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RADIATION TESTS ON SELECTED ELECTRICAL INSULATING MATERIALS FOR HIGH-POWER AND HIGH VOLTAGE APPLICATION

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ABSTRACT

This report presents a comprehensive set of test results on the irradiation of insulating materials and systems used for the windings of rotating machines, dry-type transformers, and magnet coils. The materials were: Novolac, bisphenol-A, and cycloaliphatic types of epoxy; saturated and unsaturated polyesterimide; silicone, phenolic, and acrylic resins. The reinforcement consisted of glass mat, glass roving, glass cloth, mica paper, polyester mat, polyester roving, polyester cloth, aromatic polyamide paper, or combinations thereof.

The materials were irradiated in an 8 MW pool reactor up to integrated doses of 10^8 Gy. On most samples, flexural properties were examined as recommended by IEC Standard 544. For tapes and varnishes, the breakdown voltage was measured. The adhesion of copper bars glued together with an epoxy resin was examined by means of a lap–shear test. A cupping test by means of the Erichsen apparatus was used to measure the flexibility of varnishes.

The results are presented in tables and graphs for each of the materials tested. Those from mechanical tests show that the radiation resistance of composite resin-rich insulations depends not only on the base resin combination and the reinforcement material but, to a large degree, also on the adhesion between the two. It appears that better adhesion, and consequently higher radiation resistance, is obtained by special surface treatments of glass fibres. For laminates, higher radiation resistance is obtained with glass mat and resin combinations than with glass cloth as reinforcing materials. The breakdown voltage tests show that the application of mechanical stress to most irradiated samples causes the insulation layer to crack, resulting in lower dielectric strength. For a number of materials, the critical properties of flexural strength and breakdown voltage are above 50% of the initial value at doses between 10^7 and 10^8 Gy, i.e. a radiation index of 7 to 8 at 10^5 Gy/h.

CONTENTS

1. INTRODUCTION

Ionizing radiation is a factor that influences or accelerates the ageing of electrical insulating materials in installations such as high-energy accelerators, nuclear power stations, or fusion reactors. The dose estimates for the Large Electron–Positron storage ring (LEP) under construction at the European Organization for Nuclear Research (CERN) show that materials located near the vacuum chamber may, over 10 years of operation, accumulate integrated doses of 1×10^8 Gy (1 Gy = 1 J/kg = 100 rad) [1,2]. At such high doses many materials, in particular organics, undergo substantial changes in their mechanical and electrical properties or become completely unusable [3]. On the other hand, for reasons of economy the size of such an installation (for LEP the circumference of the accelerator ring tunnel is 27 km) calls for the application of standard materials and methods of fabrication. It is, however, well understood that a careful choice of materials is essential.

This report gives a representative selection of electrical insulating materials and systems for application in nuclear industry, including impregnating resins, glass- and mica-reinforced resin systems, and insulating tapes and varnishes. Electrical and mechanical tests were carried out on these materials, and the change of their characteristic properties as a function of absorbed dose is reported. Most materials were irradiated up to 10^8 Gy. The irradiation conditions are described in Section 2 and the tests and test methods in Section 3. The results are presented in comprehensive tables and graphs and are further discussed in Sections 4 and 5.

2. IRRADIATION CONDITIONS

It is known that radiation damage to materials does not depend only on the total integrated dose; it may also depend on the dose rate, as well as on environmental parameters such as humidity and temperature. For this reason three types of routine radiation tests are carried out at CERN:

i) accelerated irradiation at high dose rates (usually > 10 kGy/h) for material selection and acceptance tests;

ii) irradiation at lower dose rate (0.01 to 1 kGy/h) for dose-rate effect studies;

iii) life exposure of material samples, and tests carried out on components exposed *in situ* to follow up the degradation during operation.

Dose-rate effect studies at CERN [4] and in other institutes [5 – 12] have shown that the damage effect of the same integrated dose can be up to a factor of 10 higher at low dose rates (service dose rate). This is especially true for elastomers and thermoplastic components as used in cable industry [5]. On the other hand, practical experience at CERN during 25 years has shown no unexpected substantial failure of materials (except some types of cables) which could be attributed to dose-rate effects. This indicates that a sufficiently large safety margin is included in the specified end-point criteria to allow for such hidden damage effects. It must be stated that at CERN the dose accumulation during operation of the accelerator is controlled by an integrating passive dosimetry system [13,14].

For the LEP project the performance of the materials used in the tunnel should be sufficiently reliable for a steady operation period of 30,000 hours. According to the present design parameters for average current intensity, the estimated doses are about 1×10^5 Gy for cables and service equipment and 3×10^7 Gy for magnet coils. The expected service dose rates are therefore of the order of 3 Gy/h to 1000 Gy/h.

During the lifetime of the nuclear power stations where high-voltage motors and dry-type transformers are used, the expected doses are 10^2 to 10^6 Gy.

All samples for this study were irradiated in the ASTRA 8 MW pool reactor in Seibersdorf, Austria [15]. Depending on material composition and size, two irradiation positions have been selected: 'Plane 1' and 'position 35'.

2.1 Position 'Plane 1'

The irradiation position Plane 1 is located outside the reactor core, about 26 cm from the core edge. The standard arrangement consists of four cylindrical containers of 9 cm diameter, 160 cm total length and approximately 30 cm usable length for irradiation; these containers can be irradiated simultaneously. The gamma dose rate for the two containers in the centre is 2.5×10^5 Gy/h, and about 1.8×10^5 Gy/h for the two lateral containers at a reactor power of 8 MW. The dose variation within the irradiation container is ± 12% in the horizontal plane and ± 10% in the vertical one. The reduction in dose rate in the radial direction is compensated by turning the container by 180° after half the irradiation time has elapsed. Thus the deviation of the dose to each individual sample should be not greater than ± 5%. The gamma dose rate is measured at the beginning and end of each irradiation by means of an ionization chamber.

The thermal neutron and fast neutron fluxes are measured by means of activation detectors. The values are given in Table 1. The flux within the radiation container varies by ± 15%, which again is reduced to ± 7% by turning the container by 180°. The contribution of neutrons to the total dose to the samples is below 5%.

Throughout irradiation the samples are cooled by forced-air convection. The temperature within a test sample has been measured, during an irradiation of 17 hours, by a Chromel–Alumel thermocouple. The mean temperature found was 62°C.

2.2 Position 35

Metals irradiated in a nuclear reactor become highly radioactive and can usually only be handled by a telemanipulator for reasons of safety. To avoid this complication when testing, and also to be able to use the reactor for irradiations when it is not in operation, a fuel element is removed from the middle of the core and a cylindrical irradiation container of 7 cm diameter, 150 cm total length, and up to 50 cm usable length for irradiation is inserted into the vacant position. The intensity of the radiation field varies considerably during the irradiation time, depending on the prior history of the reactor core and the time which elapses between reactor shutdown and start of irradiation. For this reason the gamma dose rate is continuously monitored by ionization chambers which are located outside the reactor core in a zone of low radiation intensity.

The dose rate in the container is measured before and after the irradiation and varies typically from 1×10^5 Gy/h to 1×10^4 Gy/h. The dose rate between the top and bottom of the container varies within a factor of 2. The aim of the present irradiation of samples was, however, to keep the dose variation below ± 10% by confining the position of the samples to within ± 10 cm of the central part of the irradiation container. For the massive adhesion samples the dose was increased by 15% to compensate for absorption in the metal. In position 35 the energy spectrum of the gamma rays is typical for reactor fission products, with a mean contribution situated between 0.5 and 6.0 MeV and a peak value at about 1.0 MeV. Therefore, for organic materials the radiation effects in this position are fully comparable with those encountered in the position Plane 1. It must be stressed that the radiation type and energy is also representative of the radiation spectrum to be expected in LEP, and in various other installations.

The samples are irradiated in air, and with a temperature of the reactor-pool water of 40°C the sample temperature is not expected to exceed 45°C.

The main characteristics of the irradiation positions are summarized in Table 1. More information about the irradiation facility can be found in Ref. 15. The integrated doses to the individual samples are given in the tables, and the results are discussed in Section 4.

3. MATERIAL SELECTION, TESTS, AND TEST METHODS

In the past, tensile and flexural tests have been carried out at CERN on a large number of irradiated electrical insulating materials. The reason for this is that mechanical properties are very sensitive to radiation, and experience shows that electrical breakdown of insulating materials is usually a consequence of severe mechanical deterioration.

For some of the materials tested, the characteristics of tensile and flexural properties are not relevant because of the nature and form of the material, for example tapes and varnishes. For this reason other characteristics were tested, complying with their practical application.

The materials presented in this report are frequently used in the construction of electrotechnical equipment and products. Based on earlier experience they have, however, been selected for application and operation in ionizing radiation environment.

3.1 Mechanical tests

The IEC standard 544-3 recommends flexural strength as the property for determining the effects of ionizing radiation on non-flexible insulating materials. Flexural properties were therefore determined on all materials which can be brought to a rigid form, e.g. by casting and curing of resins or by pressing and curing of prepregs. It must be stressed that most of the tested materials are also used in a relatively thick solid layer in the electrical apparatus. Therefore, this method can be considered to be representative.

The testing method employed a three-point loading system utilizing a centre load on the sample (size: 80 mm × 10 mm × 4 mm) according to ISO 178. The distance between the two supports was 67.0 mm and the speed of the crosshead was 2 mm/min. As an end-point criterion for the definition of radiation resistance we require, in accordance with IEC 544-3, that at a given dose D the ultimate flexural strength of the material is above 50% of its initial value at zero dose.

The resins used as impregnating materials or as binder for prepregs were of the following types: epoxy (Novolac, bisphenol A, and cycloaliphatic); polyesterimide (saturated and unsaturated); silicone, phenolic, and acrylic resins.

The reinforcements consist of glass mat, glass roving, glass cloth (which can be desized or sized by silane or dextrin), mica paper, polyester mat, polyester roving, polyester cloth, aromatic polyamide paper, or combinations thereof. Details of the reinforcement materials can be found in Appendix 1.

Resins are mainly used to impregnate windings of rotating machines, dry-type transformers, and magnet coils. Prepregs are combinations of resins and fillers and are also used in this equipment.

Combinations of resins and reinforcements are also applied as spacers and supports in cases where electrical and mechanical stresses occur.

A very critical point in large pieces of electrical equipment is the interface between the insulating resin and the conductors, especially when mechanical stress is applied tangentially to the interface. Therefore, the adhesion of copper bars glued together with an epoxy resin, with and without primer, has been examined by means of a tensile lap-shear test, taking DIN 53 283 as a basis. The sample configuration and dimensions can be seen in the figure below Table 13.

The following tests have been carried out for various types of varnish:

i) The cupping test, by means of the Erichsen apparatus, has been used to measure the flexibility of the varnish according to test method ISO 1520 or DIN 53156. A 0.05 mm coat of varnish was applied to a 50 mm wide soft copper panel. The varnished metal sheet was deformed according to the test method until cracks were observable with a magnifier (magnification 10×) or the varnish peeled off. This test allows assessment of the flexibility and adherence of the base. The larger the depth of penetration (in millimetres) the better the flexibility and adherence.

ii) A 1/64-inch ball weighing 32 g was applied for 30 s on five points on the varnish of a30 mm × 30 mm metal sheet. The depth of penetration during application of the pressure was measured, and also the remaining deformation after removal of the ball.

3.2 Electrical tests

Insulating tapes which remain flexible in the cured state are used for the insulation of conductor elements, armature bars, coil ends in large motors, high-voltage generators and dry-type transformers. These insulating tapes consist of one or more layers of foil and a binder. The sheets of foil are made from mica paper, glass cloth, polyester film, polycarbonate film, polyimide film or combinations thereof, and the binders are resins of the epoxy, polyurethane, silicone, and acrylic types. Some tapes are applied in the cured state, and some are cured after application; a bonding between the layers is then obtained. To simulate these applications each tape was wrapped around a copper bar, 1.5 mm × 10.5 mm, with half the width of the tape overlapping. They were irradiated in this arrangement and tested for electrical breakdown, first on straight bars and then on bent bars. The bending was done to get information about the brittleness of the insulation. This is of some practical importance because the insulations are under constant mechanical stress (e.g. vibration) when in service.

The breakdown test was carried out according to IEC Publ. 243. The inner electrode was the copper bar and the outer one was a wrapped-around aluminium foil, 20 mm wide.

The impregnating varnishes and resins, the coating varnishes, and the trickle resins were tested on copper panels as described under subsection 3.1. The breakdown voltage was tested, under oil, between the copper panel and a round electrode of 6 mm diameter. The varnishes and resins tested were of the following types: epoxy, phenolic, silicone, alkyd-phenolic, and polyesterimide.

The voltage versus current characteristic on a varnish of polyurethane filled with silicon-carbide for corona protection was determined taking IEC Publ. 93 as a basis. The d.c. high voltage was continuously increased and the current between two applied electrodes was recorded.

Breakdown voltage was measured on a glass–mica and silicone insulated power cable for high-voltage application on the basis of IEC Publ. 243. After irradiation the 30 cm long cable samples were bent over a core having a diameter (51 mm) equal to three times that of the cable. The testing voltage was applied on the 50 mm^2 central aluminium conductor, whereas the surface of the bent cable was put to ground. The voltage was increased in a sequence of one-minute steps until breakdown of the insulation.

Usually 50% of the initial value of the properties tested and described here was taken as the basis when judging the radiation resistance.

4. RESULTS AND DISCUSSION

The results are presented in the form of tables and graphs, where each material described is identified by a number. In the discussion below, we refer to these numbers.

4.1 Pure resin combinations (Table 2 and Figs. 1 to 6)

The radiation resistance of composite insulating materials depends primarily on the binding material, in particular in cases where the other components are inorganic, e.g. glass tape, mica, etc. For this reason pure resins that are generally used as binding materials were included in this study. On the other hand, not too much importance should be attributed to these results since the radiation resistance may be considerably improved by the reinforcing materials.

Comparing the results and taking the half-value dose for flexural strength after irradiation as the parameter, the following radiation resistance was found:

– No. 338, epoxy resin + isocyanate	up to 1×10^8 Gy
– No. 348, epoxy resin: DGEBA + anhydride + other components	up to 3×10^7 Gy
– No. 336, epoxy resin: DGEBA + anhydride + other components	up to 1×10^7 Gy
– No. 337, silicone resin	up to 1×10^7 Gy
– No. 369, silicone resin	up to 1×10^7 Gy
– No. 368, epoxy resin: DGEBA + anhydride + other components	up to 3×10^6 Gy

The isocyanate–epoxy resin combination No. 338, which was specially developed for high-temperature application, shows outstandingly good mechanical properties at 10^8 Gy; this can be explained by a strong cross-linking of the isocyanate–epoxy molecule groups.

Resin No. 348 also shows very high radiation resistance. This was achieved by modification of single components (e.g. using a latent accelerator) of resin No. 97 presented in Ref. 16 (Part II, p. 39).

The differences in the other resins are due to the different anhydrides and additives.

Visual inspection shows a darkening of all pure resin samples with increased radiation dose. Although the coloration effect is very pronounced, it cannot be brought into direct correlation with the degradation of the mechanical properties.

4.2 Vacuum pressure impregnating (VPI) resins with mica content (Table 3, and Figs. 7 to 12)

All the materials listed in Table 3 were obtained by using as binder the pure resin combinations described in the previous subsection. In all cases the mechanical properties and the radiation resistance increased, although to a different extent, probably owing to the difference in adhesion between the resin and the reinforcing materials.

A very high radiation resistance exceeding 10^8 Gy was obtained by combining the silicone resin No. 337 with the mica paper + glass-cloth tape in material No. 340. A combination of similar reinforcement material with epoxy resins Nos. 97 [16] and 336 yields a radiation resistance of 10^7 Gy (materials 341 and 339).

The three materials Nos. 355, 356, and 357 all contain the same epoxy resin as binder(No. 368) and exhibit a radiation resistance of 10^7 Gy. The material combination No. 357 with polyester mat is equivalent to No. 355 with glass-cloth backing tape. This means that replacement of the glass-cloth tape by polyester mat has no influence on radiation resistance. Combinations Nos. 355 and 357 contain paper made of calcinated mica, whereas No. 356 contains paper made of uncalcinated mica. For the latter the radiation resistance decreases more quickly after a dose of 10^7 Gy. An analogous behaviour of these types of material is observed after application of thermal and electrical stresses.

4.3 Resin-rich insulation with mica (Table 4, and Figs. 13 to 17)

As in the preceding subsection, all materials of this group contain mica, and at doses exceeding 10^7 Gy a delamination was occasionally observed. Therefore, as in high-voltage application, the kind of adhesion between mica particles in the insulating tape is very important for the radiation resistance. It is expected that gases produced by radiation at high dose rates of 2×10^5 Gy/h cannot diffuse out quickly enough and hence may cause local increase of pressure within the sample, with the further consequence of separations within the mica layer.

High radiation resistance within the mica-containing materials was obtained with combination No. 351. The flexural strength decreases only slightly at 3×10^7 Gy, and is still at 50% of the initial value at 10^8 Gy. The only difference between materials No. 351 and No. 352 is the desized glass-cloth of the latter. From this one would not, however, expect the lower radiation resistance shown in Table 4. Also surprising is the pronounced increase in flexural strength and modulus of elasticity of material No. 354 at a dose above 10^7 Gy.

