QUALIFICATION OF POLYMER MATERIALS FOR NUCLEAR POWER APPLICATIONS

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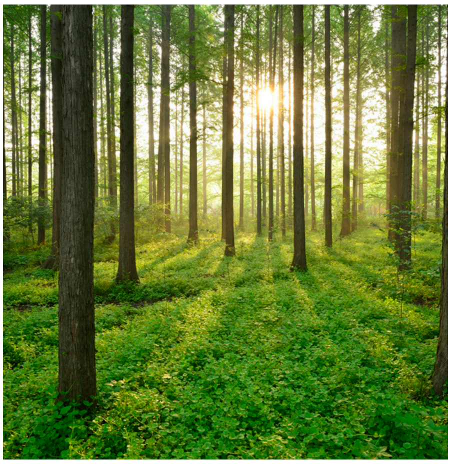

POLYMERIC MATERIALS IN NUCLEAR APPLICATIONS

Energiforsk

Qualification of polymer materials for nuclear power applications

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Foreword

The Energiforsk Polymers in Nuclear Applications Program aims to increase the knowledge of aspects affecting safety, maintenance and development of components containing polymers in the Nordic nuclear power plants. A part of this is to investigate possibilities to facilitate and simplify the work that is performed in the nuclear business.

Polymer materials and products such as sealings, pipes, insulation and cables are present everywhere in a nuclear power plant. But information on important technical specifications such as exact material composition is still hard to obtain. The purpose of this study is to investigate how the Nordic power plants work with the issue of qualification of polymeric materials. The survey shows that there is no common qualification process, but that the processes most often follow the processes of the technical area (electrical, mechanical or construction) that the polymeric components are considered as belonging to.

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These are the results and conclusions of a project, which is part of a research Program run by Energiforsk. The author/authors are responsible for the content.

Summary

The purpose of this study was to help clarify how the Nordic Nuclear power industry, as well as the supply chain, work with qualification of polymeric materials.

There are regulations on both international and national level on function of components and systems of the Nordic NPPs. These regulations do not usually specify which type of polymer material to be used, thus a specification on the material could be found in the NPP internal documents which are the base for the permit of operation given by the authorities.

The procedure of qualification was briefly described for three different polymer components (cables, membranes and seals). There were differences in the procedures, not just because the components belong to different technical areas (electrical, mechanical, and construction), but also because there are no general standard methods for qualifying a polymer material itself. The qualification of polymer materials is determined by the regulations of the system function and performance.

The level of involvement of polymer product suppliers in the qualification process varies, and much depends on their history and expertise, such as whether they were the supplier during the installation or if they have many customers within the nuclear industry.

In Nordic nuclear power plants, many components are very old due to long service life of the plant, making it difficult to find spare parts in the same materials as before. In these cases, qualification is often carried out in close collaboration with the supplier. Sometimes the supplier handles the testing and assessments, while other times the nuclear power company conducts its own tests, either internally or in cooperation with an external test lab.

Interviewed participants highlighted the potential to use existing documentation and expertise on polymer material qualifications in electrical components as a basis for similar qualifications in mechanical and construction areas. They suggested grouping o-rings into a few categories to streamline procurement and emphasized the need for more material data from suppliers for better assessments.

Additionally, there was a desire for more specific storage guidelines, end-of-life criteria verification, and education on accelerated aging.

Keywords

Acceptance criteria, material qualification, NPP, rubber, sealings, O-rings, polymer ageing, cable, membrane

Acceptanskriterier, kvalificering av material, kärnkraftverk, gummi, o-ringar, polymer åldring, kabel, membran

Sammanfattning

Syftet med denna studie var att bidra till en tydligare förståelse av hur den nordiska kärnkraftsindustrin, liksom leverantörskedjan, arbetar med kvalificering av polymera material.

Det finns regler på både internationell och nationell nivå gällande funktion av komponenter och system inom de nordiska kärnkraftverken. Dessa regler specificerar vanligtvis inte vilken typ av polymermaterial som ska användas, vilket innebär att specifikationen för materialet kan finnas i kärnkraftverkets interna dokument, som ligger till grund för drifttillståndet utfärdat av myndigheterna.

Kvalificeringsprocessen beskrevs kortfattat för tre olika polymera komponenter (kablar, membran och tätningar). Det fanns skillnader i procedurerna, inte bara på grund av att komponenterna tillhör olika tekniska områden (elektriska, mekaniska och konstruktion), utan också för att det inte finns några generella standardmetoder för kvalificering av ett polymermaterial i sig. Kvalificeringen av polymermaterial styrs av regler för systemets funktion och prestanda.

