ESTIMATE OF LIFE PERFORMANCE OF CABLE INSULATING MATERIALS FROM ACCELERATED RADIATION DAMAGE TESTS FOR THE CERN LEP PROJECT

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ABSTRACT

The Large Electron Positron storage ring, LEP, is at present under construction at CERN. It is estimated that the cables installed in this machine will be exposed to doses of $10^5$ to $5 \times 10^5$ Gy depending on the beam energy. The materials specified for insulation and sheath of these cables are polyethylene, ethylene-propylene rubber and flame retardant halogen-free polyolefins. Radiation damage tests have been carried out on these materials both at high dose rates of $10^5$ Gy/h and low dose rates of 100 Gy/h. From the results of these tests estimates are made on the life performance of the cables. It is shown that depending on the materials, the specified end point criterion of 100% elongation at $10^6$ Gy can be expected to be reduced to 4 to 20% due to long term radiation aging effects. Taking this into account and under the present assumptions of LEP operation parameters for 10 years, the radiation induced degradation must be expected to be severe to moderate for the higher energy stages of the LEP project.

Les anneaux de stockage à électrons et positons, LEP, sont actuellement en cours de construction au CERN. Selon l'énergie des faisceaux, la dose à laquelle les câbles seront exposés dans cette installation est estimée de $10^5$ à $5 \times 10^5$ Gy. Les matériaux spécifiés pour l'isolation et la gaine de ces câbles sont le polyéthylène, le caoutchouc éthylène-propylène et des polyolefines exempts d'halogène. Des essais sur la dégradation de ces matériaux due aux rayonnements ionisants ont été effectués tant à des débits de dose élevés de $10^5$ Gy/h qu'à de faibles débits de dose de 100 Gy/h. A partir des résultats obtenus lors de ces essais, des estimations de vie de ces câbles dans des champs de rayonnement ont été obtenus. La dégradation définie selon le critère de 100% d'allongement pour la rupture à $10^5$ Gy sera réduite selon le matériau, de 4 à 20% par les effets d'irradiation à long terme. Par conséquent, il faut estimer les dégâts causés par le rayonnement LEP, importants à modérés, selon les définitions d'opération actuelles en 10 ans.

1. Introduction

At CERN, the European Organization for Nuclear Research, a large amount of radiation damage test data are available that have been obtained on commercial cable insulating materials in accelerated irradiations at high dose rates. These data have to be used with some caution for the estimate of life performance since it is known that in long-term irradiations at low dose rates some materials degrade more for the same total dose, in particular owing to the presence of oxygen. On the other hand, to carry out radiation damage tests at dose rates as close as possible to the service dose rate is an unrealistic requirement. In fact, at CERN the decision on the acceptance of a material has to be taken between the closing date of a tender and the date when the contract is placed, which in general leaves a very limited time of a few months only for testing. The installation as such is however designed to operate for several decades.

In this paper we describe the present practice at CERN to select the cable insulation and sheath materials on the example of the LEP project. LEP is the Large Electron Positron ring for colliding beam experiments. This will be installed in an underground ring tunnel of
approximately 3.5 metres diameter and 27 kilometres circumference. In this tunnel hundreds of kilometres of cables of all types will be exposed continuously during operation to synchrotron radiation in the 100 keV to 1 MeV range emitted by the circulating electron beams.

It should be noted that cable insulating materials are an important but not the only subject of the radiation damage test programme at CERN. Results of the work on other items can be found in the literature\textsuperscript{5-7}.

2. Dose estimates and measurements

Before an assessment of the material performance in the radiation environment could be made the expected dose levels had to be defined and evaluated\textsuperscript{3}. At the existing CERN proton accelerators high radiation levels only occur at loss points such as injection, ejection, dump and target areas. As mentioned above, in LEP the radiation level will be uniform in all curved sections. In order to keep the doses at values that still allow the use of standard materials, the vacuum chamber will be surrounded by a lead shield\textsuperscript{9}. The actual doses to the cables at the cable tray depend on the energy of the circulating electrons, e.g. for 85 GeV the dose is about $10^5$ Gy and for 100 GeV about $5 \times 10^5$ Gy. These values are estimated for an operation time of 30,000 hours in 10 years. Hence the mean dose rate to which the cables will be exposed is of the order of 3 Gy/h to 15 Gy/h.

It is a practice at CERN to follow up and record the dose to the materials and components by integrating passive dosimeters\textsuperscript{10-11}. Such high-level dosimetry will also be carried out for LEP; it presents a very important and integral part of the assessment of radiation endurance together with samples taken from cables at regular intervals for testing after exposure in their natural environment.

3. Material and test specification

The large variety of insulating materials available on the market and the freedom of compounding by the cable manufacturers complicate the estimate of the material performance. CERN as an international
organization purchases cables from manufacturers all over Europe. Nevertheless results of accelerated and long-term irradiation tests have shown some consistency within a certain group of compounds. Therefore known groups of compounds are required in our specifications. These are at present ethylene propylene rubber (EPR) for insulation and sheath for power cables, low-density polyethylene (PE) as insulation, and polyolefin as sheath for signal and control cables. All materials are free from halogens and, apart from PE, have fire retardant properties.

Of further importance for the estimate of the performance of the materials is the selection of test methods and end-point criteria. Even within a given method, e.g. tensile test, one would arrive at completely different appreciations of radiation resistance if one takes tensile strength or elongation at break as critical parameter. At CERN we have selected elongation at break, and as end-point criterion we require at present that it is above 100% after an absorbed dose of $10^6$ Gy with irradiation at high dose rates (5-50 Gy/s).