Material No. 342 shows satisfactory results up to 3×10^7 Gy and material No. 353 to 1×10^7 Gy.

4.4 VPI resin insulation without mica content (Table 5, and Figs. 18 to 22)

All materials of this group are solventless epoxy resins reinforced with glass cloth or aromatic polyamide paper. Appropriate measures have been taken to increase radiation resistance, for example by special surface treatment of the glass fibres (No. 343), or by desizing (No. 349). The results show a clear increase of the radiation resistance by a factor of 10 compared with the pure resins mentioned in subsection 4.1. In fact the half-value dose of flexural strength is around, or even above, 10^8 Gy. This also indicates that the adhesion between the resin and the surface of the reinforcing material is stronger and more consistent for glass cloth and aromatic polyamide paper than for the mica-containing compounds described in subsections 4.2 and 4.3.

4.5 Laminates (Table 6, and Figs. 23 to 30)

The tested laminates show large differences in composition and consequently in radiation resistance. In decreasing order they can be classified as follows:

- No. 364, mica tape with inorganic binder — $\gg 10^8$ Gy
- No. 360, glass mat + epoxy Novolac — $> 10^8$ Gy
- No. 359, glass mat + polyester resin — up to 1×10^8 Gy
- No. 332, glass mat + epoxy resin — up to 3×10^7 Gy
- No. 358, glass mat + polyester resin — up to 3×10^7 Gy
- No. 331, glass cloth + epoxy resin — up to 1×10^7 Gy
- No. 361, polyester cloth + epoxy resin — up to 1×10^7 Gy
- No. 330, glass cloth + epoxy resin — up to 5×10^6 Gy

The results clearly indicate the higher radiation resistance of glass mat + resin combinations compared with glass cloth as the reinforcing material. The differences can be as high as a factor of 10, also within a given group of materials because of the unidirectionally oriented fibres of the reinforcement. Attention therefore has to be paid to the composition and designation of the materials when they are selected for use in a high-radiation environment.

4.6 Special material combinations (Table 7, and Figs. 31 to 38)

The mechanical properties of material combination No. 365 (glass roving with polyester resin) remain almost unchanged after an absorbed dose of 10^8 Gy, and for materials Nos. 345, 366, and 367 (again glass roving with polyester or epoxy resin) the values are still above 50% of the initial value at that dose. All these materials are characterized by a strong bond between resin and glass fibres, a strong cross-linking, and a high proportion of glass compared with the resin part. This results in a high flexural strength, a high modulus of elasticity, and an outstanding radiation resistance.

Material No. 344 is a special glass rope impregnated with a standard epoxy resin (No. 336, subsection 4.1). This special glass rope consists of relatively short and more or less non-oriented glass fibres covered with a woven glass sheath. The mechanism of fracture is therefore different for glass ropes and laminates, because no separation can occur in the different planes of the layers. The different planes are interconnected by random fibres which expand whilst still adhering to the resin structure. The half value of the flexural strength for this material is approached at about 3×10^7 Gy.

Materials Nos. 362 and 363 differ in their glass content and their base resin, which for the former is a cycloaliphatic–anhydride system and for the latter a bisphenol A–anhydride system (resin No. 368, subsection 4.1). The mechanical properties decrease rapidly for material No. 362 above 3×10^6 Gy, whereas the initial values for material No. 363 are relatively low at zero dose and decrease by 50% at 3×10^7 Gy.

4.7 Conductor insulating tapes (Table 8, and Figs. 39 to 48)

Of the ten insulating tapes, all except one (the last in Table 8) contain mica. Breakdown voltage tests have been carried out on these specimens as described in subsection 3.2. In order to have some information on the degree of brittleness of the insulation, the test was not only carried out on the straight sample but also on a 45° bent sample.

The mica-containing tapes can be divided into two groups: combinations with and without film. Numbers E 01, E 02, and E 03 belong to the second group. All of them maintain the value for breakdown voltage within specification requirements at 5×10^7 Gy. The materials with film all show a higher initial value of breakdown voltage. The high dielectric strength of the films is, however, already destroyed at the lowest radiation dose used in this test, i.e. 5×10^6 Gy. On the straight conductor the breakdown voltage levels off at a value of tapes without film. Exceptions to this are the epoxy-impregnated combinations Nos. E 08 and E 09, where the breakdown voltage remains unchanged up to 5×10^7 Gy on the straight conductor. The sample without mica maintains the breakdown voltage up to 10^7 Gy and decreases to 50% of the initial value at 5×10^7 Gy.

A common feature of all breakdown voltage measurements on 45° bent samples is that there is evidence of severe radiation damage. The mean values given in Table 8 come from five test specimens. Among the bent specimens, some were torn during bending, and thus could not be measured: in that column, the numbers in brackets indicate how many specimens remained to be measured from each sample of 5. In some cases no test was possible since all specimens were torn. For the same reason, any test at a higher degree of bend, e.g. 90° or even 180°, would have been impossible. It must be stressed that this test is a very severe one, and in practice an insulated conductor installed in an electrotechnical apparatus or machine will never be bent by 45°. Nevertheless, the results obtained are very instructive since they show clearly that after mechanical degradation of an insulator due to radiation, application of mechanical stress is the cause of electrical failure that otherwise would not occur.

4.8 Impregnating and coating varnishes
(Table 9 and Figs. 49 to 54 for varnishes containing solvents,
and Table 10 and Figs. 55 to 57 for solventless varnishes)

Breakdown voltage tests on varnishes with and without solvent content did not show any significant changes when irradiated and non-irradiated samples were compared. The phenolic impregnating varnish (No. E 15, Table 9) adhered only partly or not at all after a radiation dose of 10^7 Gy, and for No. E 17 the breakdown voltage went down to 50% of the initial value at 5×10^7 Gy. For the other products the value remained unchanged or even increased slightly.

The results of the flexibility tests in Tables 9 and 10 clearly indicate that radiation may cause either hardening or softening of the varnish, depending on which of the components degrade. Materials Nos. E 11, E 12, E 17, E 15, and E 16, with decreasing flexibility, belong to the first category and comprise alkyd–phenolic, polyesterimide, and epoxy resins. A very pronounced increase of flexibility is observed for No. E 14, which has a silicone–polyester base. This may be due to an initial cross-linking followed by a degradation of the polyester component so that finally only the silicone component remains. Materials Nos. E 18 and E 19, based on unsaturated polyesterimide, are rigid products with a high aromatic content. The flexibility has the highest value at 10^7 Gy and decreases again at 5×10^7 Gy, but the depth of penetration at this dose is still a factor of 2 higher than the initial value.

In a coating varnish of the phenol–formaldehyde type No. E 20, a reduction in penetration according to Erichsen was only noticeable after a radiation dose of 10^7 Gy (see Table 11). This indicates some brittleness of the film; however, in practice this has no influence on the insulating properties. As regards the deformation after application of a 1/64-inch ball of 32 g for 30 s, no change due to radiation was observed, neither in the depth of penetration nor in the remaining deformation after removal of the ball.

A comparison of the results of breakdown voltage with the flexibility shows that any change in the latter to higher or lower brittleness does not influence the insulating properties as long as the varnish adheres to the conductor.

4.9 Anticorona varnish (Table 12)

The specific surface resistance was measured on a polyurethane varnish filled with SiC (No. E 21), used for HV application in general. After an exposure of 3×10^7 Gy the voltage current characteristic remained unchanged and the appearance of the varnish did not alter. The good performance of the material is due to the high content of SiC filler and its perfect adhesion to the resin.

4.10 Adhesive (Table 13)

All tested samples treated with primer based on low-viscosity epoxy resin cured at high temperature showed, both before and after irradiation, a significantly higher shear strength compared with the samples without primer. After an absorbed dose of 10^7 Gy the mean value of the shear strength was 6 MPa for the samples treated with primer and 3.9 MPa for those without, and the half-value doses were about 3×10^5 Gy and 1×10^6 Gy, respectively.

4.11 Power cable (Table 14)

Breakdown voltage tests were carried out on a silicone resin/mica/glass insulated power cable for a nominal voltage $U_n = 6.6$ kV. After an exposure to 10^7 Gy the breakdown voltage was still higher than twice the nominal voltage; in practice, however, the load carried by such a cable does not exceed $U_n/\sqrt{3}$.

When interpreting the measured breakdown voltage and the minimum dielectric strength, it should be borne in mind that they were not only influenced by radiation but also by the mechanical stress that was applied after irradiation and before testing by bending the cable as required by the Standard. To keep the cable bent during irradiation was not possible owing to the configuration of the container. After bending, an increased brittleness was observed with increased radiation dose; this probably resulted in the fracture of some insulating tapes, which in turn caused the measured reduction in dielectric strength.

5. CLASSIFICATION OF TESTED MATERIALS ACCORDING TO RADIATION INDEX

The fourth part of the IEC Standard 544, at present in press [17], deals with a classification system, the purpose of which is to provide a guide for the selection and indexing of insulating materials in radiation environments. The Radiation Index (RI) in this Standard is determined by the logarithm ($\log_{10}$) of the absorbed dose in grays (rounded down to two significant figures) above which the appropriate critical property value has changed to the end-point criterion under specified conditions. For example, a material which satisfies a particular end-point criterion to a dose of 2×10^4 Gy has an RI of 4.3 [i.e. $\log (2 \times 10^4) = 4.306$].

In the present report we give the RI in the corresponding tables with the results for the mechanical and electrical tests. The flexural strength, as recommended in the Standard, and the breakdown voltage have been taken as critical properties. The end-point value is defined as 50% of the initial value.

The Standard IEC 544-4 requires a qualifier to be given with the RI, which identifies the dose rate at which the value has been obtained. This qualifier is in the present case 10^5 Gy/h and is given at the top of each table containing the results and RIs. As was discussed in the Introduction, the user of these data must be aware of possible dose-rate effects and therefore take into account some safety factors when applying RI at service dose rates which are usually lower. Experiments are being carried out at CERN to assess the size of this factor for the type of materials discussed in this report.

6. CONCLUSIONS

The present report summarizes a large number of results of radiation test data of a very representative set of insulating materials and systems used in electrotechnical equipment for high-energy accelerators, nuclear power stations, fusion reactors, etc. The interpretation of the mechanical and electrical test data increase our knowledge of the radiation resistance of insulating materials [18, 19]; this allows a number of interesting conclusions to be drawn:

1. The radiation resistance of composite VPI and resin-rich insulations depends not only on the base resin combination and the reinforcement material but, to a large degree, also on the adhesion between these two (compare No. 340 with Nos. 341 and 339 and other results in subsection 4.2). This adhesion depends on the selection of the resin and/or the selection and treatment of the reinforcing material. It appears that better adhesion and consequently higher radiation resistance is obtained by resin combinations with solid insulation materials without mica (compare the results in subsection 4.4 with those in subsections 4.2 and 4.3). However, mica is required for certain applications because of its outstanding dielectric properties. In combinations with mica, better results are obtained with silicon resin than with epoxy resin.
2. The test results of laminates show big differences (see subsection 4.5). Higher radiation resistance is obtained with glass mat resin combinations than with glass cloth as the reinforcing material.
3. For a number of insulating tapes the breakdown voltage decreases below 50% of the initial value between 10^7 and 5×10^7 Gy. The application of mechanical stress to most irradiated samples causes the insulating layer to crack, which then results in electrical failure.
4. Material combinations containing film and inorganic components are sensitive to radiation because the organic film component is destroyed. The combination silicone resin/mica/glass gives the best results (see Table 8).
5. Unlike the insulating tapes, the impregnating and coating varnishes do not show any significant reduction of breakdown voltage up to 5×10^7 Gy. This is irrespective of the fact that the material becomes softer or harder by radiation, as measured by the Erichsen depth. The insulating properties are maintained as long as the varnish adheres to the conductor.
6. In Tables 3 and 4 materials are listed in which the resin is different whilst the other components are the same. Since the resin is the sensitive part, the conclusion can be drawn that because of a more dense network of cross-linked polymers, epoxy resins of the Novolac type have higher radiation resistance than the bisphenol A type.
7. The results again show the inferiority of cycloaliphatic epoxy resins.
8. Epoxy resins modified with a plasticizer show an increasing mechanical strength after radiation because the plasticizing part becomes brittle.
9. The tested anticorona varnish showed unchanged voltage/current characteristics even after an exposure of 3×10^7 Gy.

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APPENDIX 1

Reinforcement materials and trade names

1. REINFORCEMENT MATERIALS

Glass mat, a product made of glass filaments, staple fibres, or strands, cut or uncut, oriented or not, held together in the form of a sheet.

Glass roving, a collection of parallel strands or parallel filaments assembled without intentional twist.

Glass cloth, a fabric woven from textile glass continuous yarns in warp and weft which can be desized or sized. Silan-size is designed to obtain a good bond between the glass surface and resins. Dextrin-size is purely to improve mechanical properties of the glass yarn.

Mica paper is a pure crystalline, electrical grade foil composed of several layers of minute overlapping flakes of mica, held together solely by the surface attraction between flakes.

Polyester mat, polyester roving, polyester cloth are similar to the corresponding glass products but are made from polyester yarns instead of glass.

Aromatic polyamide paper is a paper-like product made from polyamide fibres.

2. TRADE NAMES

of BBC [20–22]:
Micadur
Orlitherm
Veridur
Veridur-K
Orlidur

of Isola:
Samica
Samicatherm
Delmat
Vetronit
Fluoridit
Samicanit INOR
Polyglas
Epoflex

APPENDIX 2

Standards cited in this report

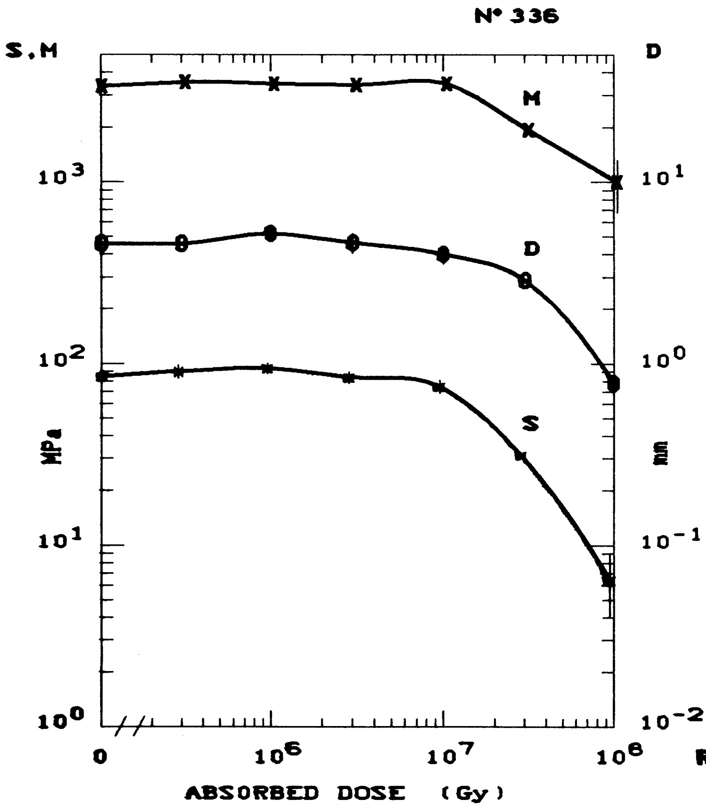
IEC 93	Recommended methods to measure transverse and surface resistivity of electrical insulating materials.
IEC 243	Recommended test methods for the determination of breakdown voltage of solid insulating materials.
IEC 544	Guide for determining the effects of ionizing radiation on insulating materials (4 parts).
ISO 178	Plastics—determination of flexural properties of rigid plastics.
ISO 1520	Cupping tests by means of Erichsen apparatus.
DIN 53156	Cupping tests by means of Erichsen apparatus.
DIN 53283	Lap-shear test.

