"Radiation to Materials" at CERN

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***Abstract*— Irradiation tests are continuously needed at the European Organization for Nuclear Research (CERN), to experimentally assess the radiation tolerance of commercial non-metallic materials for use in high-radiation areas. The "Radiation to Materials" (R2M) activity organizes such tests and provides expertise in the interpretation of results, for the design and upgrade of devices absorbing critical doses during their lifetime. The various activities covered by the R2M are presented. Up to ten irradiation tests per year are organized in external ^{60}Co facilities, in which samples absorb up to several MGy of gamma dose at dose rates in the kGy/h range. Cables, O-rings, lubricants, glues, optical materials, and insulators are examples of possible tested materials. In parallel, selected samples are irradiated in a mixed neutron and gamma irradiation station built close to the neutron time-of-flight facility. Dedicated research studies, mainly focused on oil, greases, and elastomeric O-rings, are being performed to deepen the understanding of radiation effects in these critical materials. As an example, the mechanical and structural characterization of two elastomeric ethylene-propylene-diene monomers (EPDM)-based commercial materials irradiated in gamma radiation up to 3 MGy of dose is presented.**

***Index Terms*— Ethylene-propylene-diene monomers (EPDM) elastomers, gamma dose, irradiation facilities, lubricants, materials, mixed field irradiation, radiation.**

I. Introduction

COMMERCIAL and custom-made non-metallic materials are extensively used in high radiation areas of research facilities producing intense radiation levels. The radiation effects in specific materials are in most cases not precisely known [1]. For this reason, the radiation tolerance of specific components needs to be experimentally assessed to validate design choices and ensure the accelerator vital functions.

At the European Organization for Nuclear Research (CERN), irradiation tests on materials and components were extensively performed between the 1960s and the 2000s [2], resulting in the compilation of the Yellow Reports, such as [3], [4], [5]. This knowledge is currently being updated, as new products are continuously released in the market and many of the products previously studied are now obsolete or discontinued. New data are now needed for reliable design and upgrades of various devices operating in the accelerator complex. Among others, beam intercepting devices are extremely critical due to the operation in high radiation areas, and their radiation tolerance needs to be carefully addressed. The maintenance of these devices and the early detection of degradation phenomena is often very complicated or impossible. Considering that failure impact would be very severe, in some cases determining the earlier replacement of equipment, the selection of reliable radiation tolerant materials is of utmost importance.

The Radiation to Materials (R2M) work package, within the Radiation to Electronics (R2E) Project [6], aims at minimizing the risk of radiation-induced failures and the reduction of design safety margins in the accelerator machine. The R2M coordinates the design and realization of irradiation tests, provides expertise in the interpretation of the results collected in post-irradiation characterizations and is responsible for dedicated research studies currently mainly focused on lubricants [7] and elastomeric O-rings, among the most sensitive used materials. Additionally, support is provided to numerous groups, facilities and projects, such as the High Luminosity Large Hadron Collider (LHC) upgrade, heavily relying on the R2M for what concerns the identification of radiation-tolerant products for specific challenging applications [7], [8]. The R2M specifically focuses on the study of non-metallic materials and components.

II. Radiation Effects in Organic Materials: An Overview

In a simplified description, at the structural scale radiation induces modifications in the structure of polymeric materials, leading to the cleavage of molecular bonds and either recombination with other chain segments, thus generating further cross-linking and polymerization, or termination, and thus broken points in the chain network. At the macroscopic scale, materials can correspondingly become softer or harder. Additional radiation-induced macroscopic effects, such as production of gas, production of acids, color change, oxidation, and separation of multi-phase materials, such as greases can be observed. These effects can dramatically affect the properties of these materials [1], [2], determining their functional or structural failure, and possibly compromising the operation of the device they are part of [7].

Radiation-induced effects are usually described as a function of the total absorbed dose [1], [5], but they can greatly depend

Manuscript received 14 October 2022; revised 10 January 2023; accepted 25 January 2023. Date of publication 1 February 2023; date of current version 16 August 2023. This work was supported in part by the European Organization for Nuclear Research's (CERN) Sources, Targets and Interactions (STI) Group; and in part by the Radiation-to-Electronics (R2E) Project.