Graden av leverantörernas deltagande i kvalificeringsprocessen varierar, och mycket beror på deras erfarenhet och expertis, exempelvis tidigare installationer eller om de har flera kunder inom kärnkraftsindustrin.

I de nordiska kärnkraftverken är många komponenter väldigt gamla på grund av anläggningarnas långa driftstid, vilket gör det svårt att hitta reservdelar i samma material som tidigare. I sådana fall genomförs kvalificeringen ofta i nära samarbete med leverantören. Ibland ansvarar leverantören för tester och bedömningar, medan kärnkraftverket ibland utför egna tester, antingen internt eller i samarbete med ett externt testlaboratorium.

Intervjuade personer betonade potentialen i att använda befintlig dokumentation och expertis för kvalificering av polymera material i elektriska komponenter som en grund för liknande kvalificeringar för produkter inom områdena mekanik och bygg. De föreslog att o-ringar kunde grupperas i kategorier för att effektivisera inköpsprocessen och framhöll behovet av mer materialdata från leverantörer för bättre bedömningar. Dessutom uttrycktes ett behov av mer specifika riktlinjer för lagring, verifiering av livslängdskriterier och utbildning i ämnet accelererad åldring.

List of content

1 Introduction 7
1.1 Background 7
1.2 Scope 7
2 Regulations of nuclear power 8
2.1 International regulations 8
2.2 Swedish regulations 9
2.3 Finnish regulations 9
2.4 Other countries 9
2.5 Other industries 10
3 Qualification of polymer materials 11
3.1 Overview 11
3.2 Examples of qualification procedure 11
3.2.1 Electrical components 12
3.2.2 Mechanical components 12
3.2.3 Construction components 13
3.3 Qualification Testing 14
4 Remarks and possible future work 16
5 Conclusion 17
6 Acknowledgements 18
7 References 19

1 Introduction

1.1 BACKGROUND

Qualification of new or changed polymer materials and products such as sealings, pipes, insulation and cables are of importance to maintain a sustainable and secure power production in nuclear power industry. This can be done in different ways; the methods and routines differ from one industry or country to another. Some suppliers of components and spare parts declare changes in the material composition, but in general, it’s difficult to get sufficient technical documentation from suppliers. Often only a few parameters are provided, not a full description.

1.2 SCOPE

The purpose of this study was to help clarify how the Nordic Nuclear power industry, as well as the supply chain, work with qualification of polymeric materials.

The project plan included desktop study and interviews.

Desktop study of existing literature i.e.
- Standardization reports or existing standards (international and industry)
- Scientific reports/articles in this subject
- Workflow from other industries such as other power plants
- Laws and regulations

Interviews
- Interviewing Swedish and Finnish nuclear power industry representants such as procurement/ purchase, maintenance, technicians, R&D, suppliers, academia etc.

Report and presentation
- Study and interviews are summarized in report and presented to Energiforsk. Report should also point out any possible ideas for future studies/work within this matter.

2 Regulations of nuclear power

2.1 INTERNATIONAL REGULATIONS

The most important actor in driving safety regulations and guidelines for qualification in the nuclear power industry is the International Atomic Energy Agency (IAEA). IAEA is the world's central intergovernmental forum for scientific and technical cooperation in the nuclear field and has 178 member states that are expected to follow stated regulations. IAEA provides technical and scientific advice about nuclear safety in form of international collaborating and providing technical standards, scientific reports and arranging meetings/conferences. [1]

According to IAEA regulations, polymer material in the containment should maintain their integrity under both normal and extreme conditions. The materials should resist embrittlement, cracking, and swelling due to temperature fluctuations, moisture, and radiation. It is crucial that polymer materials are protected from hydrogen burning and radioactive aerosols. Regular assessment of ageing mechanisms and appropriate replacement intervals are essential. Materials should create minimum debris, fire hazards, and toxic gas release. Coatings and liners must ensure good adhesion, low permeability, and withstand environmental stresses without compromising safety functions. Design should allow for easy inspection, replacement, and maintenance. [2]

For the European nuclear power there are also Euratom (similar function as IAEA) and CEN standards that are legally binding for EU countries and for electrical components there are also IEEE and IEC standards. The requirements are the same as for other industries but with addition of regulation regarding nuclear safety which are mainly based on regulation and guidelines from IAEA. [3]

Another collaboration between the Finnish and Swedish power industry around electrical components is "Elkomponentgruppen" (the electrical component group), where qualification among other subjects is discussed. ref

All the regulations have in common that they are focused on functions and safety which means that polymer materials are not regulated specifically, other than that system function should be maintained for a certain time during a so-called design basis event (could be a simulation of a loss of coolant accident (LOCA) or other system failure).