Table 1
Characteristics of irradiation positions

Irradiation position	Gamma dose rate (Gy/h)	Neutron flux ($cm^{-2} s^{-1}$)		Precision in dose (%)		Cooling	Sample temperature (°C)
		Thermal	Fast (E > 1 MeV)	γ	n		
Plane 1 Central containers	2.5×10^5	4.3×10^{11}	1.8×10^{10}	± 5	± 7	Forced air	62
Plane 1 Lateral containers	1.75×10^5 to 1.95×10^5	1.6×10^{11}	1.5×10^{10}				
Position 35	1×10^4 to 1×10^5			± 10 for central part		Air	45

Table 2
Pure resin combinations

No.	Material Type Supplier Remarks	Dose (Gy)	Flex. strength at max. load S (MPa)	Deflexion at max. load D (mm)	Modulus of elasticity M (GPa)	RI IEC 544-4 at 10^5 Gy/h
336	Solventless epoxy resin (Base: DGEBA + anhydride hardener + other components)	0.0	85.0 ± 3.0	4.6 ± 0.1	3.36 ± 0.02	7.3
		3.0×10^5	90.6 ± 7.5	4.6 ± 0.1	3.54 ± 0.09	
	Micadur resin	1.0×10^6	94.4 ± 6.0	5.2 ± 0.3	3.47 ± 0.11	
	BBC, Baden	3.0×10^6	84.2 ± 6.0	4.6 ± 0.6	3.41 ± 0.16	
	HV machine insulation application	1.0×10^7	75.0 ± 6.1	4.0 ± 0.4	3.46 ± 0.06	
		3.0×10^7	31.4 ± 0.0	2.9 ± 0.0	1.93 ± 0.0	
		1.0×10^8	6.4 ± 2.5	0.8 ± 0.3	1.00 ± 0.32	
337	Solventless silicone resin	0.0	26.6 ± 0.9	6.6 ± 2.0	0.94 ± 0.06	7.3
	Veridur resin	1.0×10^6	26.7 ± 2.8	8.1 ± 2.0	0.99 ± 0.04	
	BBC, Baden	3.0×10^6	28.5 ± 1.2	7.3 ± 2.3	1.07 ± 0.06	
	High-temperature machine insulation application	1.0×10^7	27.4 ± 0.2	6.0 ± 0.3	1.13 ± 0.03	
		3.0×10^7	9.2 ± 2.7	1.0 ± 0.3	1.60 ± 0.02	
338	Resin combination (class H)	0.0	93.8 ± 5.7	4.0 ± 0.7	3.61 ± 0.17	> 8.0
	Veridur-K resin	1.0×10^6	89.7 ± 10.8	4.1 ± 0.6	3.80 ± 0.20	
	BBC, Baden	3.0×10^6	107.0 ± 5.8	4.9 ± 0.3	3.77 ± 0.04	
	High-temperature machine insulation application	1.0×10^7	96.3 ± 11.2	4.3 ± 0.5	3.86 ± 0.12	
		3.0×10^7	93.5 ± 16.6	4.1 ± 0.7	3.94 ± 0.07	
		1.0×10^8	60.2 ± 7.2	5.2 ± 0.4	1.98 ± 0.15	
348	Modified magnet coil resin (Base DGEBA + MNA + other components)	0.0	127.4 ± 3.2	10.6 ± 0.1	3.12 ± 0.12	7.8
		1.0×10^6	118.5 ± 2.1	10.6 ± 0.2	3.11 ± 0.07	
	Orlitherm-N resin	3.0×10^6	122.4 ± 3.7	11.7 ± 0.8	3.23 ± 0.07	
	BBC, Baden	1.0×10^7	120.6 ± 10.6	9.1 ± 2.4	3.44 ± 0.11	
	Magnet coil insulation application	3.0×10^7	110.0 ± 34.2	5.9 ± 2.4	3.70 ± 0.22	
		1.0×10^8	52.7 ± 5.0	4.8 ± 0.4	1.94 ± 0.06	
368	Solventless epoxy resin	0.0	136.2 ± 18.7	9.6 ± 2.5	3.21 ± 0.10	6.6
	Art. No. SIB 785	1.0×10^6	111.0 ± 40.2	7.4 ± 2.9	3.24 ± 0.09	
	Isola	3.0×10^6	119.2 ± 26.7	8.3 ± 3.8	3.32 ± 0.05	
	HV application in VPI systems	1.0×10^7	19.4 ± 4.6	12.9 ± 3.6	3.48 ± 0.06	
		3.0×10^7	5.9 ± 2.5	0.4 ± 0.0	2.46 ± 0.97	
369	Solventless silicone resin	0.0	21.3 ± 3.2	9.3 ± 0.3	0.74 ± 0.12	7.3
	Art. No. IM 9793	1.0×10^6	27.8 ± 0.9	8.8 ± 0.3	0.97 ± 0.06	
	Isola	3.0×10^6	29.0 ± 1.8	7.0 ± 1.0	1.12 ± 0.07	
	HV application in VPI systems at high temperature	1.0×10^7	24.1 ± 3.8	4.0 ± 0.9	1.30 ± 0.05	
		3.0×10^7	8.8 ± 2.9	0.9 ± 0.3	1.68 ± 0.10	



MATERIAL: SOLVENTLESS EPOXY RESIN BASE DGEBA + ANHYDRIDE HARDENER + OTHER COMPONENTS

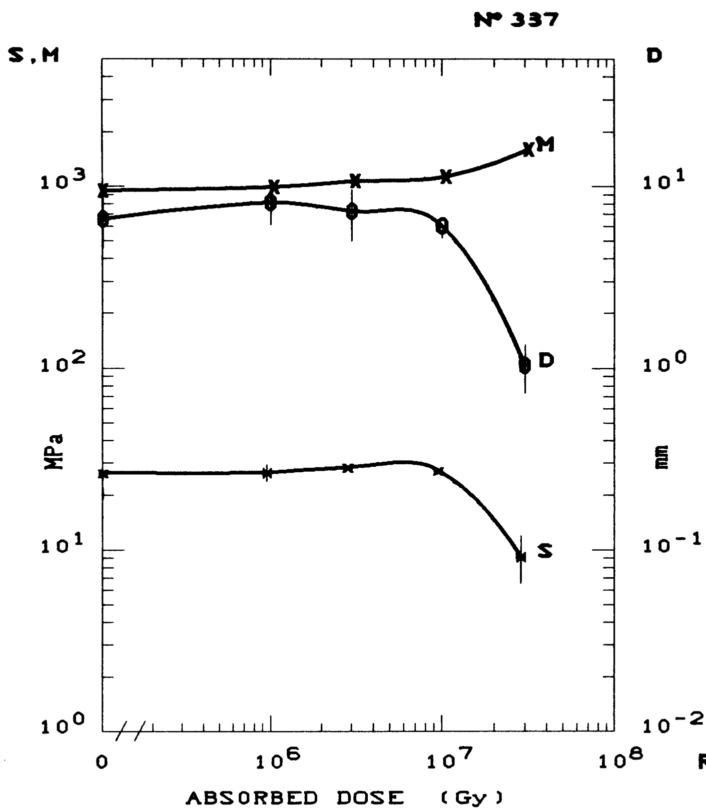
TYPE : MICADUR RESIN

SUPPLIER: BBC, BADEN

REMARKS : HV MACHINE INSULATION APPLICATION

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	85.0 MPa
D	DEFLEXION AT MAX. LOAD	4.6 mm
M	MODULUS OF ELASTICITY	3364.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.3

Fig. 1



MATERIAL: SOLVENTLESS SILICONE RESIN

TYPE : VERIDUR RESIN

SUPPLIER: BBC, BADEN

REMARKS : HIGH-TEMPERATURE MACHINE INSULATION APPLICATION

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	26.6 MPa
D	DEFLEXION AT MAX. LOAD	6.6 mm
M	MODULUS OF ELASTICITY	944.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.3

Fig. 2

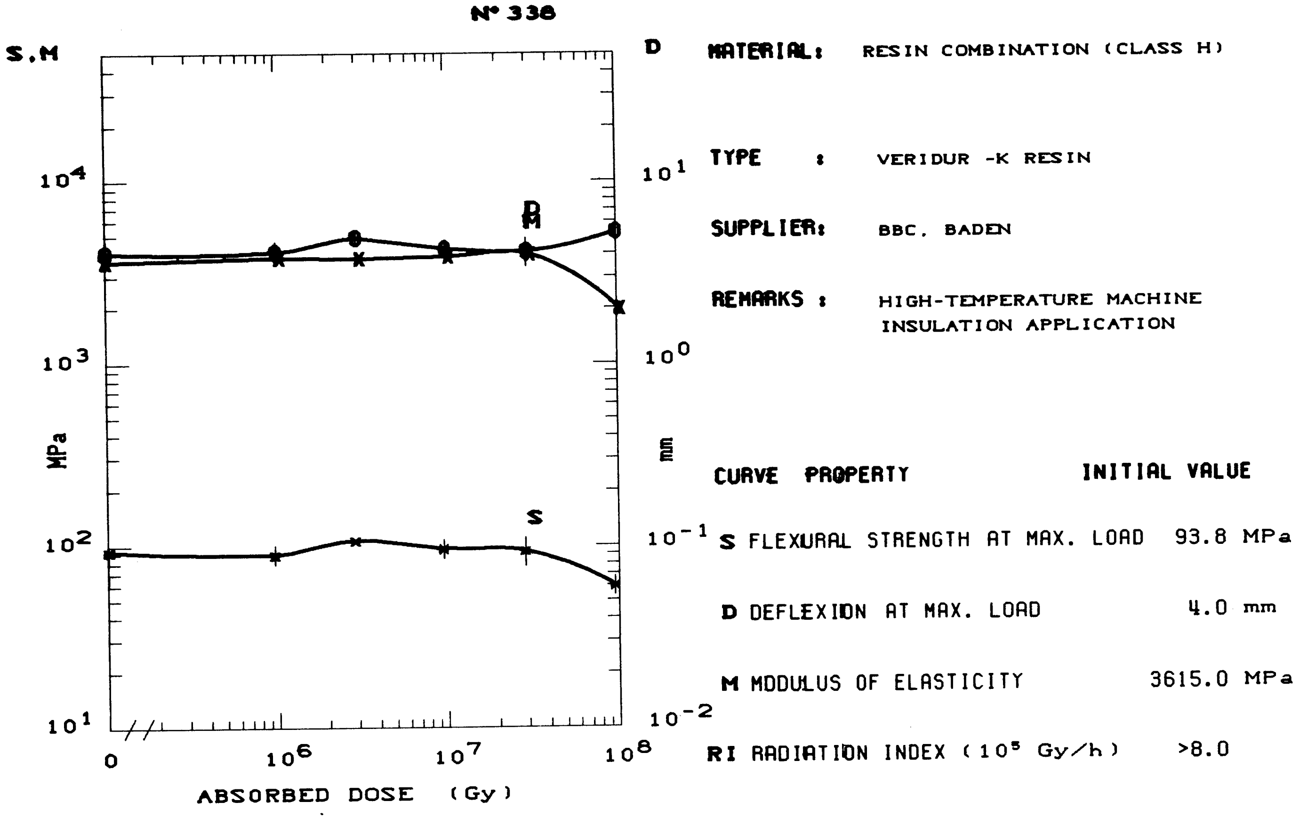

N° 338
S,M
D
10^4
10^3
10^2
10^1
MPa
10^1
10^0
mm
10^{-1}
10^{-2}
0
10^6
10^7
10^8
ABSORBED DOSE (Gy)
MATERIAL: RESIN COMBINATION (CLASS H)
TYPE : VERIDUR -K RESIN
SUPPLIER: BBC, BADEN
REMARKS : HIGH-TEMPERATURE MACHINE INSULATION APPLICATION
CURVE PROPERTY INITIAL VALUE
S FLEXURAL STRENGTH AT MAX. LOAD 93.8 MPa
D DEFLEXION AT MAX. LOAD 4.0 mm
M MODULUS OF ELASTICITY 3615.0 MPa
RI RADIATION INDEX (10^5 Gy/h) >8.0

Fig. 3

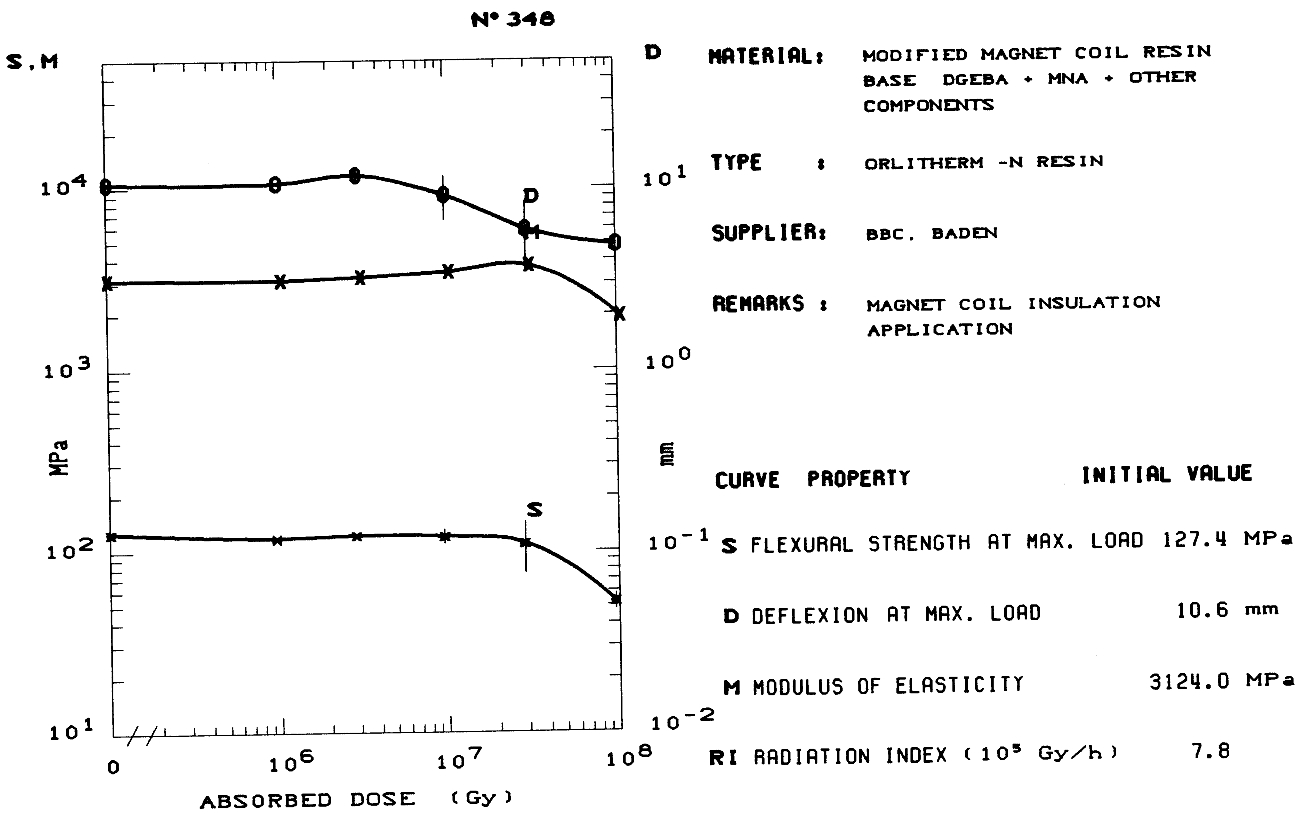
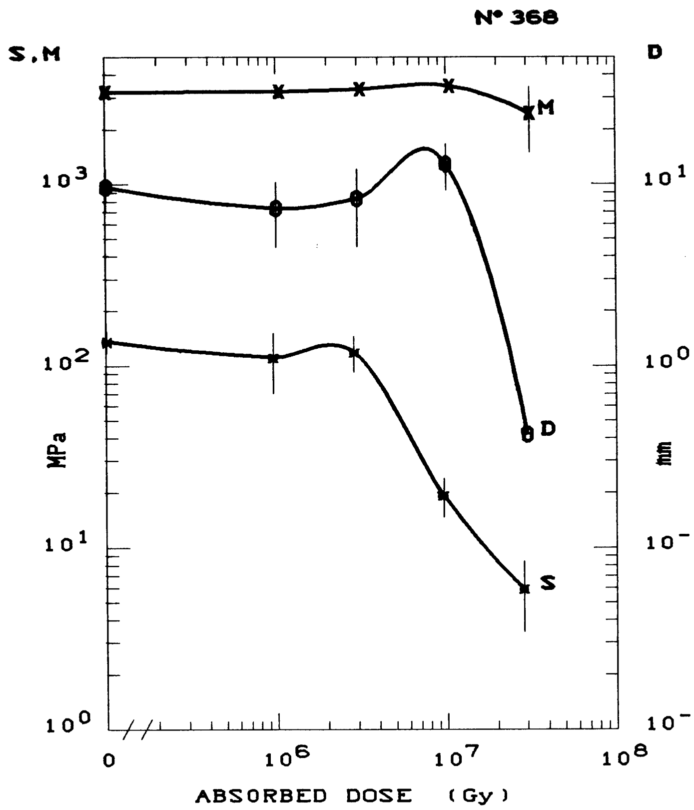

N° 348
S,M
D
10^4
10^3
10^2
10^1
MPa
10^1
10^0
mm
10^{-1}
10^{-2}
0
10^6
10^7
10^8
ABSORBED DOSE (Gy)
MATERIAL: MODIFIED MAGNET COIL RESIN BASE DGEBA + MNA + OTHER COMPONENTS
TYPE : ORLITHERM -N RESIN
SUPPLIER: BBC, BADEN
REMARKS : MAGNET COIL INSULATION APPLICATION
CURVE PROPERTY INITIAL VALUE
S FLEXURAL STRENGTH AT MAX. LOAD 127.4 MPa
D DEFLEXION AT MAX. LOAD 10.6 mm
M MODULUS OF ELASTICITY 3124.0 MPa
RI RADIATION INDEX (10^5 Gy/h) 7.8