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Color versions of one or more figures in this article are available at https://doi.org/10.1109/TNS.2023.3241785.

Digital Object Identifier 10.1109/TNS.2023.3241785

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on other irradiation parameters, such as the radiation type and energy spectrum, the dose rate, the amount of oxygen in the atmosphere, the temperature, etc. [2]. Radiation data on specific commercial materials are largely incomplete, and, for this reason, further results need to be collected [9].

III. Irradiation Tests in External Facilities

CERN continuously organizes irradiation tests of various materials and components in external commercial irradiation facilities through R2M support and coordination. Test outcomes are fundamental to finalize design choices, to maximize the lifetime of complex and expensive equipment, to minimize maintenance, earlier replacements, and failures and for a reliable operation and upgrade of the CERN accelerator complex. The total absorbed dose is generally used as the main figure of merit to assess the resistance of these materials to radiation [2], [5].

The types of irradiated samples are extremely varied, reflecting the differentiated needs of CERN's accelerator complex and experimental areas. Among others, cables, wires, tubes, insulators for magnets, vacuum components, elastomeric seals, resins, optical fibers, electrical heaters, lubricants and lubricated components, glues, adhesives, and structural materials, such as grouts are irradiated. On average, ten irradiation campaigns are organized every year, with an increasing demand related to foreseen intensity increases and future upgrades.

Sample size ranges from 1 cm^3 samples to more than 1 m long cable bundles. The number of samples irradiated in a single test can range from few items to hundreds of small samples. Total doses of interest usually range from 0.1 to 20 MGy, as measurable radiation effects in organic materials typically begin to occur in this range [1], [2], [5]. Dose rates approximately ranging between 1 and 30 kGy/h are available and suitable for these studies. Irradiations up to the mentioned dose levels correspondingly last between some weeks and some months, in the case of uninterrupted service. Interruptions are frequently present, depending on the facility schedule and to allow various dose steps during a single test, realized by adding samples at different times in the used facility spot. Tests are normally accelerated in comparison to operation conditions, in which the same doses are absorbed over several years or decades of service [7], [8]. The main assumption in the realization of these irradiation tests is that the radiation effects mainly depend on the total absorbed dose.

Other irradiation conditions can influence radiation effects as well. Accordingly, samples may need to be irradiated in controlled or monitored temperature conditions, while in other cases irradiation under a specific atmosphere, such as inert gas or ventilation conditions, might be necessary to more closely reproduce the environment expected in operation.

Considering the limitations of the current knowledge, safety factors are usually taken into account when defining radiation tolerance thresholds [2]. Acceptance criteria for irradiated samples are not universal and depend on the specific material, on the chosen post-irradiation characterization, and on the specific final use. Centralization of the testing activities through the R2M contributes to better defining generally agreed end-points and acceptance criteria for materials.

Research studies currently being performed in different irradiation conditions, as discussed in Sections V and VI, will contribute to better estimate the design safety margins to be applied and to verify the used assumptions.

The large sample volume to be irradiated yearly, and the high necessary target doses require the use of commercial ^{60}Co gamma-irradiation facilities, whose access is regulated by a contract between CERN and external providers of irradiation services.

The dose levels foreseen in operation at CERN are estimated by FLUKA Monte Carlo calculations, in collaboration with the Monitoring Calculation Working Group and can be measured both in operation and during tests by use of dosimeters provided by the high-level dosimetry service, whose readout is performed at CERN [10].

Comprehensive coverage of the radiation levels available at CERN and relevant for the R2M is beyond the scope of this article. However, as presented in [7], a total absorbed dose of 0.1 MGy during operation can be generally considered as a threshold of dose relevance for many polymeric materials, while doses exceeding 1 MGy are to be considered as critical and require the use of components whose radiation tolerance has been experimentally tested. When expected doses over lifetime exceed 10 MGy, the use of such materials should be avoided. If not possible, then regular monitoring and maintenance should be planned, and failure scenarios should be carefully accounted for.