For polymer material there are not really any specific regulations on material selection other than generally stating that it should be durable and hold for the specifics of the components where they are mounted. If possible, polymer materials are recommended to not be used in radiated zones due to their degradation properties compared to ie. metallic and ceramics materials. There are

[1] (IAEA), (IAEA: List of member states)
[2] (Design of the Reactor Containment and Associated Systems for Nuclear Power Plants No. SSG-53, 2019), (Equipment Qualification for Nuclear Installations No. SSG-69, 2021), (Safety of nuclear power plants : commissioning and operation No. SSR-2/2 (Rev. 1), 2016)
[3] (CEN-CENELEC: About CEN), (IEEE Standards)

a few studies, mainly on some specific polymer material components, that can be used as reference when qualifying polymer materials. [4]

2.2 SWEDISH REGULATIONS

In Sweden the nuclear power industry is regulated in national law in terms of safety and is monitored by the Swedish Radiation Safety Authority (SSM). [8] SSM is issuing licence for nuclear activities, production and auditing, they also offer education and participate in scientific projects to continually improve the safety in various areas. The regulations are stated in "Strålsäkerhetsmyndighetens författningssamling" SSMFS. [5]

In Sweden there are several ongoing collaboration initiatives within the nuclear power industry, one is PAKT (Provisions and Specifications for Nuclear Power Plants) which is providing suppliers and contractors with public documents that helps to interpret the requirement and guidelines in SSMFS for the Swedish types of reactor /power plant setups. [6]

2.3 FINNISH REGULATIONS

Finland has similar regulatory structure as Sweden. The main rules and regulations that Finnish nuclear power plants must follow are stated in national laws in the form of the Regulatory Guides on nuclear safety (YVL) set by the Finnish radiation safety authority (STUK). On top of these there are numerous national as well as international standards for different fields of applications. From these standards the plant specific guidelines have been derived. [7]

2.4 OTHER COUNTRIES

Most countries use the IAEA guidelines as the basis for their regulations, but with some difference in how it is applied in laws and regulations.

In UK, one difference from many other countries is that more of the polymer materials used in nuclear industry are fixed in recipes of the formulations which is owned by the NPP, and the suppliers manufactures spare part on licence. This lets the NPP have full control of what materials are used in the plant, which could be an advantage to not be limited to one supplier. However, for example rubber formulation is not only dependent on the constituents but also the processing, which can lead to different qualities of the rubber depending on where its manufactured and the process itself.

Another difference can be seen for example in USA, where the NPP's are operated in private corporations which don't collaborate in the same extent as in Sweden and Finland which means that they are more reluctant to share knowledge and

[4] (Burnay, 2001)
[5] (SSMFS 2008:13 Strålsäkerhetsmyndighetens författningssamling), (Lag (1984:3) Om kärnteknisk verksamhet, sfs nr 1984:3, 1984)
[6] (PAKT - Provisions and Specifications for Nuclear Power Plants))
[7] (About STUK, n.d.), (Regulatory Guides on nuclear safety and security (YVL))

suppliers need to accommodate for the specific regulations for each NPP separately.

2.5 OTHER INDUSTRIES

Electronic, mechanical and construction components used in any industry in EU and is described in a harmonised CEN standard needs to be CE marked, for some materials the CE mark can be obtained by self-reporting different properties and sometimes material testing and reoccurring audits must be done by an accredited entity to get a CE mark. [8]

The automotive industry often uses their own standards and methods, different certifications for different markets and countries. An often-used quality system in automotive is IATF 16949. Internal test standards or requirements (ie. Volvo:s Technical Requirements, TR) may be based on official standards such as ISO, EN or ASTM and can be modified on method or requirement to suit the product's area of use. To be able to qualify a new material for a product these tests can be performed by the manufacturer, supplier or an independent test facility depending on the criteria. Material suppliers and part manufacturers are highly involved in material selections. Usually, the specific product name of the material or materials is then stated in the specification or drawing for the product. This is to fix the supplier or manufacturer to not use any other material than the tested. It´s not uncommon that there is more than one approved material specified in the drawings, this is to give the supplier more flexibility in case of i.e. availability issues on market. There are also cases where the material properties are specified, i.e. for rubber where a specification can, be EPDM hardness Shore A 50. In-line quality tests on parts can be made at manufacturer to secure quality or documentation. [9]