Fig. 4



MATERIAL: SOLVENTLESS EPOXY RESIN

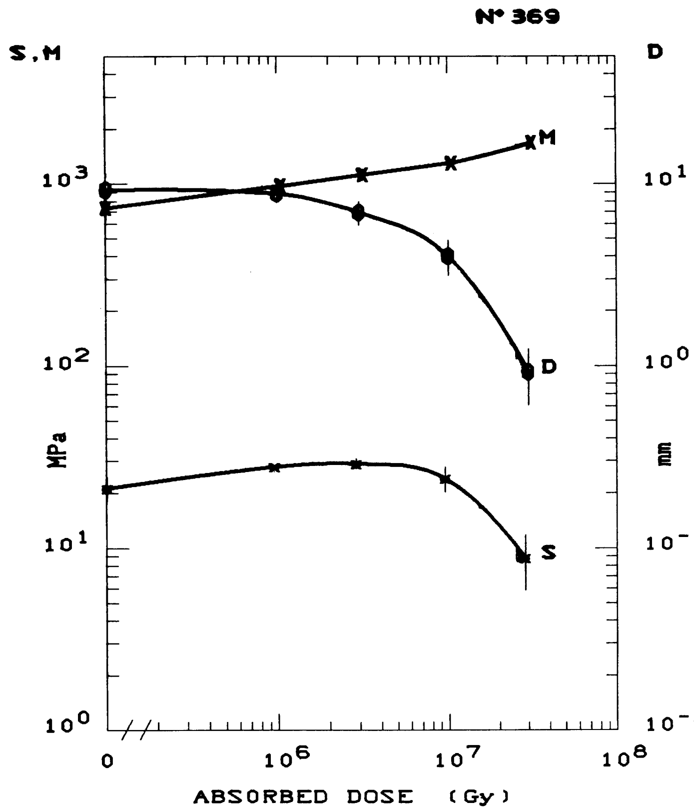
TYPE : ART. NO. SIB 785

SUPPLIER: ISOLA

REMARKS : HV APPLICATION IN VPI SYSTEMS

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	136.2 MPa
D	DEFLEXION AT MAX. LOAD	9.6 mm
M	MODULUS OF ELASTICITY	3212.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	6.6

Fig. 5



MATERIAL: SOLVENTLESS SILICONE RESIN

TYPE : ART. NO. IM 9793

SUPPLIER: ISOLA

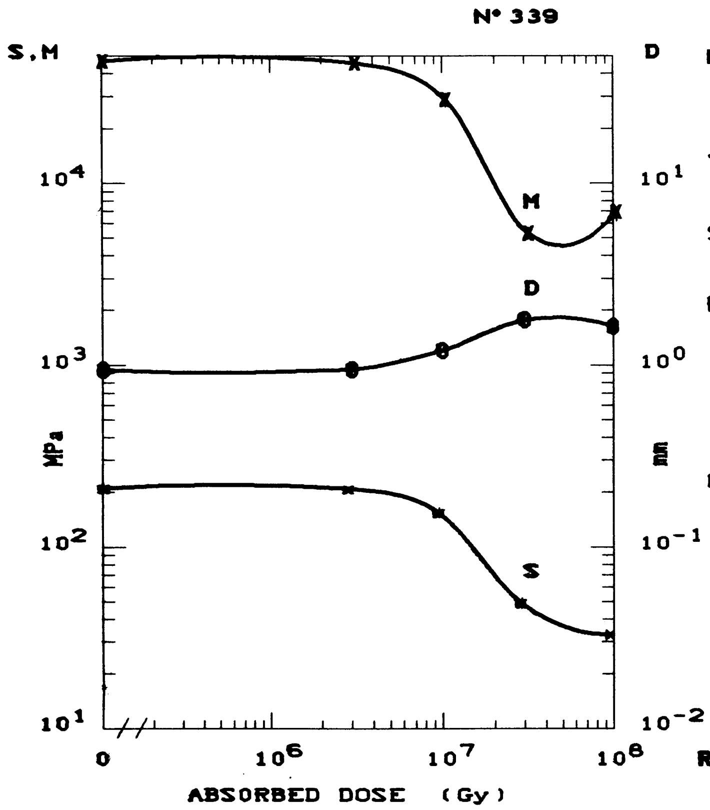
REMARKS : HV APPLICATION IN VPI SYSTEMS AT HIGH TEMPERATURE

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT BREAK	21.3 MPa
D	DEFLEXION AT BREAK	9.3 mm
M	MODULUS OF ELASTICITY	736.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.3

Fig. 6

Table 3
VPI insulation with mica content

No.	Material Type Supplier Remarks	Dose (Gy)	Flex. strength at max. load S (MPa)	Deflexion at max. load D (mm)	Modulus of elasticity M (GPa)	RI IEC 544-4 at 10^5 Gy/h
339	Solventless epoxy resin (CERN No. 336) reinforced with mica-paper + glass cloth backing tape (Class F, Type 1)	0.0	210.4 ± 12.5	0.9 ± 0.1	46.80 ± 1.44	7.1
		3.0×10^6	209.4 ± 8.6	0.9 ± 0.1	45.70 ± 0.70	
	Micadur insulation Orlidur insulation	1.0×10^7	154.5 ± 9.3	1.2 ± 0.0	28.77 ± 2.40	
	BBC, Baden	3.0×10^7	49.1 ± 3.1	1.8 ± 0.1	5.30 ± 0.39	
	HV machine insulation application	1.0×10^8	33.1 ± 0.8	1.6 ± 0.1	6.95 ± 0.26	
340	Solventless silicone resin (CERN No. 337) reinforced with mica paper + glass-cloth backing tape (Class H, Type 1)	0.0	70.2 ± 20.2	1.0 ± 0.2	15.42 ± 1.94	> 8.0
		3.0×10^6	50.4 ± 2.1	0.9 ± 0.4	19.40 ± 6.98	
	Veridur insulation	1.0×10^7	64.8 ± 28.0	0.8 ± 0.1	20.00 ± 7.57	
	BBC, Baden	3.0×10^7	42.0 ± 11.0	0.9 ± 0.4	17.10 ± 9.30	
	High-temperature machine insulation application	1.0×10^8	34.5 ± 4.2	0.8 ± 0.2	15.40 ± 4.88	
341	Solventless magnet coil resin (CERN No. 97), reinforced with mica paper + glass-cloth backing tape (Class F, Type 2)	0.0	186.0 ± 9.2	1.0 ± 0.1	39.48 ± 1.78	7.2
		3.0×10^6	176.0 ± 7.4	1.0 ± 0.0	40.00 ± 0.57	
	Orlitherm-S insulation	1.0×10^7	173.9 ± 4.1	1.0 ± 0.1	37.62 ± 1.88	
	BBC, Baden	3.0×10^7	61.3 ± 4.3	1.0 ± 0.1	12.46 ± 0.59	
	Conductor insulation for magnets	1.0×10^8	37.8 ± 3.2	1.0 ± 0.1	8.05 ± 0.17	
355	Solventless epoxy resin reinforced with Samica + glass-cloth tape	0.0	187.0 ± 48.1	1.4 ± 0.4	44.00 ± 7.19	6.7
		3.0×10^6	114.0 ± 61.1	1.2 ± 0.4	29.00 ± 17.57	
	Resin: 3402 (785) Tape: Samicapor 366.53	1.0×10^7	76.0 ± 31.9	1.1 ± 0.2	18.00 ± 8.93	
	Isola	3.0×10^7	47.5 ± 15.7	1.1 ± 0.2	10.20 ± 5.27	
	VPI HV application	1.0×10^8	38.2 ± 6.3	1.2 ± 0.1	6.91 ± 0.01	
356	Solventless epoxy resin reinforced with Samica + glass-cloth tape	0.0	164.5 ± 23.1	1.2 ± 0.4	45.20 ± 5.52	6.9
		3.0×10^6	132.0 ± 71.2	1.1 ± 0.3	27.60 ± 19.47	
	Resin: 3402 (785) Tape: Samicapor 366.58	1.0×10^7	76.2 ± 20.4	1.3 ± 0.3	11.90 ± 4.68	
	Isola	3.0×10^7	26.3 ± 1.3	1.6 ± 0.2	2.74 ± 0.63	
	VPI HV application	1.0×10^8	28.8 ± 1.4	1.3 ± 0.2	3.53 ± 0.40	
357	Solventless epoxy resin reinforced with Samica + polyester mat	0.0	191.1 ± 8.7	1.0 ± 0.1	40.68 ± 1.53	
		3.0×10^6	74.4 ± 13.2	0.9 ± 0.1	21.60 ± 8.70	
	Resin: 3402 (785) Tape: Samicapor 372.95-19 X	1.0×10^7	69.6 ± 8.3	0.8 ± 0.0	17.28 ± 2.63	
	Isola	3.0×10^7	40.1 ± 2.9	0.9 ± 0.1	9.48 ± 1.08	
	VPI HV application	1.0×10^8	37.4 ± 1.9	1.0 ± 0.3	8.36 ± 1.49	



MATERIAL: SOLVENTLESS EPOXY RESIN (CERN NO. 336) REINFORCED WITH MICAPAPER+GLASS CLOTH BACKING TAPE(CLASS F, TYPE1)

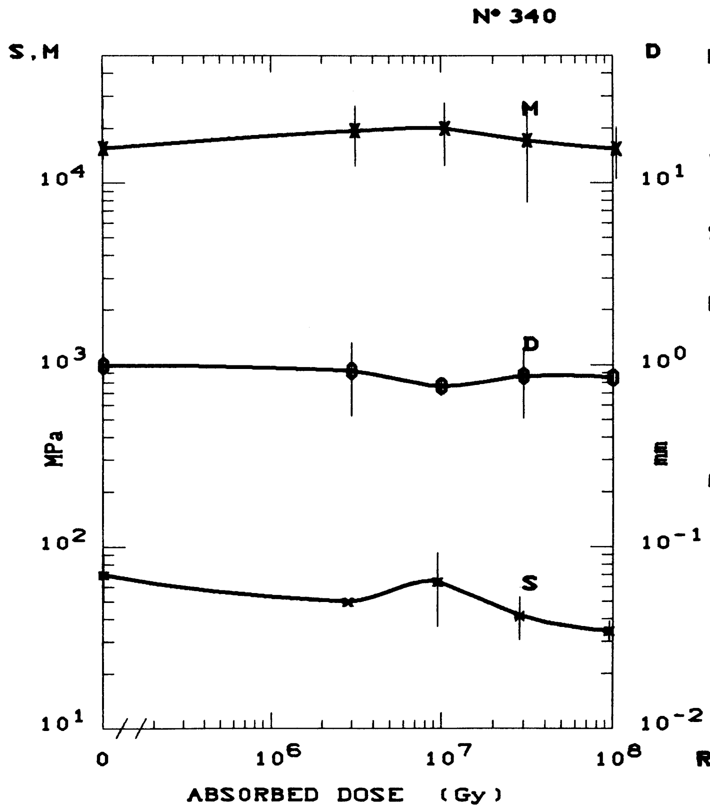
TYPE : MICADUR INSULATION
ORLIDUR INSULATION

SUPPLIER: BBC, BADEN

REMARKS : HV MACHINE INSULATION APPLICATION

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	210.4 MPa
D	DEFLEXION AT MAX. LOAD	0.9 mm
M	MODULUS OF ELASTICITY	46800.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.1

Fig. 7



MATERIAL: SOLVENTLESS SILICONE RESIN (CERN NO. 337), REINFORCED WITH MICA PAPER + GLASS CLOTH BACKING TAPE(CLASS H, TYPE 1)

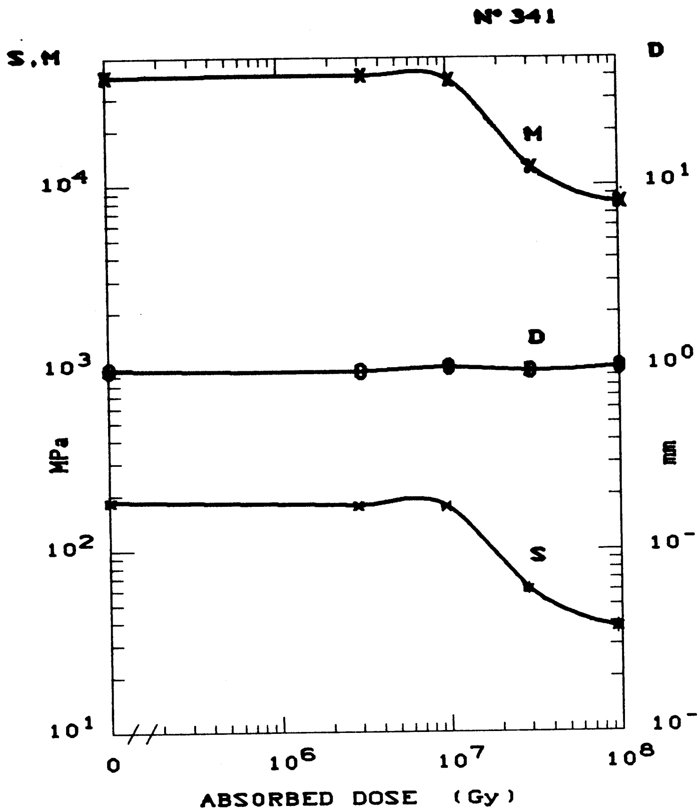
TYPE : VERIDUR INSULATION

SUPPLIER: BBC, BADEN

REMARKS : HIGH-TEMPERATURE MACHINE INSULATION APPLICATION

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	70.2 MPa
D	DEFLEXION AT MAX. LOAD	1.0 mm
M	MODULUS OF ELASTICITY	15420.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	>8.0

Fig. 8



MATERIAL: SOLVENTLESS MAGNET COIL RESIN (CERN NO. 97), REINFORCED WITH MICA PAPER + GLASS-CLOTH BACKING TAPE(CLASS F, TYPE 2)

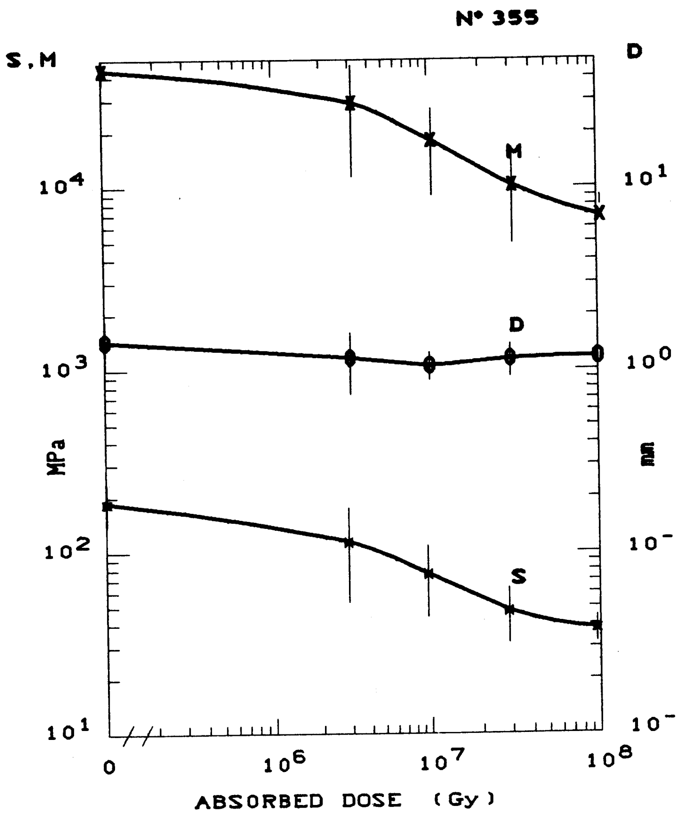
TYPE : ORLITHERM - S INSULATION

SUPPLIER: BBC, BADEN

REMARKS : CONDUCTOR INSULATION FOR MAGNETS

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	186.0 MPa
D	DEFLEXION AT MAX. LOAD	1.0 mm
M	MODULUS OF ELASTICITY	39480.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.2

Fig. 9



MATERIAL: SOLVENTLESS REINFORCED EPOXY RESIN
SAMICA + GLASS-CLOTH TAPE

TYPE : RESIN 3402 (785)
TAPE SAMICAPOR 366.53

SUPPLIER: ISOLA

REMARKS : VPI HV APPLICATION

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	187.0 MPa
D	DEFLEXION AT MAX. LOAD	1.4 mm
M	MODULUS OF ELASTICITY	44000.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	6.7