The materials used for the construction of beam intercepting devices, such as dumps and collimators at CERN may absorb doses up to the MGy range during their whole lifetime. Examples are briefly discussed in Section VIII.

IV. Examples of Radiation Induced Effects

Post irradiation characterization of the irradiated materials is generally performed at CERN, under the responsibility of the sample owner. For each test, complete technical documentation is produced, including a specification document describing the necessary requirements to plan the irradiation test, an irradiation and dosimetry report compiled by the irradiation facility, and a final test report describing the evolution of the most relevant properties with dose. All the mentioned documentation is archived in CERN's Engineering Data Management Service (EDMS).

Examples of macroscopic radiation-induced damages observed in such tests are given in this article.

Fig. 1 shows different candidate materials selected for the protective covers of magnets installed all over the accelerator complex after gamma irradiation at 10 MGy. Three of the samples maintained their original shape, while for one of them (top position) the radiation-induced deformation, eventually leading to structural failures, is evident.

Fig. 2 shows some glass samples to be used for high-precision alignment optical systems for High Luminosity LHC applications. The unirradiated samples are transparent, while a progressive darkening is reported as a function of dose. Darkening of optical components can cause their failure in operation.

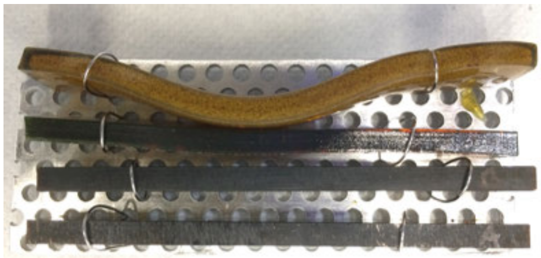

Fig. 1. Four materials candidate for the protective covers of magnets after gamma irradiation at 10 MGy. Acknowledgment: C. L. Marraco Borderas.

Fig. 2. Precision components for alignment systems: glass balls unirradiated (left) and irradiated at 10 MGy of gamma dose (right). Acknowledgment: M. Sosin.

In addition to visual inspections, specific structural, mechanical, chemical, and functional tests (not reported here) are performed on these irradiated materials, aiming at defining dose thresholds and qualifying them for use in specific operation conditions.

V. i-NEAR Mixed Field Irradiation Station at CERN

Complementary to the tests performed in gamma facilities, irradiations in a mixed field in-house station are possible at CERN since July 2021 as well, to investigate the dependence of specific radiation effects on the radiation type and spectrum. CERN is now equipped with a parasitic irradiation station located close to the spallation target of the Neutron Time-Of-Flight (n_TOF) facility [11], the i-NEAR station [12].

At i-NEAR, twenty-four samples having an overall volume of up to 100 cm^3 each can be irradiated up to doses in the MGy range, in irradiation times ranging from six months to one year, allowing low dose rate conditions to be explored in a neutron-dominated mixed radiation environment.

The spallation neutron energy spectrum in the irradiation positions spans over more than eleven orders of magnitude, with energies ranging up to several GeV. Total neutron flux at i-NEAR in a reference irradiation position and for a standard operation year corresponds to approximately $3 \cdot 10^{17}$ cm^{-2}. Total neutron fluxes can vary about a factor of 2, depending on the chosen irradiation position of the i-NEAR station. Gamma dose rates are roughly independent of the irradiation position within the i-NEAR volume and correspond to about 0.4 MGy/y for organic materials in a standard operation year. Temperature and atmosphere are not controlled during irradiation. Further details on the dosimetry and on the specific irradiation conditions available at i-NEAR can be found in [12].

In the first irradiation campaigns organized at i-NEAR during 2021 and 2022, samples of lubricants and ethylene-propylene-diene monomers (EPDM) elastomeric O-rings relevant for the CERN accelerators are irradiated. Some of them are used in beam intercepting devices at CERN, which are some of the most critical devices in terms of radiation resistance [8].

After neutron irradiation, the materials and their containers generally have a certain residual activity, depending on their specific composition. Typically, for the materials of interest this activity is about some μSv/h at 40 cm distance after some weeks of cooling, as an order of magnitude. Accordingly, materials have to be handled and disposed of following the Radiation Protection regulations. Activated samples are tested at CERN in dedicated classified laboratories.