4. Estimate of life performance from accelerated tests

4.1 Procedure

In the tunnels of the CERN high energy accelerators the predominant parameter that influences aging of cable insulating materials is ionising radiation. This will be more pronounced for LEP than for the existing CERN installations. The tunnels are however air-conditioned and therefore the fact that the combination of radiation and elevated temperature further accelerates aging¹² is not relevant.

The specification for the cables for LEP are at present in preparation and will be sent to the European cable manufacturers during the coming year. In these specifications the functional performance requirements are usually defined according to Standards of the International Electrotechnical Commission (IEC). As regards to radiation resistance 100% of remanent elongation is required after an accelerated irradiation to $10^6$ Gy as stated in the chapter above. Hence the "life" dose is given in a few hours or days. The question
arises how to interpret the results obtained in such accelerated tests in terms of dose and degradation obtained in the real life of the cable of 10 years or more.

In the case of thermal aging empirical laws exist to correlate time and temperature, which are theoretically supported by chemical kinetics and physico-chemical considerations. On the basis of these the thermal aging can be accelerated by elevating the temperature. Although also this method has its limitations it is well practiced all over. Unfortunately in the case of radiation induced aging we have no such relation which allows straight forward extrapolation from irradiation at high to low dose rates. It may be that such a relation cannot be established as the degradation mechanisms may be completely different in the two cases for some materials eg. predominance of cross-linking in the one and oxygen assisted degradation in the other. On the other hand one may hope that more profound analysis of the existing data and further investigations will yield an acceptable model and procedure. First attempts in this direction are available and give promising results.\(^{13}\)

At present for the life estimate of cables for LEP we have to rely on today's knowledge and experience. A working group has been active at CERN for seven years dealing with fire and radiation aspects of cables. This working group recommended the use of the materials cited in chapter 3 above and radiation tests are carried out on these materials both at high dose rates \((10^5 \text{ Gy/h})\) and low dose rates \((100 \text{ Gy/h})\). Comparison of the degradation at the same total dose shows for some types of compounds of PE a ten times faster and for EPR about a two times faster degradation. The factor for PVC, which was used extensively in the past, and its replacement, halogen free flame retardant polyolefin, lies between these two. At LEP the estimated dose rate of 15 Gy/h is lower by another factor 6. As it has been shown that in a simple model the end point dose is expected to decrease with the dose rate \(D\) by \(\sqrt{D}\), this means that another factor 2.5 has to be considered and consequently a reduction of the end point dose or the end point criterion by 25 for PE and 5 for EPR. Extrapolation to even lower dose rates seems not to be adequate since firstly, the curve of decrease of end point dose with dose rate must level off at some stage, and secondly: the lower the dose rate, the
longer the time it takes to reach the end point dose; in fact this time would go from decades to centuries, which appears unrealistic for any estimate.

4.2 Discussion

In practice a given cable insulation or sheath material which has the specified elongation of 100% at $10^6$ GY would have reduced this end point dose to $4 \times 10^4$ GY (factor 25 lower) for some PE's and to $2 \times 10^5$ GY (factor 5 lower) for some EPR's.

As the specified elongation of 100% includes an appreciable safety factor one could also make the approach to maintain the end point dose of $10^6$ GY and estimate the reduction in the end point criterion which would yield an absolute value of 4% elongation for PE's and 20% for EPR's. The value for flame retardant halogen free polyolefins is expected to be between these two.

Although in the second approach the relation between elongation at break and irradiation dose is not well known for the extrapolation dose rate, we use this method to estimate elongation at break for cable insulating materials, which have the specified values of 100% at $10^6$ GY for the three different energy phases of LEP:

- At 100 GeV the estimated life dose is $5 \times 10^5$ GY. The reduction factor will be about 12.5 for PE's and 2.5 for EPR's. Hence the absolute values for elongation at break will be between 8 and 40%.

- At the 86 GeV stage the estimated life dose is $10^5$ GY. As this end point is a factor 10 lower, the elongation for PE's may be estimated to be about 40% and for EPR the value should be above 100%.

- At the 50 to 60 GeV stage the doses are so low that no change of the properties of the cable insulating materials caused by radiation can be expected.
All this is based on the assumptions of LEP operation parameters and time given in ref. 9 and the factors evaluated in the section 4.1 above.

Long term irradiation of cable insulating materials at CERN\textsuperscript{14} and practical experience in operation of the existing CERN accelerators\textsuperscript{15-15} have confirmed that the order of magnitude of these factors is realistic.

5. Conclusions

It has been demonstrated from the example of the CERN LEP project that the presently specified value of 100% elongation at $10^5$ Gy from accelerated tests may in reality, due to long-term radiation effects, be as low as 4 to 20% depending on the material. This clearly leaves no room for further decrease of the end point criterion, unless the end point dose is decreased at the same time.

Under the present assumptions of LEP operation parameters and time\textsuperscript{9}, the radiation induced degradation of cable insulation and sheath materials have to be considered severe for the 100 GeV stage, moderate for the 86 GeV stage and unimportant for the 50-60 GeV stage.

As different materials exhibit different effects in long-term radiation aging, preference should clearly be given in specifications wherever possible to materials, such as EPR, which show a smaller dose rate dependance.
REFERENCES