Fig. 10

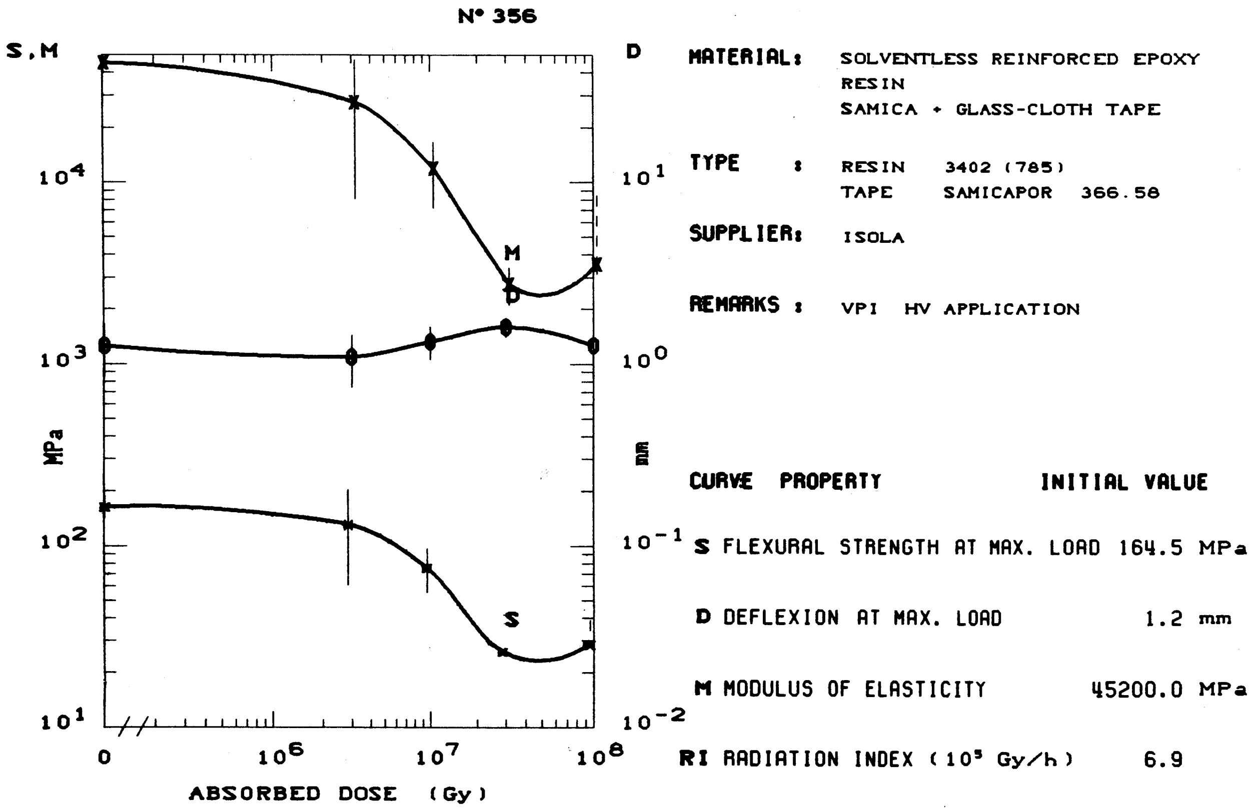

N° 356
S,M
D
10⁴
10³
10²
10¹
10¹
10⁰
10⁻¹
10⁻²
MPa
mm
M
D
S
0
10⁶
10⁷
10⁸
ABSORBED DOSE (Gy)
MATERIAL: SOLVENTLESS REINFORCED EPOXY RESIN
SAMICA + GLASS-CLOTH TAPE
TYPE : RESIN 3402 (785)
TAPE SAMICAPOR 366.58
SUPPLIER: ISOLA
REMARKS : VPI HV APPLICATION
CURVE PROPERTY INITIAL VALUE
S FLEXURAL STRENGTH AT MAX. LOAD 164.5 MPa
D DEFLEXION AT MAX. LOAD 1.2 mm
M MODULUS OF ELASTICITY 45200.0 MPa
RI RADIATION INDEX (10⁵ Gy/h) 6.9

Fig. 11

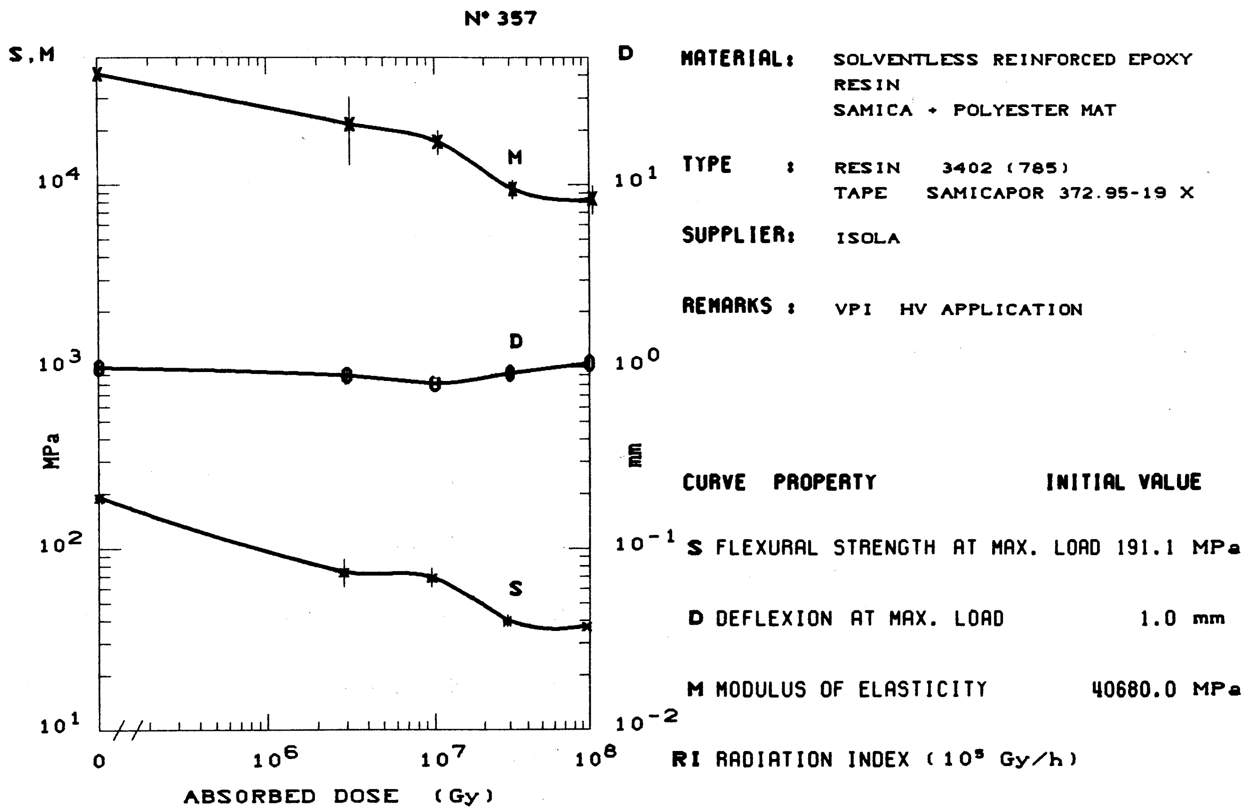
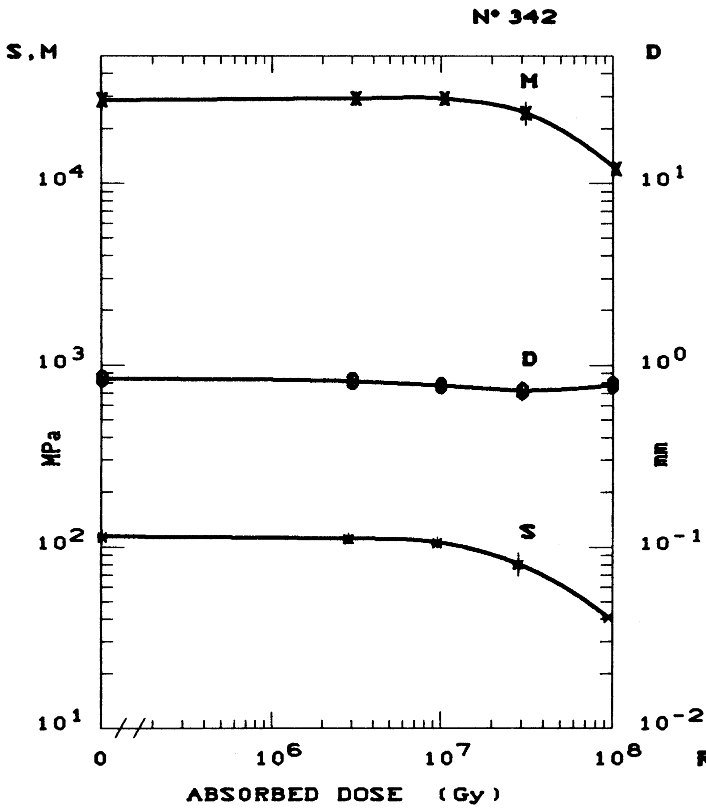

N° 357
S,M
D
10⁴
10³
10²
10¹
10¹
10⁰
10⁻¹
10⁻²
MPa
mm
M
D
S
0
10⁶
10⁷
10⁸
ABSORBED DOSE (Gy)
MATERIAL: SOLVENTLESS REINFORCED EPOXY RESIN
SAMICA + POLYESTER MAT
TYPE : RESIN 3402 (785)
TAPE SAMICAPOR 372.95-19 X
SUPPLIER: ISOLA
REMARKS : VPI HV APPLICATION
CURVE PROPERTY INITIAL VALUE
S FLEXURAL STRENGTH AT MAX. LOAD 191.1 MPa
D DEFLEXION AT MAX. LOAD 1.0 mm
M MODULUS OF ELASTICITY 40680.0 MPa
RI RADIATION INDEX (10⁵ Gy/h)

Fig. 12

Table 4
Resin-rich insulations with mica content

No.	Material Type Supplier Remarks	Dose (Gy)	Flex. strength at max. load S (MPa)	Deflexion at max. load D (mm)	Modulus of elasticity M (GPa)	RI IEC 544-4 at 10^5 Gy/h
342	Solventless epoxy resin reinforced with mica paper + glass-cloth backing tape	0.0	114.0 ± 10.5	0.8 ± 0.1	28.70 ± 3.36	7.7
		3.0×10^6	111.6 ± 7.6	0.8 ± 0.0	29.33 ± 2.40	
	Resin-rich insulation	1.0×10^7	106.4 ± 7.3	0.8 ± 0.1	29.16 ± 1.97	
	BBC, Baden	3.0×10^7	81.2 ± 11.9	0.7 ± 0.1	24.40 ± 3.57	
	HV application in general	1.0×10^8	41.3 ± 2.1	0.8 ± 0.0	11.97 ± 0.87	
351	Solventless epoxy resin reinforced with Samica + glass-cloth tape, resin-rich	0.0	127.0 ± 1.2	1.6 ± 0.3	34.40 ± 2.53	> 8.0
		3.0×10^6	124.8 ± 13.6	1.6 ± 0.2	30.24 ± 2.31	
	Samicatherm 366.28	1.0×10^7	118.5 ± 15.5	1.7 ± 0.5	29.30 ± 3.78	
	Isola	3.0×10^7	109.2 ± 6.1	1.3 ± 0.5	24.30 ± 4.61	
	HV application in general	1.0×10^8	66.6 ± 9.4	1.2 ± 0.3	9.78 ± 0.54	
352	Solventless epoxy resin reinforced with Samica + glass-cloth tape, resin-rich	0.0	128.8 ± 2.8	1.9 ± 0.5	30.70 ± 4.76	7.5
		3.0×10^6	101.1 ± 11.3	1.7 ± 1.0	25.90 ± 3.64	
	Samicatherm 366.28-50	1.0×10^7	129.9 ± 10.6	1.8 ± 0.2	28.20 ± 7.17	
	Isola	3.0×10^7	67.5 ± 8.8	1.4 ± 0.4	13.30 ± 2.48	
	HV application in general	1.0×10^8	47.8 ± 7.4	1.7 ± 0.6	6.64 ± 1.18	
353	Solventless epoxy resin (cycloaliphatic) reinforced with Samica + glass-cloth tape, resin-rich	0.0	119.0 ± 17.5	0.8 ± 0.3	39.63 ± 0.77	7.1
		3.0×10^6	75.9 ± 9.0	0.9 ± 0.2	20.80 ± 6.19	
	Samicatherm 366.95-87 X	1.0×10^7	77.1 ± 8.3	1.1 ± 0.2	13.90 ± 1.77	
	Isola	3.0×10^7	37.3 ± 2.0	1.2 ± 0.1	5.73 ± 0.45	
	HV application in general	1.0×10^8	24.6 ± 4.6	1.2 ± 0.4	7.80 ± 1.93	
354	Solventless epoxy resin reinforced with Samica + glass-cloth tape, resin-rich	0.0	89.1 ± 9.3	11.5 ± 2.5	15.04 ± 1.23	> 8.0
		3.0×10^6	72.6 ± 9.1	12.1 ± 1.2	7.07 ± 2.27	
	Samicatherm flexible 366.63	1.0×10^7	89.4 ± 9.2	7.4 ± 2.0	12.16 ± 1.29	
	Isola	3.0×10^7	120.0 ± 14.7	1.8 ± 0.2	17.30 ± 3.96	
	HV application in general	1.0×10^8	99.0 ± 28.7	1.3 ± 0.1	17.40 ± 4.76	



MATERIAL: SOLVENTLESS EPOXY RESIN REINFORCED WITH MICA PAPER + GLASS-CLOTH BACKING TAPE

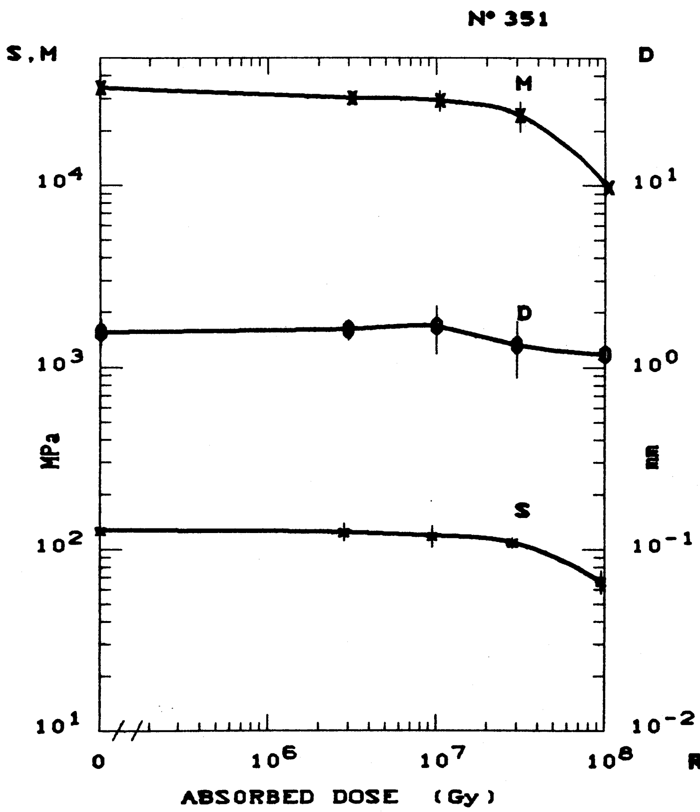
TYPE : RESIN-RICH INSULATION

SUPPLIER: BBC, BADEN

REMARKS : HV APPLICATION IN GENERAL

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	114.0 MPa
D	DEFLEXION AT MAX. LOAD	0.8 mm
M	MODULUS OF ELASTICITY	28700.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.7

Fig. 13



MATERIAL: SOLVENTLESS REINFORCED EPOXY RESIN SAMICA + GLASS-CLOTH TAPE RESIN-RICH

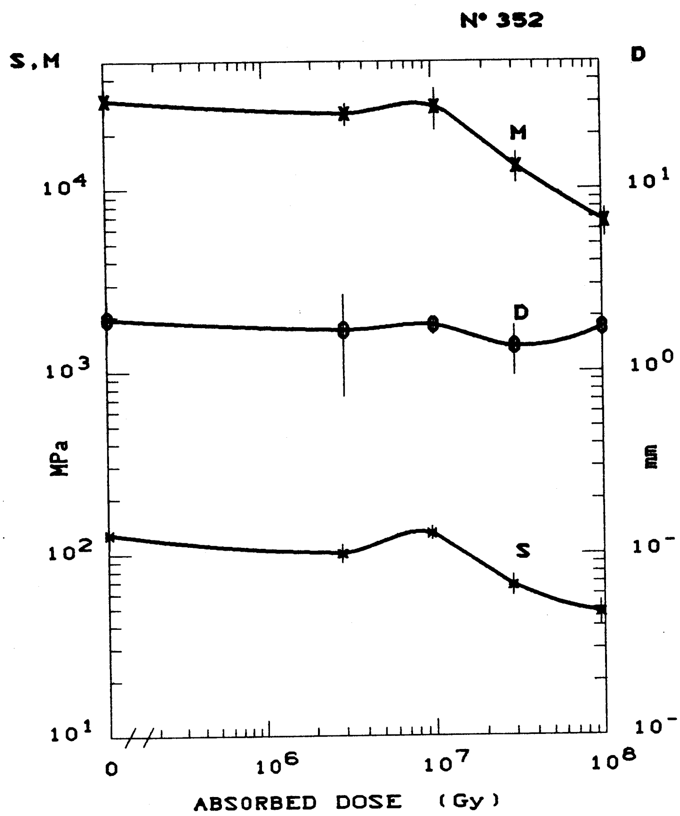
TYPE : SAMICATHERM 366.28

SUPPLIER: ISOLA

REMARKS : HV APPLICATION IN GENERAL

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	127.0 MPa
D	DEFLEXION AT MAX. LOAD	1.6 mm
M	MODULUS OF ELASTICITY	34400.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	>8.0

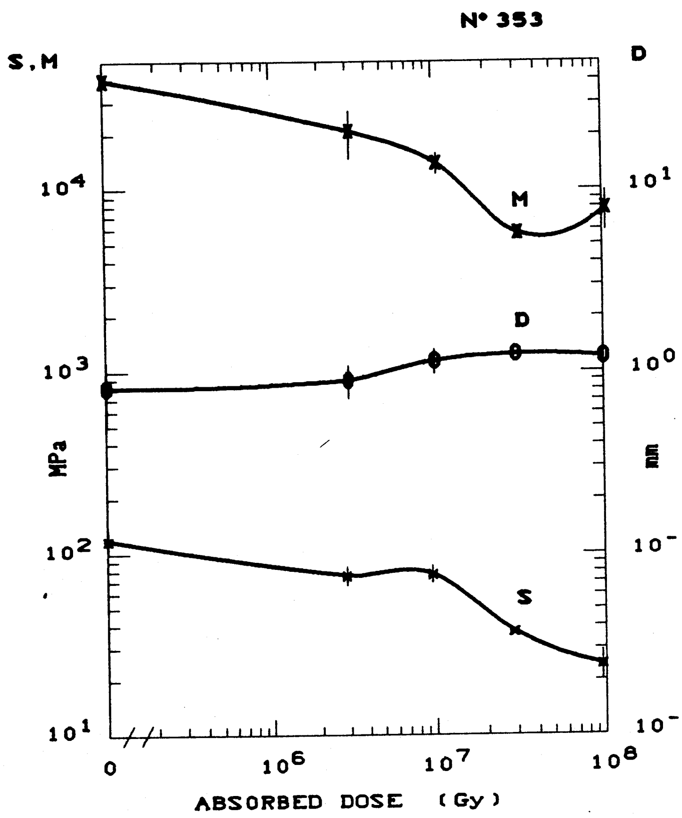
Fig. 14



MATERIAL:	SOLVENTLESS REINFORCED EPOXY RESIN SAMICA + GLASS-CLOTH TAPE RESIN-RICH
TYPE :	SAMICATHERM 366.28-50
SUPPLIER:	ISOLA
REMARKS :	HV APPLICATION IN GENERAL