Considering the relatively long irradiation time and the limited available sample volume, i-NEAR cannot satisfy alone the whole demand for irradiation of materials at CERN, but it is rather used to further explore radiation effects in low dose rate and mixed field irradiation conditions on a limited selection of materials, for comparison with standard gamma irradiation.

The scope of these investigations is to collect data in irradiation conditions much closer to the ones present in operation at CERN, in comparison to pure gamma fields. The first samples irradiated at i-NEAR are currently being tested, and the results will be described in future dedicated publications.

VI. Irradiation Studies on Lubricants: An Overview

Complementary to the qualification activities previously described, there is at CERN a need for systematic research studies aiming at a deeper understanding of radiation effects in materials and to better foresee their usability end-points in specific operation conditions. In particular, lubricants and EPDM elastomeric O-rings are currently being irradiated and tested, as they are among the most radiation sensitive polymeric materials [1]. They are nevertheless used out of necessity in high-radiation areas at CERN as part of critical equipment such as collimators and dumps [7], [8].

A large variety of commercial lubricants is currently being studied at CERN, including products already in use and new products whose resistance to radiation is considered promising [1], [14], [15].

A complete characterization is performed on samples irradiated in gamma and mixed field irradiation conditions including, but not limited to, the following tests: viscosity, test of rheological properties, Fourier transform infrared spectroscopy (FTIR), total acid number (TAN), gel permeation chromatography (GPC), microscopy, oil separation, worked penetration and tests on high-frequency reciprocating rig (HFRR) and mini traction machine (MTM) [13], [14].

To quantitatively assess the radiation effects in lubricants, macroscopic quantities, such as consistency (for greases) and viscosity (for oils) have been tentatively used so far. As a general reference, a consistency variation of approximately 10% [7] and a viscosity increase of 100% [14] have been used as end-points in previous works to determine the dose threshold of commercial greases and oils, respectively.

Complete post-irradiation characterizations aim at better understanding radiation effects enabling more accurately foreseeing the expected radiation damage in specific operation conditions and enabling a refinement of the currently used end-points.

CERN is now equipped with a material science laboratory dedicated to lubricant testing, where a penetrometer, to perform standard worked penetration tests [16] and a HFRR instrument are available. At CERN, it is possible to test radioactive samples as well, such as the ones irradiated at i-NEAR. Tribological studies are performed in collaboration with the Tribology Group of Imperial College London (U.K.). Specific investigations are ongoing in collaboration with producers of lubricants as well [14].

VII. Irradiation Studies on Elastomeric EPDM O-Rings

Elastomeric O-rings are widely used at CERN in a variety of applications, including but not limited to high radiation areas. EPDM-based elastomers are generally known to be more radiation resistant than other elastomeric materials [5], however large differences in the radiation tolerance of different commercial EPDM-based materials were observed [17]. Accordingly, it is not possible to assume that all EPDM-based materials exhibit the same resistance to radiation, and specific commercial products should be irradiated and tested.

In this section, an example of the radiation damage studies currently being performed by the R2M is detailed.

A. Selected EPDM Materials

A selection of specific products currently in use at CERN, including both special rad-hard formulations and general-purpose ones, is currently being irradiated in gamma irradiation and at i-NEAR [12].

In the frame of a recent study, two EPDM-based commercial materials for O-ring construction were irradiated.

1) Shieldseal663,[1] produced by James Walker, is a special formulation produced to be extremely stable and long-lasting in harsh environment. It is declared radiation-tolerant in gamma radiation by the producer up to 1.6 MGy [19].
2) EPDM 70.20-10 produced by Angst + Pfister is a peroxide cross-linked general-purpose EPDM-based material with a declared resistance to hot water, vapor, and aging factors [20].

The extensive use of the mentioned products at CERN, in both low- and high-radiation areas, motivates these studies.