I.e. medical- and food industry often have to follow laws, regulations which means that products have to go through certain function tests or chemical tests, often done by an accredited test facility to achieve the correct documentation. The material is then fixed in specifications and the product flow is audited by accredited body to verify the stringency. [10]

[8] (CEN-CENELEC: About CEN), (CEN standards)
[9] (About – International Automotive Task Force), (Volvo Cars - Corporate Standards)
[10] (Livsmedelslag (2006:804)), (ISO 13485:2016 Medical devices)

3 Qualification of polymer materials

3.1 OVERVIEW

In the nuclear power industry, the qualification of polymer materials is usually not a separate action, it is made as a part of the qualifying of a whole equipment or system. The qualification is done for new equipment that will be introduced in the plant/site/transport or if a spare part needs to be replaced with a new material.

An environmental qualification is a process that verifies whether the new equipment can perform its safety functions under the environmental stresses caused by design basis accidents, ensuring common-cause failures are avoided. This qualification is only required for safety related equipment. The qualified life of such equipment is the period during which it has been proven, through testing, analysis, or experience, to operate within acceptable criteria under normal and accident conditions, including extreme natural events. Condition-based qualification involves monitoring specific indicators of the equipment or its components, correlating these measurements with the equipment's ability to function as required during a design basis event. The aim is to set an acceptance criteria for a material or equipment that can be tested against.

Nuclear power plants in both Sweden and Finland (it is the same for most power plants and other industry) are highly dependent on the suppliers when it comes to choosing materials.

In general, when a new component or system containing polymer material is to be qualified, NPP's need to confirm that the system still applies to the regulations stated in SSMFS or YVL (STUK). The specific requirements for the system are stated in the original permit to operate given by the national authorities (SSM or STUK). The permit is based on thorough documentation on how the NPP fulfils the requirements and is provided by the NPP. Usually there is no specification in this permit on which polymer material to use, other than type of polymer group and when applicable hardness grade (e.g. a water pump seal may be specified to EPDM of hardness Shore A).

NPP and supplier uses inhouse experience and searching own documentation on what has been used before in similar conditions. If it is a completely new material or the material used before is not available, the material needs to be evaluated and documented.

3.2 EXAMPLES OF QUALIFICATION PROCEDURE

NPP's expertise and organisation in both Sweden and Finland are often divided into the areas: Electrical and I&C (Instrumentation & Control), Mechanical, Building and construction linked to these areas. Below are some examples on how qualification can be made in the different areas.

3.2.1 Electrical components

For electrical components the polymer materials could be cable insulation, covers and circuit boards.

The specific type of polymer material in the cable insulation is generally not regulated, although the NPP's usually want to minimize the number of different polymers in the cables. Also, halogen containing materials is avoided as much as possible.

When replacing a cable or installing new electrical equipment in a safety area, it's important to first identify the environment. The specific conditions and the design basis event that the installation must meet, should be clearly detailed in a technical specification.

For cables, the requirements are usually quite simple and covers the required insulating ability in certain environments. The selection of the new cable is done in close collaboration with the supplier who has the product knowledge. To approve the cable for the safety critical environments in the NPP's the cable needs to be tested against the normal operating conditions and specific accident conditions.

For the Swedish NPP's specific conditions can be found in TBE (Technical Regulations for electrical equipment) documents for different places in and around the reactor containments. The TBE documents does also give guidelines and acceptance criterions for different electrical components and their use, the KBE documents give requirements and guidelines on how to audit the equipment/components. [11]

To verify that the cable is fulfilling the requirements, it is tested in accelerated aging conditions and after that tested in the appropriate accident conditions. The acceptance criteria for a cable typically focus on its electrical performance, and for the insulation, there may also be requirements related to hardness and elongation at break.

3.2.2 Mechanical components

Mechanical components are, for example, valves, pumps, pipes, and heat exchangers. The polymer materials in these are mainly o-rings, seals, membranes, and pipes.