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	128.8 MPa
D	DEFLEXION AT MAX. LOAD	1.9 mm
M	MODULUS OF ELASTICITY	30700.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.5

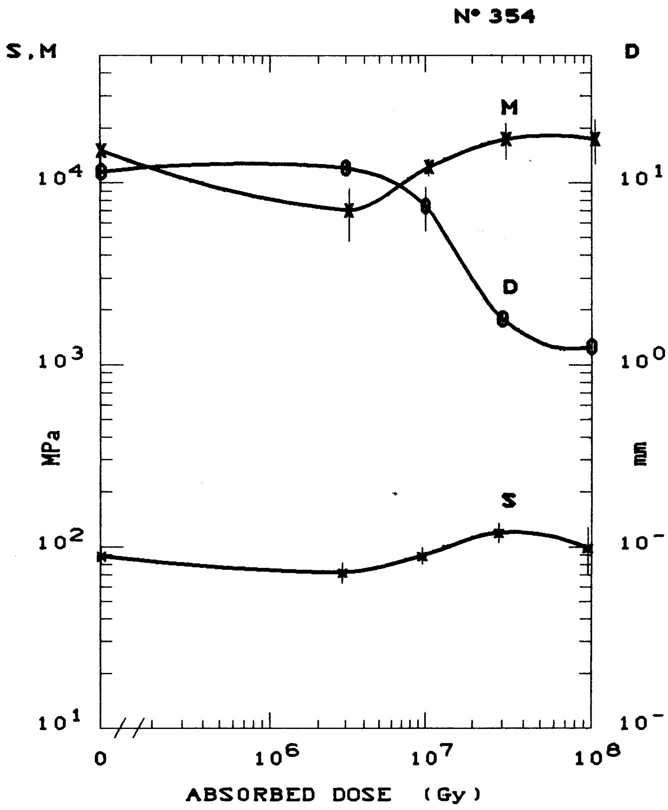
Fig. 15



MATERIAL:	SOLVENTLESS REINFORCED EPOXY RESIN (CYCLOALIPHATIC) SAMICA + GLASS-CLOTH TAPE RESIN-RICH
TYPE :	SAMICATHERM 366.95-87 X
SUPPLIER:	ISOLA
REMARKS :	HV APPLICATION IN GENERAL

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	119.0 MPa
D	DEFLEXION AT MAX. LOAD	0.8 mm
M	MODULUS OF ELASTICITY	39630.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.1

Fig. 16



MATERIAL: SOLVENTLESS REINFORCED EPOXY RESIN
SAMICA + GLASS-CLOTH TAPE
RESIN-RICH

TYPE : SAMICATHERM FLEXIBLE 366.63

SUPPLIER: ISOLA

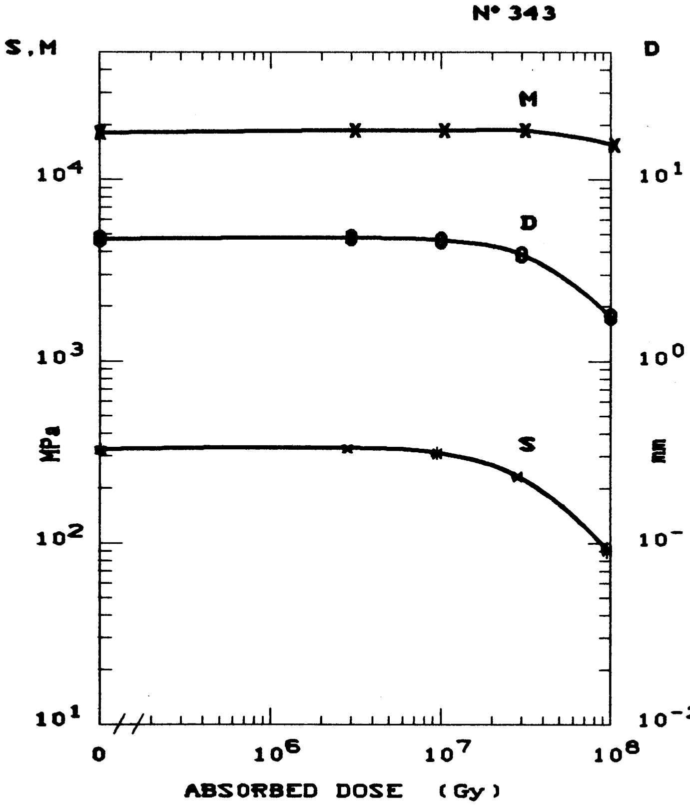
REMARKS : HV APPLICATION IN GENERAL

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	89.1 MPa
D	DEFLEXION AT MAX. LOAD	11.5 mm
M	MODULUS OF ELASTICITY	15040.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	>8.0

Fig. 17

Table 5
VPI insulation without mica content

No.	Material Type Supplier Remarks	Dose (Gy)	Flex. strength at max. load S (MPa)	Deflexion at max. load D (mm)	Modulus of elasticity M (GPa)	RI IEC 544-4 at 10^5 Gy/h
343	Solventless epoxy resin (CERN No. 336) reinforced with fibre-silanized glass-cloth backing	0.0	326.4 ± 20.7	4.7 ± 0.1	18.08 ± 0.16	7.7
		3.0×10^6	334.5 ± 10.8	4.8 ± 0.4	18.63 ± 0.89	
	Micadur insulation	1.0×10^7	314.3 ± 24.1	4.6 ± 0.4	18.64 ± 0.03	
	BBC, Baden	3.0×10^7	234.4 ± 2.8	3.9 ± 0.1	18.56 ± 0.70	
	Magnet coil insulation application	1.0×10^8	92.1 ± 9.2	1.8 ± 0.2	15.52 ± 0.73	
346	Solventless epoxy resin (CERN No. 336), reinforced with aromatic polyamide paper (laminates)	0.0	157.0 ± 45.8	12.8 ± 1.8	4.83 ± 0.85	> 8.0
		3.0×10^6	189.6 ± 0.0	12.3 ± 0.0	5.10 ± 0.81	
	Micadur insulation	1.0×10^7	174.0 ± 18.6	12.1 ± 1.9	5.56 ± 0.18	
	BBC, Baden	3.0×10^7	152.8 ± 25.6	8.8 ± 0.8	5.62 ± 0.11	
	Low-voltage motor insulation application	1.0×10^8	83.4 ± 21.0	3.1 ± 1.1	5.46 ± 0.05	
347	Solventless epoxy resin (CERN No. 97), reinforced with aromatic polyamide paper (laminates)	0.0	223.0 ± 39.4	11.8 ± 3.1	5.20 ± 0.23	7.9
		1.0×10^7	194.7 ± 0.0	12.8 ± 0.0	5.18 ± 0.03	
	Orlitherm-S insulation	3.0×10^7	193.8 ± 6.2	11.7 ± 1.1	5.74 ± 0.22	
	BBC, Baden	1.0×10^8	81.9 ± 22.3	3.0 ± 0.9	5.78 ± 0.16	
	Magnet coil insulation application					
349	Solventless epoxy resin (CERN (No. 97), reinforced with thermally desized glass-cloth backing (Type 5)	0.0	231.0 ± 11.4	2.9 ± 0.3	17.55 ± 0.99	7.9
		3.0×10^6	225.6 ± 26.5	3.0 ± 0.3	16.88 ± 0.72	
	Orlitherm-S insulation	1.0×10^7	244.5 ± 17.2	3.3 ± 0.3	17.46 ± 0.66	
		3.0×10^7	168.0 ± 31.8	3.6 ± 0.6	15.81 ± 1.02	
	BBC, Baden	1.0×10^8	104.1 ± 10.3	2.6 ± 0.1	13.53 ± 0.88	
	Magnet coil insulation application					
350	Solventless epoxy resin No. 332 (Base: DGEBA + MNA + other components), reinforced with fibre-silanized glass-cloth backing (Type 3)	0.0	324.0 ± 18.8	4.2 ± 0.3	19.24 ± 0.65	> 8.0
		3.0×10^6	301.2 ± 19.2	4.0 ± 0.3	19.06 ± 0.63	
		1.0×10^7	272.7 ± 8.8	3.6 ± 0.3	18.63 ± 0.94	
	Orlitherm-D insulation	3.0×10^7	248.8 ± 11.7	3.5 ± 0.2	19.16 ± 0.20	
	BBC, Baden	1.0×10^8	170.0 ± 8.0	3.5 ± 0.8	15.78 ± 0.51	
	Magnet coil insulation application					



MATERIAL: SOLVENTLESS EPOXY RESIN (CERN NO. 336) REINFORCED WITH FIBRE-SILANIZED GLASS-CLOTH BACKING

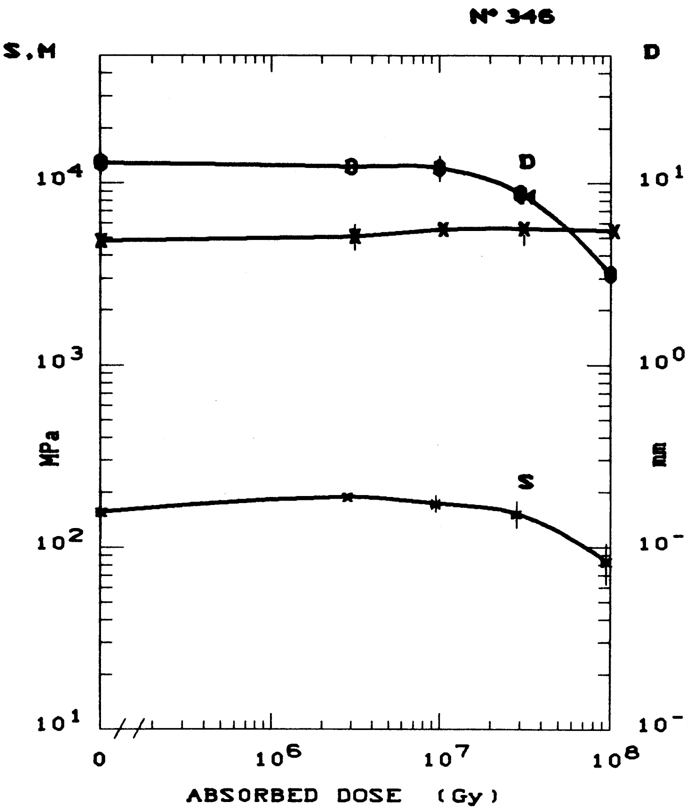
TYPE : MICADUR INSULATION

SUPPLIER: BBC, BADEN

REMARKS : MAGNET COIL INSULATION APPLICATION

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	326.4 MPa
D	DEFLEXION AT MAX. LOAD	4.7 mm
M	MODULUS OF ELASTICITY	18090.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.7

Fig. 18



MATERIAL: SOLVENTLESS EPOXY RESIN (CERN NO. 336), REINFORCED WITH AROMATIC POLYAMIDE PAPER (LAMINATES)

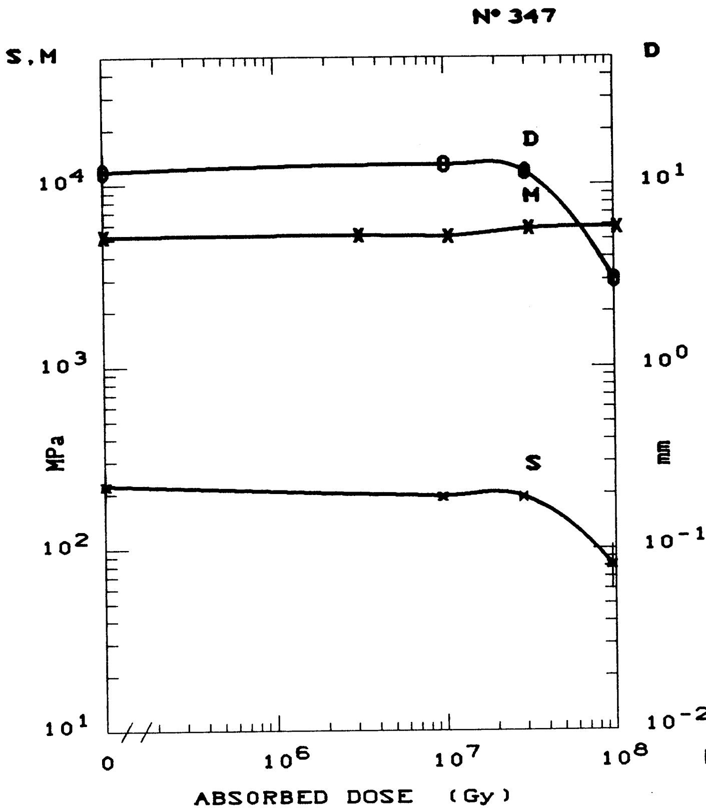
TYPE : MICADUR INSULATION

SUPPLIER: BBC, BADEN

REMARKS : LOW-VOLTAGE MOTOR INSULATION APPLICATION

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	157.0 MPa
D	DEFLEXION AT MAX. LOAD	12.8 mm
M	MODULUS OF ELASTICITY	4830.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	>8.0

Fig. 19



MATERIAL: SOLVENTLESS EPOXY RESIN (CERN NO. 97), REINFORCED WITH AROMATIC POLYAMIDE PAPER (LAMINATES)

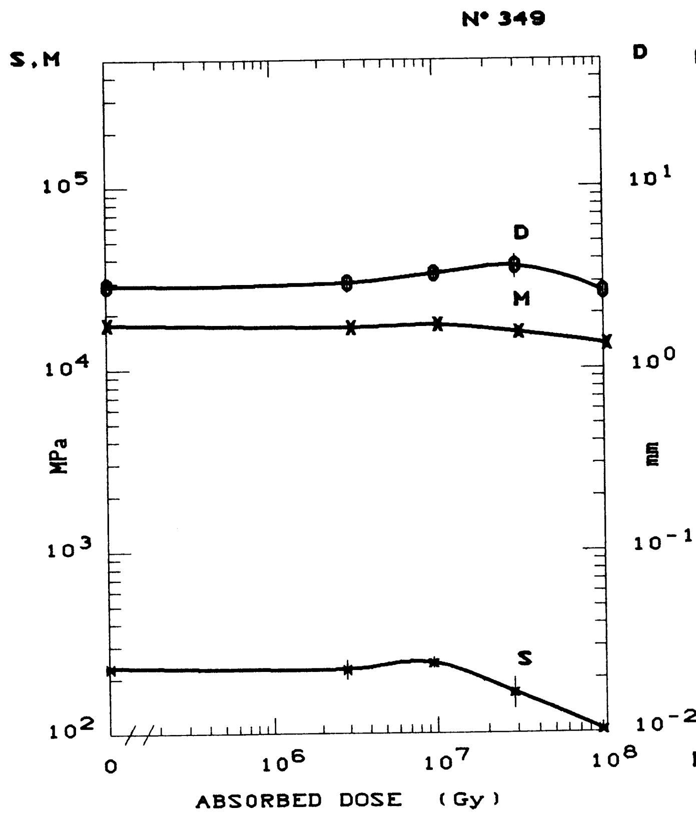
TYPE : ORLITHERM-S INSULATION

SUPPLIER: BBC, BADEN

REMARKS : MAGNET COIL INSULATION APPLICATION

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	223.0 MPa
D	DEFLEXION AT MAX. LOAD	11.8 mm
M	MODULUS OF ELASTICITY	5201.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.9

Fig. 20



MATERIAL: SOLVENTLESS EPOXY RESIN (CERN NO. 97), REINFORCED WITH THERMALLY DESIZED GLASS-CLOTH BACKING (TYPE 5)