B. Irradiation Conditions

Samples of both materials were irradiated in a commercial ^{60}Co gamma facility. Total absorbed dose levels of 2 and 3 MGy, at a dose rate of approximately 5.2 kGy[H$_2$0]/h, equivalent to 4.68 kGy[air]/h, were delivered. Temperature during irradiation was not controlled. Relative humidity during irradiation corresponds to about 40%. Samples were irradiated in air, in a ventilated environment to prevent ozone accumulation. Dosimetry in the irradiation facility was undertaken with alanine dosimeters with a measurement uncertainty of ±5%.

[1]Registered trademark.

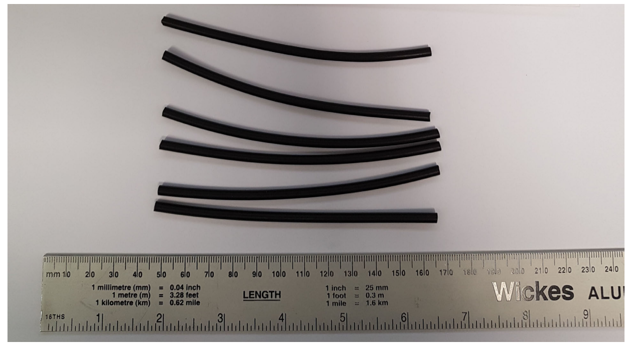

Fig. 3. Example of irradiated O-ring slices.

C. Methods

The characterization performed on irradiated and non-irradiated reference samples includes standard measurements relevant to elastomeric materials, such as tensile test, hardness test, swelling test, and differential scanning calorimetry test (DSC).

All the tests reported in this article have been performed at the *Laboratorio di Scienza e Tecnologia dei Materiali*, Department of Mechanical and Industrial Engineering, University of Brescia, Italy.

As shown in Fig. 3, samples were irradiated in the form of 120 mm long slices cut from O-rings having an inner diameter of approximately 600 and 4.0 mm cross section diameter. Six O-ring slices per dose point per material were irradiated.

Uniaxial tensile test is performed using a universal testing machine Instron mod. 3366. The instrument is equipped with a load cell of 10 kN maximum capacity. Tests are performed at a crosshead speed of 50 mm/min, at room temperature. Force and displacement sampling values were measured every 10 ms. Tensile test allows the Young's modulus, the elongation at break and the stress at break to be measured.

Glass transition temperature is measured using DSC Q100 calorimeter by TA Instruments. Samples of approximately 10 mg of material are extracted from the irradiated O-ring slices for this test. Nitrogen is used as purge gas, and samples are heated from −80 °C to 140 °C, increasing the temperature at a rate of 10 °C/min. Glass transition temperature was evaluated for all the materials on this heating scan.

Swelling experiments were carried out on samples with an initial mass ranging from 150 and 200 mg. Samples are immersed in tetrahydrofuran solvent at room temperature and weighed repeatedly until the swollen sample reaches a stable mass. The process usually takes 48–96 h. The solvent is afterward evaporated under vacuum, at 70 °C, until the dried sample reaches a stable mass.

The equilibrium swelling ratio (SR$_{eq}$) and the weight loss (WL) in percentage are evaluated using the following equations:

$$\mathrm{SR_{eq}} = m/m_d \tag{1}$$

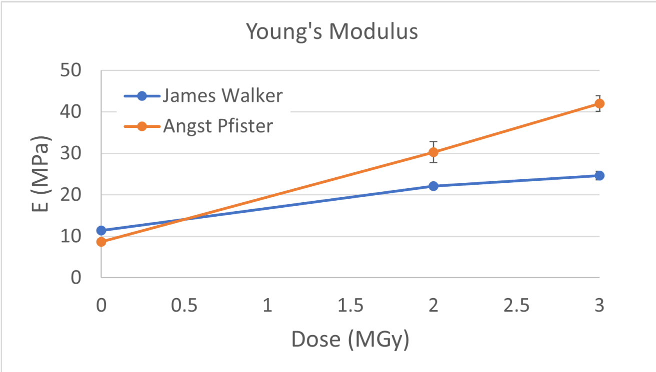

Fig. 4. Young's modulus E of James Walker Shieldseal 663 (blue) and of Angst + Pfister EPDM 70.20-10 (orange) as a function of the gamma dose. The line connecting the points is a guide for the eyes only.