For polymer materials in mechanical components, similar as for electrical components, the material requirements are based on the function of the system they are part of. The difference is that most mechanical components are subjected to pressure in some way and often in combination with hot water and steam. Usually, there is no further specification on the material than polymer type and hardness in technical specifications and blueprints. Most of NPP's rely heavily on the suppliers for their knowledge in material selection. The polymer materials are often exchangeable, and suppliers suggest a replacement interval, sometimes the intervals are changed due to material failure before time or material lasting longer than expected. If the changing interval is going to be increased, the NPP's can do

[11] (TBE-KBE)

laboratory tests to simulate longer lifetime. A lot of mechanical components/equipment in the Swedish and Finnish NPP's have been used for decades, dating back to when the NPP were built, it means that spare parts such as o-rings, seals and membranes can be hard to get and needs to be special ordered which can be very difficult and expensive.

When, for an example, a rubber membrane in a valve needs to be changed to another material, due to prolonging of the lifetime, it needs to be tested to confirm that the requirement at the new lifetime is fulfilled.

The suppliers of membranes might be able to confirm that the rubber material will be suitable for the continuous use, but for materials/components that also needs to withstand a design basis event usually some extra tests need to be performed.

An example of operating conditions for a membrane could be a pressure span and an average temperature of use or an environment of water/steam on the pressure side and air from the outside. Many valves are part of the backup safety system, where they are not used in normal NPP operation, except for scheduled test runs. Which means that the normal environment then would be air and ambient temperature. An example of a design basis event could be exposure to high-pressure hot water or steam for a specified time interval, and in some cases, it may also involve a specific radiation dose. The overall acceptance criterion for a valve is no leaking, which for the membrane corresponds to a certain change in material properties, which usually for rubbers are measured by compression set, hardness, elongation at break. The acceptance criteria for material tests must be set with aspect to the system it is used in, but some guideline values are maximum 80 % compression set and maximum 50 % decrease in elongation at break. [12]

3.2.3 Construction components

The area of construction components covers polymer materials in, for example, sealing materials, coatings, and insulations. Most polymer materials used in construction components are located outside the radiation zone, with some exceptions, and many are not subjected to any design basis event.

An example of a material that might be qualified for replacement is worn-out seals for a manhole in the containment structure. Another example is expansion joints in temporal storage basin for radioactive waste, where the original material from the supplier discontinued and needed to be replaced with another. In this case the supplier suggested a similar material, samples of the new material were placed in the basin beside inspection samples of the current material. After some time (years) the material was taken out and both materials were tested for tensile strength, elongation at break and hardness. The rubber materials were still slightly radioactive when tested at an external laboratory (RISE AB), so the testing had to be approved by the authorities (SSM). Additionally, the process had to be supervised by experts from the commissioner (SKB, Svensk Kärnbränslehantering), who also ensured that the lab and equipment were properly cleaned afterward. The lab and equipment needed to be cleaned by experts from the commissioner.

[12] (Burnay, 2001)

When the results were compared the values for the new material were similar to the old which led to the conclusion that the new material could be used as replacement.

3.3 QUALIFICATION TESTING

Testing of the polymer materials may be performed on behalf of either the power plant or the supplier. Nuclear power industry is a relatively small customer for the suppliers, that sometimes do not offer to do the extra tests, with some exceptions. The actual testing of components or materials can be performed in NPP's own, at suppliers and/or external testing facilities.

Tests are designed by continuously used parameters and environment as well as the design basis event. The acceptance criteria and test procedure for the material or component are determined after discussions between the NPP's and supplier and is based on the system specification. For example, the TBM or TBE documents can often be of help in the test design, by presenting design basis event parameters and guidelines.

The time and temperature for accelerated aging tests are determined based on the supplier's recommended replacement interval or expected lifetime of the material. In these tests, higher temperatures are used to simulate long-term aging in a shorter period, allowing researchers to predict how the material will degrade and perform over time under normal conditions.

Normal conditions are usually tested by accelerated ageing and is then followed by test at the design basis event conditions. Polymer and rubber materials are more susceptible to oxidative and thermal degradation compared to metals and other non-interchangeable system parts. This means it is the "weaker" part of the system, which is the main contributing factor for the lifetime of the system.

When possible, the entire component can be tested. However, since polymer parts are often interchangeable, accelerated aging is typically performed separately on these parts. The design basis event test is preferably performed on the system but can also be performed separately on the polymer part.