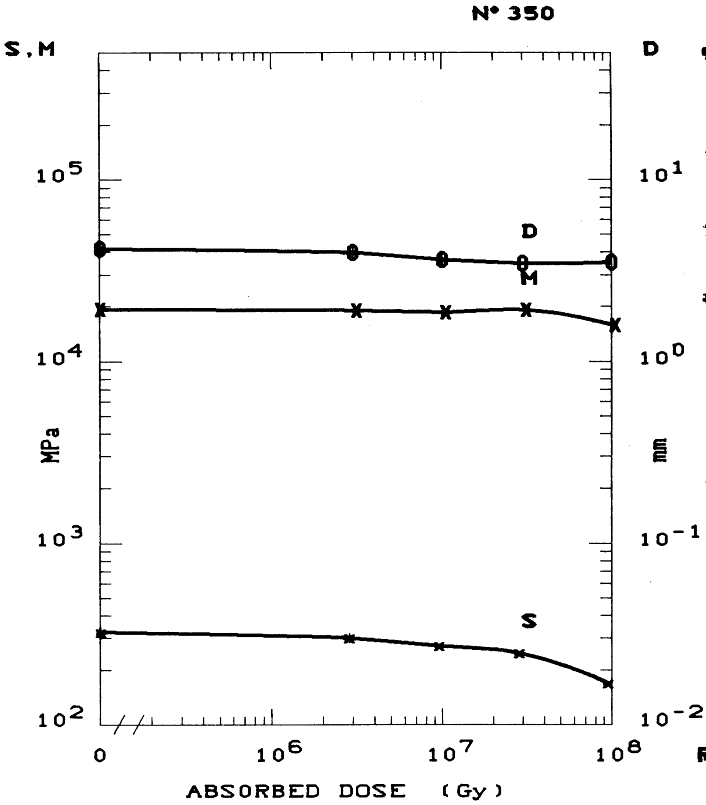
TYPE : ORLITHERM-S INSULATION

SUPPLIER: BBC, BADEN

REMARKS : MAGNET COIL INSULATION APPLICATION

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	231.0 MPa
D	DEFLEXION AT MAX. LOAD	2.9 mm
M	MODULUS OF ELASTICITY	17550.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.9

Fig. 21



MATERIAL: SOLVENTLESS EPOXY RESIN NO. 332 BASE DGEBA+MNA+OTHER COMPONENTS REINFORCED WITH FIBRE-SILANIZED GLASS-CLOTH BACKING (TYPE 3)

TYPE : ORLITHERM-D INSULATION

SUPPLIER: BBC, BADEN

REMARKS : MAGNET COIL INSULATION APPLICATION

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	324.0 MPa
D	DEFLEXION AT MAX. LOAD	4.2 mm
M	MODULUS OF ELASTICITY	19240.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	>8.0

Fig. 22

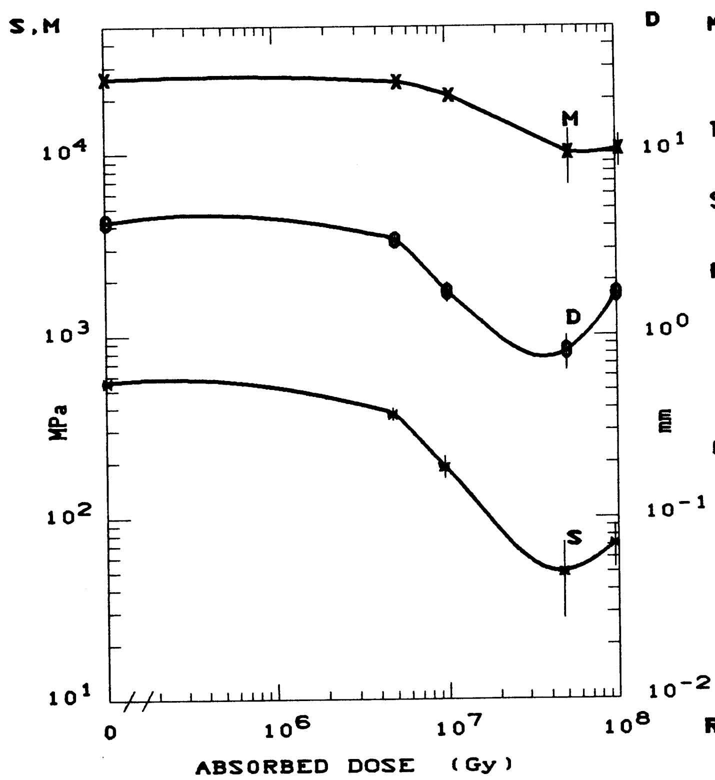
Table 6
Laminates

No.	Material Type Supplier Remarks	Dose (Gy)	Flex. strength at max. load S (MPa)	Deflexion at max. load D (mm)	Modulus of elasticity M (GPa)	RI IEC 544-4 at 10^5 Gy/h
330	Epoxy + glass cloth	0.0	559.5 ± 12.7	4.2 ± 0.1	25.83 ± 0.20	6.8
	Vetronit G-10 432.81	5.0×10^6	371.7 ± 29.0	3.4 ± 0.2	24.81 ± 0.40	
	Isola	1.0×10^7	190.4 ± 26.5	1.7 ± 0.2	20.91 ± 1.11	
	Laminate with high mechanical resistance	5.0×10^7	50.4 ± 22.5	0.8 ± 0.2	10.10 ± 3.33	
		1.0×10^8	72.0 ± 19.2	1.7 ± 0.7	10.50 ± 2.12	
331	Epoxy + glass cloth	0.0	453.0 ± 16.1	4.2 ± 0.0	20.31 ± 0.35	6.8
	Vetronit G-11 432.86	5.0×10^6	285.2 ± 13.6	3.2 ± 0.1	18.60 ± 0.97	
	Isola	1.0×10^7	216.9 ± 29.3	3.4 ± 0.2	14.88 ± 0.79	
	Laminate with high mechanical resistance at elevated temperature	5.0×10^7	82.0 ± 7.6	2.2 ± 0.1	9.84 ± 0.37	
		1.0×10^8	78.4 ± 5.5	2.0 ± 0.0	8.93 ± 0.49	
332	Epoxy + glass mat	0.0	364.0 ± 6.8	5.8 ± 0.3	15.78 ± 0.31	7.4
	Vetronit 541.12	5.0×10^6	334.0 ± 15.9	5.4 ± 0.1	14.94 ± 0.34	
	Isola	1.0×10^7	340.8 ± 8.5	5.2 ± 0.2	15.69 ± 0.37	
	Laminate for shaped pieces	5.0×10^7	146.0 ± 32.3	3.9 ± 0.9	10.68 ± 1.06	
		1.0×10^8	116.4 ± 2.9	3.0 ± 0.7	9.62 ± 0.41	
358	Polyester (halogenated) + glass mat	0.0	250.5 ± 12.3	5.2 ± 0.2	11.16 ± 0.44	7.3
	Delmat 64.247	3.0×10^6	185.1 ± 11.1	4.5 ± 0.4	10.32 ± 0.49	
	Isola	1.0×10^7	159.0 ± 2.2	3.9 ± 0.2	9.81 ± 0.29	
	Flame-resistant laminate	3.0×10^7	117.9 ± 8.5	3.9 ± 1.1	8.63 ± 0.39	
		1.0×10^8	50.8 ± 3.6	1.6 ± 0.2	7.35 ± 0.41	
359	Polyester (isophthalic) + glass mat	0.0	125.5 ± 8.5	4.5 ± 0.2	9.87 ± 0.38	7.9
	Delmat 64.243	3.0×10^6	133.2 ± 3.8	5.0 ± 0.5	9.45 ± 0.32	
	Isola	1.0×10^7	133.2 ± 9.9	5.2 ± 0.4	9.60 ± 0.29	
	Flame- and tracking-resistant laminate	3.0×10^7	111.8 ± 6.0	5.1 ± 0.3	9.06 ± 0.34	
		1.0×10^8	60.0 ± 6.8	3.6 ± 0.2	5.15 ± 0.46	
360	Epoxy + glass mat	0.0	464.4 ± 19.0	5.0 ± 0.3	19.95 ± 0.78	> 8.0
	Delmat 64.841	3.0×10^6	424.2 ± 20.9	4.6 ± 0.2	19.56 ± 0.83	
	Isola	1.0×10^7	440.3 ± 24.1	4.8 ± 0.2	20.01 ± 0.47	
	Laminate with high mechanical resistance at elevated temperature	3.0×10^7	451.0 ± 15.2	4.8 ± 0.2	21.17 ± 0.21	
		1.0×10^8	343.2 ± 27.1	4.3 ± 0.4	17.38 ± 0.58	

Table 6 (cont.)

No.	Material Type Supplier Remarks	Dose (Gy)	Flex. strength at max. load S (MPa)	Deflexion at max. load D (mm)	Modulus of elasticity M (GPa)	RI IEC 544-4 at 10^5 Gy/h
361	Epoxy + polyester	0.0	132.5 ± 4.6	13.9 ± 0.3	5.40 ± 0.17	6.9
	Fluoridit 31	1.0×10^6	127.5 ± 10.1	14.4 ± 1.4	5.28 ± 0.17	
	Isola	3.0×10^6	121.8 ± 10.5	15.0 ± 0.4	5.25 ± 0.22	
	For use in SF6 applications	1.0×10^7	62.1 ± 10.4	2.1 ± 0.1	5.22 ± 0.52	
		3.0×10^7	16.2 ± 2.1	0.6 ± 0.1	4.18 ± 0.25	
364	Inorganic binder with mica paper	0.0	268.0 ± 41.1	1.4 ± 0.2	94.70 ± 3.76	⩾ 8
	Samicanit INOR 422.15	3.0×10^6	231.0 ± 45.1	1.3 ± 0.2	87.30 ± 8.47	
	Isola	1.0×10^7	250.0 ± 41.7	1.4 ± 0.2	94.80 ± 9.75	
	Inorganic laminate for temperatures up to 700 °C	3.0×10^7	232.0 ± 50.9	1.4 ± 0.2	86.40 ± 5.91	
		1.0×10^8	213.0 ± 35.1	1.2 ± 0.2	86.00 ± 7.51	

N° 330



MATERIAL: EPOXY + GLASS CLOTH

TYPE : VETRONIT G-10 432.81

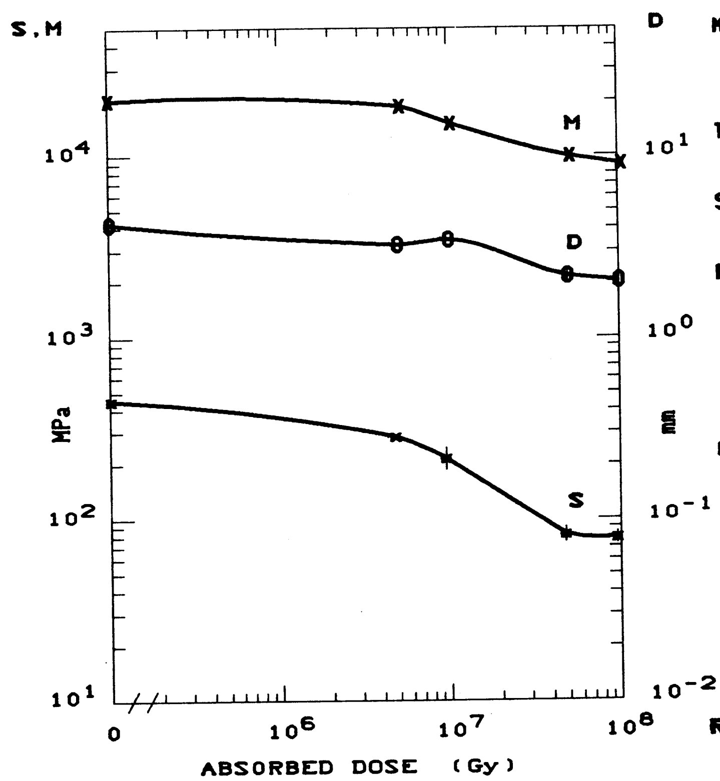
SUPPLIER: ISOLA

REMARKS : LAMINATE WITH HIGH MECHANICAL RESISTANCE

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	559.2 MPa
D	DEFLEXION AT MAX. LOAD	4.2 mm
M	MODULUS OF ELASTICITY	25836.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	6.8

Fig, 23

N° 331



MATERIAL: EPOXY + GLASS CLOTH

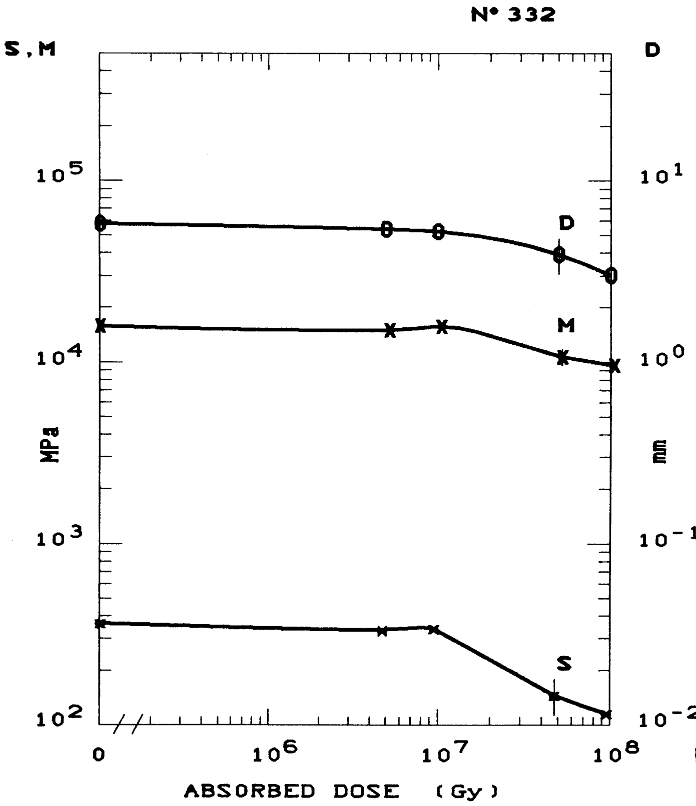
TYPE : VETRONIT G-11 432.86

SUPPLIER: ISOLA

REMARKS : LAMINATE WITH HIGH MECHANICAL RESISTANCE AT ELEVATED TEMPERATURE

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT BREAK	453.0 MPa
D	DEFLEXION AT BREAK	4.2 mm
M	MODULUS OF ELASTICITY	20310.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	6.8

Fig. 24



MATERIAL: EPOXY + GLASS MAT

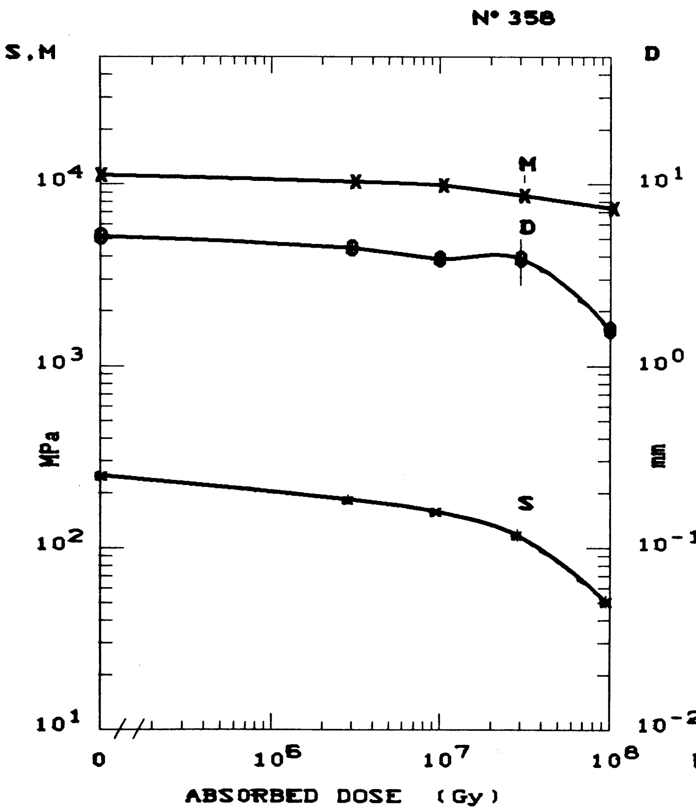
TYPE : VETRONIT 541.12

SUPPLIER: ISOLA

REMARKS : LAMINATE FOR SHAPED PIECES

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	364.0 MPa
D	DEFLEXION AT MAX. LOAD	5.8 mm
M	MODULUS OF ELASTICITY	15777.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.4

Fig. 25



MATERIAL: POLYESTER (HALOGENATED) + GLASS MAT

TYPE : DELMAT 64.247

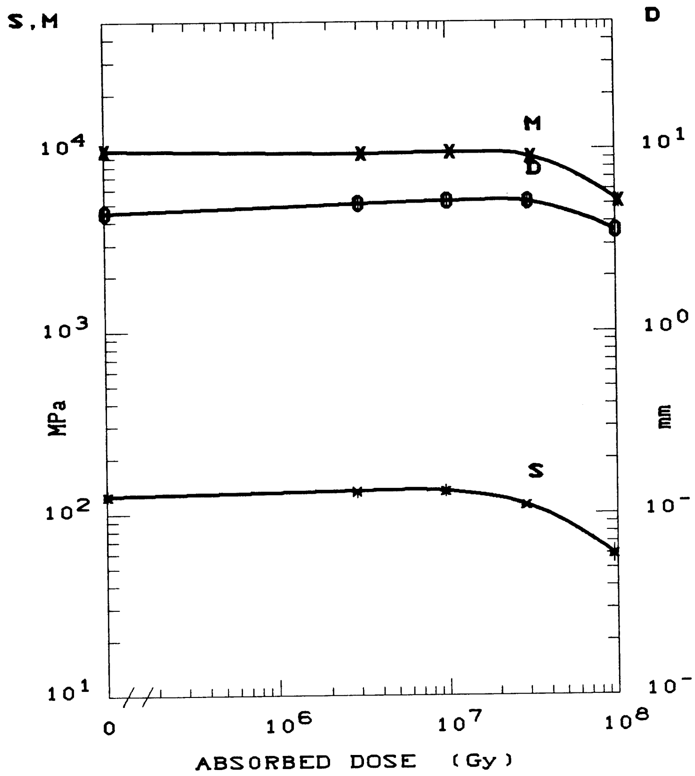
SUPPLIER: ISOLA

REMARKS : FLAME-RESISTANT LAMINATE

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	250.8 MPa
D	DEFLEXION AT MAX. LOAD	5.2 mm
M	MODULUS OF ELASTICITY	11170.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.3