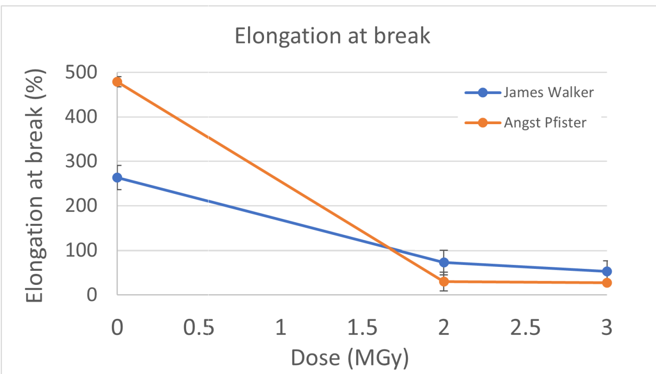

Fig. 5. Elongation at break of James Walker Shieldseal 663 (blue) and of Angst + Pfister EPDM 70.20-10 (orange) as a function of the gamma dose. The line connecting the points is a guide for the eyes only.

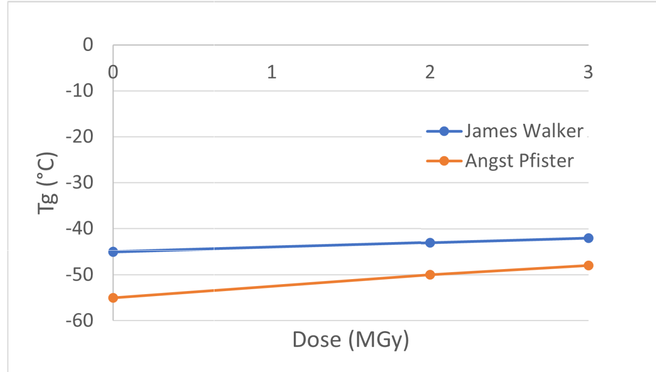

Fig. 6. Glass transition temperature T_g of James Walker Shieldseal 663 (blue) and of Angst + Pfister EPDM 70.20-10 (orange) as a function of the gamma dose. The line connecting the points is a guide for the eyes only.

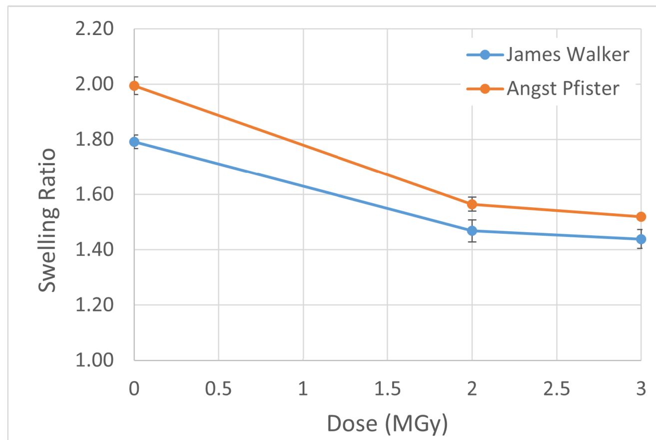

Fig. 7. Swelling ratio SR_{eq} of James Walker Shieldseal 663 (blue) and of Angst + Pfister EPDM 70.20-10 (orange) as a function of the gamma dose. The line connecting the points is a guide for the eyes only.

$$\mathrm{WL} = \frac{m_0 - m_d}{m_0} \cdot 100 \tag{2}$$

where m_0 is the initial mass of the sample, m is the mass of the swollen sample and m_d is the mass of the dried sample. The values of SR_{eq} and of WL are averaged over three measurements.

D. Results

Tensile test results correspond to the average of six different samples.

Fig. 4 shows the Young's modulus E evolution as a function of the dose for the two EPDMs. For both materials, a progressive increase is reported. At the maximum investigated dose level of 3 MGy, E increases of about a factor 2 for James Walker's EPDM, while it increases of about a factor 5 for Angst + Pfister's one.

