sensor demonstrated to have the ability to measure within cables i.e. in the insulation material. However, shielding material can cut the NMR signal.
- The evaluated longer ( $T_2$ ) component is in correlation with the rubber “age” and rigidity. Additionally, results from our mechanical assessments demonstrated similar trends to the NMR evaluation.



## Acknowledgements

Our deepest gratitude to SSM for making this project possible and Elena Calota for giving us the opportunity to continue.

We are also grateful for the support from Vattenfall!

Josef Sumegi – Vattenfall Ringhals.

Abu Rahmeh Samer – Vattenfall Forsmark.

Prof. Istvan Furo & Dr. Pavel Yushmanov – KTH

Full report:

<https://www.stralsakerhetsmyndigheten.se/en/publications/reports/safety-at-nuclear-power-plants/2021/202101/>



Strål  
säkerhets  
myndigheten

Swedish Radiation Safety Authority



**VATTENFALL**