Some of the NPP's have testing facilities on site, but usually they are not flexible and limited to only a few types of test conditions. In some cases, the suppliers have their own test facilities, especially those who manufacture nuclear power components. Also testing for radioactive exposure is normally not easily available. An external testing laboratory is often hired to perform tests when test parameters are complex, or the own laboratory lacks the necessary capacity.

External testing facilities that can simulate radioactive exposure is not easily available because they are expensive to build and maintain, making access sometimes limited to large research institutions, government agencies, and international collaborations. Given the high radiation levels involved, these facilities are subjected to stringent safety and regulatory requirements, which can limit their availability and the scope of research.

Testing can also be performed by other test laboratories, which are not specialized in materials for nuclear application. Most of the polymer materials in nuclear power plants are not normally subject to direct radiation, which means, that for these applications you only need to consider the normal ageing effects on the material like temperature, time and wear or load. All test facilities must be accredited by a third party such as ISO or similar. [13]

[13] (ISO/IEC 17025 - Testing and calibration laboratories), (SSMFS 2008:13 Strålsäkerhetsmyndighetens författningssamling)

4 Remarks and possible future work

Following are some comments from the interviews about qualification of polymer material:

There are documentation and expertise on qualification of polymer materials in electrical components that could be used as a start and help when performing qualifications in the mechanical and construction areas.

It would be interesting to establish similar Nordic collaborations for mechanical and construction areas, like those for electrical components in the "Elkomponentgruppen." Increased collaboration between these different areas could also be beneficial.

There are many o-rings in a NPP with a lot of different article numbers which are hard to manage. If it would be possible to group them in to maybe 3-4 different qualities based on placement and conditions, it would save a lot of time and money when purchasing spare parts.

To be able to do a better assessment it is desirable to get more material data from the suppliers.

Some areas and materials of interest are ageing in humidity and overheated steam (also dirty steam), behaviour of silicone material in steam (a minimum of 20-year lifetime is desired) ageing behaviour and proper selection of joint compounds.

More specific guidelines and regulations for storing polymer materials were desired.

Verifying the end-of-life acceptance criteria for different applications and material types.

It would be of interest to have a simplified polymer handbook as assistance when choosing polymer material. However, with an emphasis on that it is just a guideline and there needs to be a thorough investigation on parameters and suitability in every aspect.

Education about accelerated aging regarding calculations with Arrhenius equation, for instance determining test periods and to calculate activation energies to be able to make a safe plan for prolonging the change interval for some materials.

5 Conclusion

In conclusion, this study aimed to clarify how the Nordic nuclear power industry and its supply chain address the qualification of polymeric materials, a critical component for maintaining safety and reliability in power production. The study shows some variability in qualification methods across different countries, as well as the challenges posed by limited and insufficient supplier documentation. There is a need for enhanced standardization and collaboration among various sectors, particularly in the mechanical and construction areas, similar to existing initiatives like the "Elkomponentgruppen" for electrical components.

Moreover, grouping similar polymer components, such as o-rings, into fewer categories could streamline procurement processes and reduce costs. The desire for more comprehensive material data from suppliers was a recurring theme in the interviews, underscoring the importance of reliable information in making informed decisions. Future work could focus on developing more specific guidelines for material storage, verifying end-of-life acceptance criteria, and creating a simplified polymer handbook to assist stakeholders in making appropriate material choices.

Educational initiatives regarding accelerated aging and its implications for material performance could also be focus for the future, enabling the industry to optimize maintenance schedules and prolong the service life of polymer materials. By addressing these key areas, the Nordic nuclear power industry can strengthen its qualification processes, ultimately enhancing safety and sustainability in power generation.

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QUALIFICATION OF POLYMER MATERIALS FOR NUCLEAR POWER APPLICATIONS

Polymer materials and products are present everywhere in a nuclear power plant, and material qualification and control are important issues. The purpose of this study is to investigate how the Nordic power plants work with qualification of polymeric materials. The results can be used as a benchmark and base for improvements.

A new step in energy research

The research company Energiforsk initiates, coordinates, and conducts energy research and analyses, as well as communicates knowledge in favor of a robust and sustainable energy system. We are a politically neutral limited company that reinvests our profit in more research. Our owners are industry organisations Swedenergy and the Swedish Gas Association, the Swedish TSO Svenska kraftnät, and the gas and energy company Nordion Energi.

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