Fig. 5 shows the elongation at break evolution for the two EPDMs, evidencing a sharp decrease with dose. For both materials, the elongation at break at 2 MGy falls below the absolute value of 100%, often indicated as one of the conditions for a material to be defined as elastomeric, marking a severe deterioration of the materials with dose. The relative decrease of the elongation at break is however more severe for Angst + Pfister's EPDM than for James Walker's one. At 2 MGy, James Walker EPDM retains about 28% of its original elongation at break, while Angst + Pfister EPDM retains about 6% only. Minor differences between the retained elongation at 2 and 3 MGy are reported, suggesting that at 2 MGy already, the ability of the material to recover the original shape is greatly compromised.

Both systems presented a reduction of the stress at break (not reported here) as well. For James Walker EPDM, the stress at break decreases from 18 (unirradiated) to 8 MPa after irradiation at 3 MGy, almost linearly decreasing with the absorbed dose. For Angst + Pfister EPDM, the stress at break dropped from 10 MPa (unirradiated) to about 5 MPa at 2 MGy, maintaining the same value at 3 MGy as well.

Fig. 6 shows the T_g evolution as a function of the dose for the two EPDMs, reporting a moderate but progressive increase for both materials. For James Walker EPDM, a slight overall T_g increase of 3 °C is reported, from −45 °C for the nonirradiated to −42 °C at 3 MGy. For Angst + Pfister EPDM, an increase of 7 °C is reported, from −55 °C for the nonirradiated to −48 °C at 3 MGy.

Fig. 7 shows SR_{eq} evolution as a function of the dose for the two materials. A progressive and significant SR_{eq} decrease with dose is observed, indicating that cross-linking is the prevalent radiation induced effect at the microscopic scale. The finding is in agreement with the increase of stiffness and T_g, as a consequence of the increased network density, and with the reduction of the strain at break, due to a limited mobility of the chain.

Weight loss results (not reported here) do not show significant evolution with dose.

E. Discussion

At the mechanical level, a progressive hardening (increase of the Young's modulus E) and a very severe embrittlement (decrease of the elongation at break) of both materials with the dose are reported.

At the structural level, a progressive increase of the transition glass temperature T_g is reported, as well as a progressive decrease of the SR, evidencing that the cross-linking is the dominant radiation-induced effect. Increased cross-linking levels are in fact associated with higher T_g values and lower SR values, and they correspond to a progressive hardening of the material at the macroscopic level, leading to embrittlement.

The qualitative evolution of the two materials with the dose is comparable, indicating that the same type of radiation-induced mechanisms are occurring in both EPDMs in the selected irradiation conditions. Severe degradation of the most important mechanical quantities is reported at the investigated dose levels, motivated by the increased cross-linking.

The sharp decrease of the elongation at break suggests that at 2 MGy of dose the degradation of both materials largely exceeds their usable conditions as elastomeric materials. This is indeed expected for EPDM-based materials, whose radiation tolerance is generally lower than 2 MGy [2], [5], [14], as further discussed in Section VII-F and as summarized by Fig. 8.

Finally, it is important to note that the relative change of the tested quantities is definitely more pronounced for the Angst + Pfister material. James Walker EPDM overall shows a greater stability as a function of the dose and it is for this reason considered as more reliable for use in high-radiation areas.

Further tests at lower gamma doses are planned, aiming at a deeper understanding of the radiation degradation mechanisms on these materials.

F. End-of Life Conditions and General Dose Thresholds

To quantitatively assess the overall radiation effect in elastomeric materials using a simplified approach, it is convenient and practical to use the evolution of the elongation at break as a function of the dose as figure of merit. In fact, the elongation at break is one of the most radiation sensitive properties as a function of the dose. A 50% reduction of the original elongation at break usually marks a moderate endpoint of material degradation, while a drop of the absolute elongation at break value below 100% marks a severe end-point for the material, which becomes no more elastomeric by definition.

Both James Walker and Angst + Pfister EPDMs tested in this study largely exceed these end-points at the minimum investigated gamma dose of 2 MGy, suggesting that the most important degradation phenomena occur at lower doses.

Fig. 8 shows a comparison between three commercial EPDM O-rings including James Walker Shieldseal663 (referred to as EPDM 3 in the graph), irradiated in the frame of a previous study performed in neutron and gamma mixed

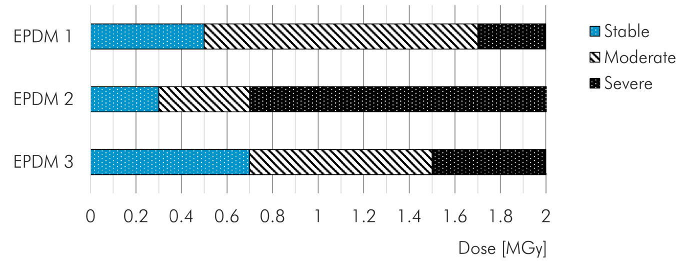

Fig. 8. Dose thresholds for three commercial EPDM O-rings irradiated in mixed neutron and gamma radiation. In the graph, EPDM 3 corresponds to James Walker Shieldseal663. Data extracted and elaborated from [17], [18].

field radiation [17]. In this study, the neutron component of the dose corresponded to about 65% of the total, the rest being deposited by gamma radiation, at a very high total dose rate of approximately 0.7 MGy/h. Dose values ranging between 0.68 and 2.06 MGy were investigated.

Despite the great differences in the irradiation conditions, severe degradation seems to occur at comparable dose values for James Walker EPDM. Further studies aiming at a systematic comparison of the radiation effects in different irradiation conditions are planned.

Remarkable differences between the dose thresholds associated with the defined end-points of different materials can be in any case observed, confirming the importance of testing and qualifying specific commercial materials for use in high radiation areas.

Dedicated case studies can help adapting the defined end-points to specific operation conditions.

VIII. Examples of Applications

Based on the collected data, defined end-points and acceptance criteria, a general methodology for the selection of greases in high-radiation areas has been proposed and used for the selection of the lubrication of several beam intercepting devices. The lubricants used in the support structure of the LHC dump [8] and the internal beam dump of the super proton synchrotron (SPS) [7] are expected to absorb a maximum total dose of about 15 MGy and of about 10 MGy over the equipment desired lifetime, respectively. Experimentally qualified greases were selected for these critical applications [7].

Additionally, radiation resistant lubrication is currently needed for hundreds of LHC devices requiring regular and precise alignments during operation. Greases for the alignment systems are currently being selected, taking into account not only the radiation tolerance, but as well other challenging requirements such as the quasi-static conditions under very high load for prolonged periods.

James Walker Shieldseal 663 EPDM elastomeric O-rings have been recently selected for several applications, including the upstream window of the LHC dump [7], the replacements of the O-rings currently installed in the beam stoppers of the SPS, the flanges for the insulation vacuum of the dipole cryostats in the arcs of the LHC and for the upgrade of the CMS ECAL detector.

Cables used at CERN where doses exceed 100 Gy have to be irradiated and qualified via mechanical tests. Irradiation tests of the most used cable types at different dose rates are currently ongoing, aiming at qualifying new products and at understanding the effect of different irradiation conditions in determining the overall mechanical damage.

All the mentioned equipment needs to operate for decades, with little or no maintenance possibility, absorbing doses up to the MGy range. Failure of these devices due to radiation damage would have a great impact on the accelerator operation, leading to shutdowns in the worst case scenario. For these reasons, irradiation tests and the R2M expertise are necessary, to ensure a continuous and reliable selection of radiation tolerant products for the whole accelerator system.

IX. Conclusion

Through different types of activities, including the selection of radiation tolerant materials from the market, the design and organization of radiation damage studies and the interpretation of post-irradiation characterizations, the R2M provides a general support to CERN, concerning the testing and irradiation of materials for high-radiation applications. Various irradiation activities are continuously performed at CERN, to qualify specific products, to finalize designs and to properly plan upgrades, aiming at minimizing the risk of failures in operation. Tests results recently allowed the successful commissioning of several challenging devices operating in high radiation areas, such as the beam dumps of the LHC and of the SPS accelerators.

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