Fig. 26

N° 359



MATERIAL: POLYESTER (ISOPHTHALIC) + GLASS MAT

TYPE : DELMAT 64.243

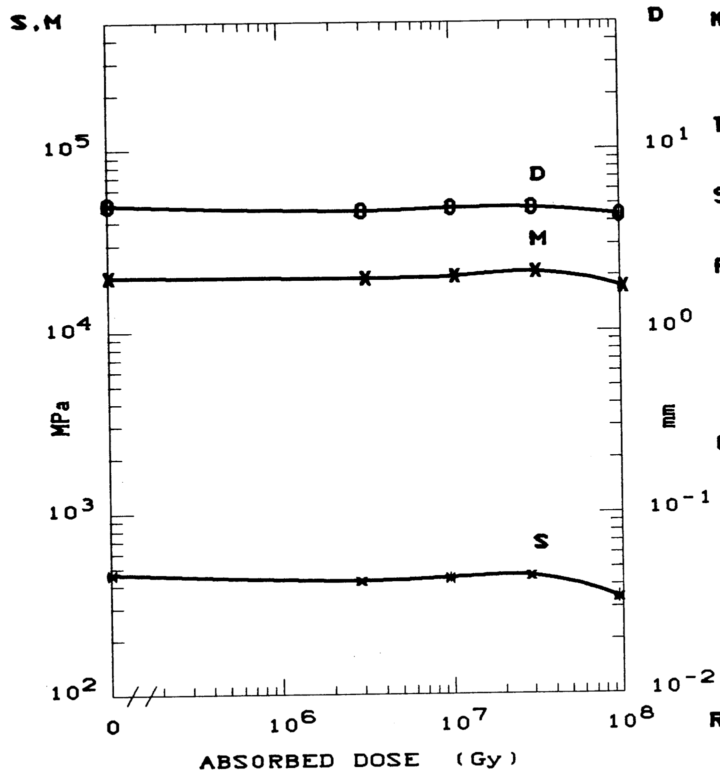
SUPPLIER: ISOLA

REMARKS : FLAME- AND TRACKING-RESISTANT LAMINATE

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	125.4 MPa
D	DEFLEXION AT MAX. LOAD	4.5 mm
M	MODULUS OF ELASTICITY	9860.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.9

Fig. 27

N° 360



MATERIAL: EPOXY + GLASS MAT

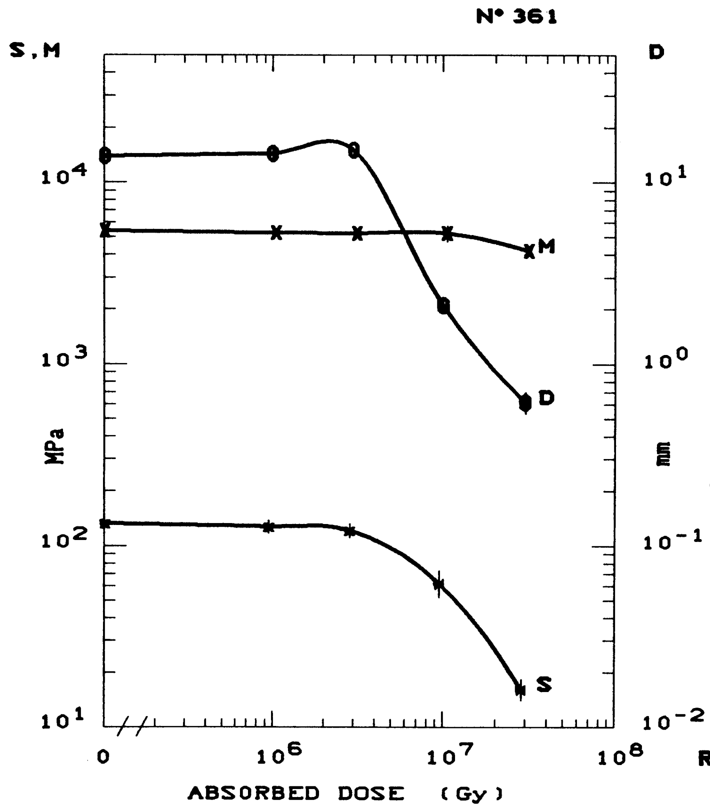
TYPE : DELMAT 64.841

SUPPLIER: ISOLA

REMARKS : LAMINATE WITH HIGH MECHANICAL RESISTANCE AT ELEVATED TEMPERATURE

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	464.4 MPa
D	DEFLEXION AT MAX. LOAD	5.0 mm
M	MODULUS OF ELASTICITY	19960.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	>8.0

Fig. 28



MATERIAL: EPOXY + POLYESTER

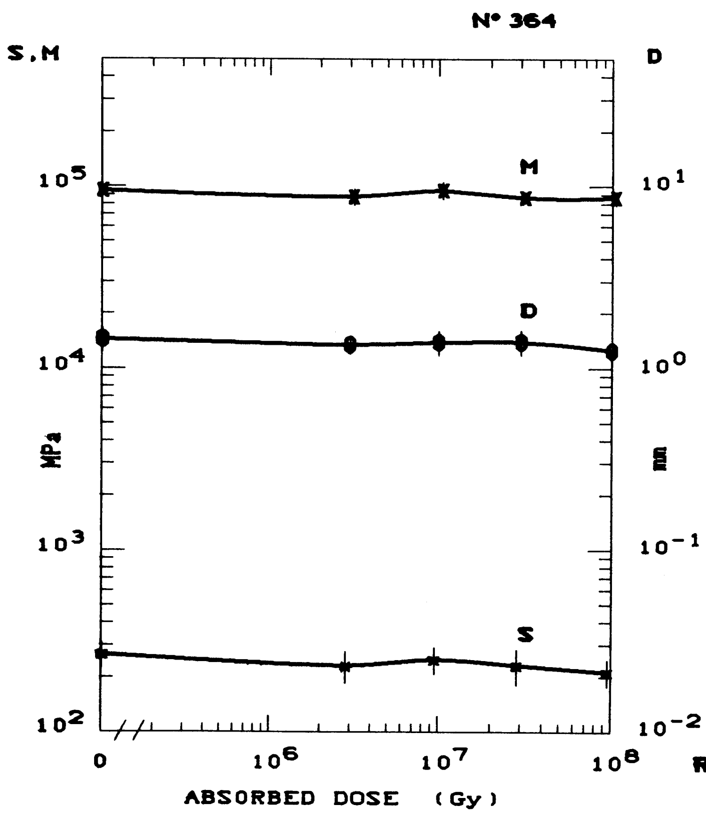
TYPE : FLUORIDIT 31

SUPPLIER: ISOLA

REMARKS : FOR USE IN SF6 APPLICATIONS

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	132.6 MPa
D	DEFLEXION AT MAX. LOAD	13.9 mm
M	MODULUS OF ELASTICITY	5410.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	6.9

Fig. 29



MATERIAL: INORGANIC BINDER WITH MICA PAPER

TYPE : SAMICANIT INOR 422.15

SUPPLIER: ISOLA

REMARKS : INORGANIC LAMINATE FOR TEMPERATURES UP TO 700 DEGREES C.

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	268.0 MPa
D	DEFLEXION AT MAX. LOAD	1.4 mm
M	MODULUS OF ELASTICITY	94700.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	>> 8

Fig. 30

Table 7
Special material combinations

No.	Material Type Supplier Remarks	Dose (Gy)	Flex. strength at max. load S (MPa)	Deflexion at max. load D (mm)	Modulus of elasticity M (GPa)	RI IEC 544-4 at 10^5 Gy/h
344	Glassrope impregnated with Micadur resin (CERN No. 336)	0.0	192.0 ± 15.5	5.4 ± 1.8	17.70 ± 1.69	7.6
		3.0×10^6	207.0 ± 85.0	4.6 ± 1.0	16.32 ± 1.96	
	Micadur insulation system	1.0×10^7	183.2 ± 14.6	4.4 ± 1.4	18.20 ± 1.61	
	BBC, Baden	3.0×10^7	112.0 ± 49.0	2.2 ± 0.3	16.45 ± 1.62	
	For fixing elements in rotating machines	1.0×10^8	60.0 ± 15.8	1.0 ± 0.0	12.53 ± 2.19	
345	Glass-reinforced epoxy resin	0.0	1170.4 ± 22.3	6.3 ± 0.2	35.04 ± 0.16	> 8.0
	GFK 101	3.0×10^6	1200.6 ± 21.6	6.4 ± 0.2	35.52 ± 0.27	
	BBC, Baden	1.0×10^7	1131.4 ± 8.2	6.1 ± 0.2	35.56 ± 0.42	
	For fixing elements in rotating machines	3.0×10^7	1045.2 ± 20.9	6.8 ± 0.2	35.84 ± 0.19	
		1.0×10^8	728.0 ± 129.6	4.6 ± 0.8	34.94 ± 0.71	
362	Epoxy (cycloaliphatic) + glass roving	0.0	135.2 ± 0.3	5.1 ± 0.4	15.08 ± 0.21	6.7
		3.0×10^6	109.6 ± 14.3	4.8 ± 0.5	13.88 ± 1.42	
	Vetronit 7310	1.0×10^7	36.0 ± 8.0	1.0 ± 0.2	9.78 ± 0.40	
	Isola	3.0×10^7	8.8 ± 6.7	0.3 ± 0.2	4.35 ± 1.16	
	As filament winding tubes, tracking-resistant	1.0×10^8	4.7 ± 4.1	0.5 ± 0.1	2.08 ± 1.46	
363	Epoxy + glass roving	0.0	52.8 ± 1.7	11.7 ± 0.6	2.36 ± 0.24	7.3
	Fluoridit 22	1.0×10^6	53.4 ± 1.3	10.4 ± 0.1	2.58 ± 0.08	
	Isola	3.0×10^6	39.6 ± 0.1	7.0 ± 0.5	2.54 ± 0.16	
	As filament winding tubes	1.0×10^7	32.3 ± 1.1	5.1 ± 0.3	2.76 ± 0.06	
		3.0×10^7	24.4 ± 0.8	3.3 ± 0.2	2.90 ± 0.01	
365	Polyester + glass roving	0.0	802.0 ± 34.7	3.6 ± 0.1	39.24 ± 1.10	> 8.0
	Polyglass 31	3.0×10^6	752.0 ± 50.8	3.6 ± 0.2	39.25 ± 1.67	
	Isola	1.0×10^7	778.0 ± 37.7	3.7 ± 0.2	38.70 ± 0.72	
	Tape for windings	3.0×10^7	758.4 ± 26.9	3.6 ± 0.3	39.46 ± 0.83	
		1.0×10^8	724.0 ± 25.1	3.5 ± 0.2	39.44 ± 0.75	
366	Polyester + glass roving	0.0	1311.0 ± 84.5	5.8 ± 0.3	43.10 ± 1.71	> 8.0
	Polyglass H-200	3.0×10^6	1215.0 ± 91.4	5.4 ± 0.4	40.96 ± 1.41	
	Isola	1.0×10^7	1245.0 ± 104.4	5.4 ± 0.3	42.48 ± 3.01	
	Tape for windings for class H machines	3.0×10^7	1034.0 ± 51.3	4.6 ± 0.2	41.72 ± 2.18	
		1.0×10^8	836.0 ± 72.7	3.8 ± 0.1	39.40 ± 4.50	

Table 7 (cont.)

No.	Material Type Supplier Remarks	Dose (Gy)	Flex. strength at max. load S (MPa)	Deflexion at max. load D (mm)	Modulus of elasticity M (GPa)	RI IEC 544-4 at 10^5 Gy/h
367	Polyesterimide + glass roving	0.0	1344.0 ± 59.4	5.8 ± 0.1	43.47 ± 2.45	> 8.0
	Polyglass H-220	3.0×10^6	1334.0 ± 61.2	5.8 ± 0.3	43.04 ± 1.38	
	Isola	1.0×10^7	1300.0 ± 61.1	5.6 ± 0.2	43.06 ± 0.59	
	Tape for windings at higher temperatures	3.0×10^7	1187.2 ± 7.6	5.1 ± 0.2	43.72 ± 0.34	
		1.0×10^8	994.0 ± 62.6	4.6 ± 0.4	43.22 ± 0.74	
393	Epoxy + glass cloth (prepreg)	0.0	531.0 ± 15.8	3.3 ± 0.3	32.25 ± 1.54	> 8.0
	Art. No. 251.70	5.0×10^6	527.4 ± 20.2	3.7 ± 0.3	32.98 ± 0.09	
	Isola	1.0×10^7	549.0 ± 39.7	3.4 ± 0.4	32.90 ± 1.69	
	For magnet coil insulation	5.0×10^7	432.0 ± 20.4	3.1 ± 0.2	31.50 ± 0.73	
		1.0×10^8	378.6 ± 21.0	2.8 ± 0.3	29.25 ± 1.01	

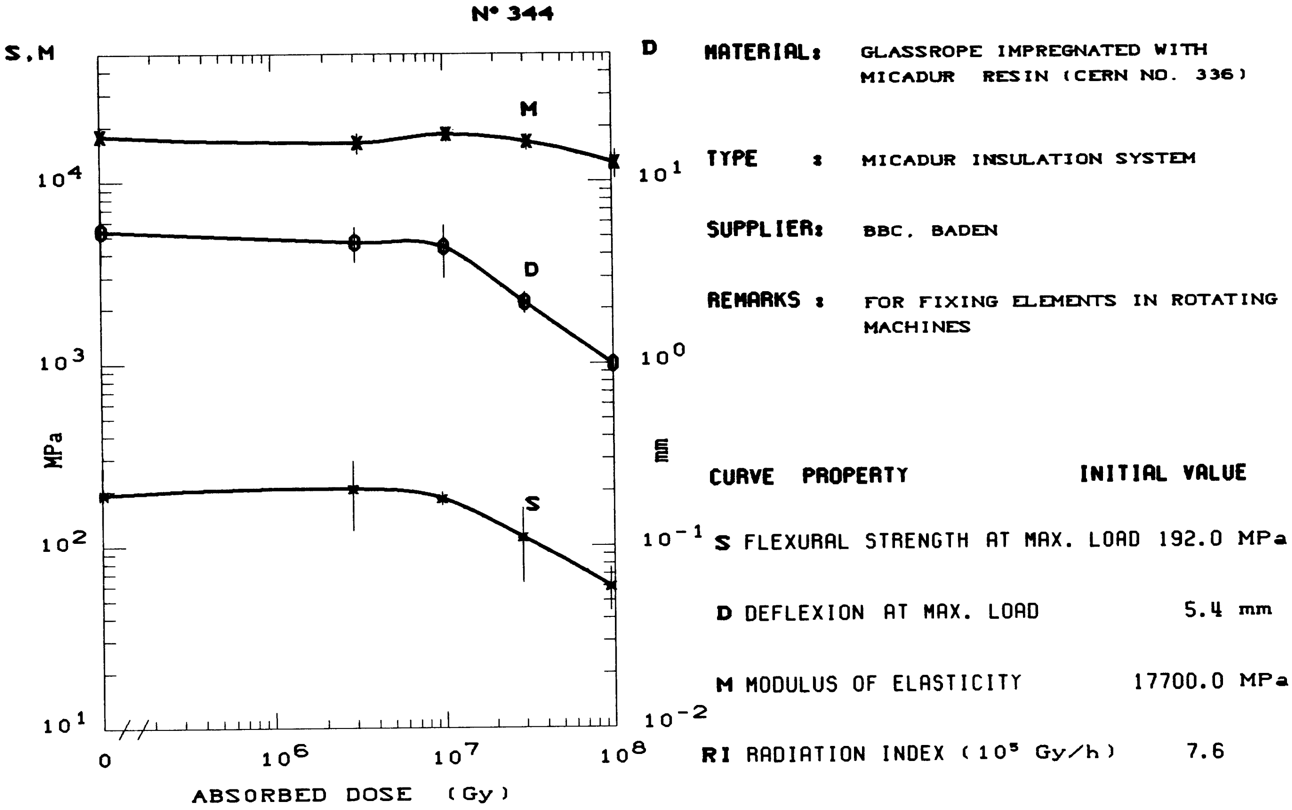

N° 344
S,M
D
M
D
S
MPa
mm
10⁴
10³
10²
10¹
10¹
10⁰
10⁻¹
10⁻²
0
10⁶
10⁷
10⁸
ABSORBED DOSE (Gy)
MATERIAL: GLASSROPE IMPREGNATED WITH MICADUR RESIN (CERN NO. 336)
TYPE : MICADUR INSULATION SYSTEM
SUPPLIER: BBC, BADEN
REMARKS : FOR FIXING ELEMENTS IN ROTATING MACHINES
CURVE PROPERTY INITIAL VALUE
S FLEXURAL STRENGTH AT MAX. LOAD 192.0 MPa
D DEFLEXION AT MAX. LOAD 5.4 mm
M MODULUS OF ELASTICITY 17700.0 MPa
RI RADIATION INDEX (10⁵ Gy/h) 7.6

Fig. 31

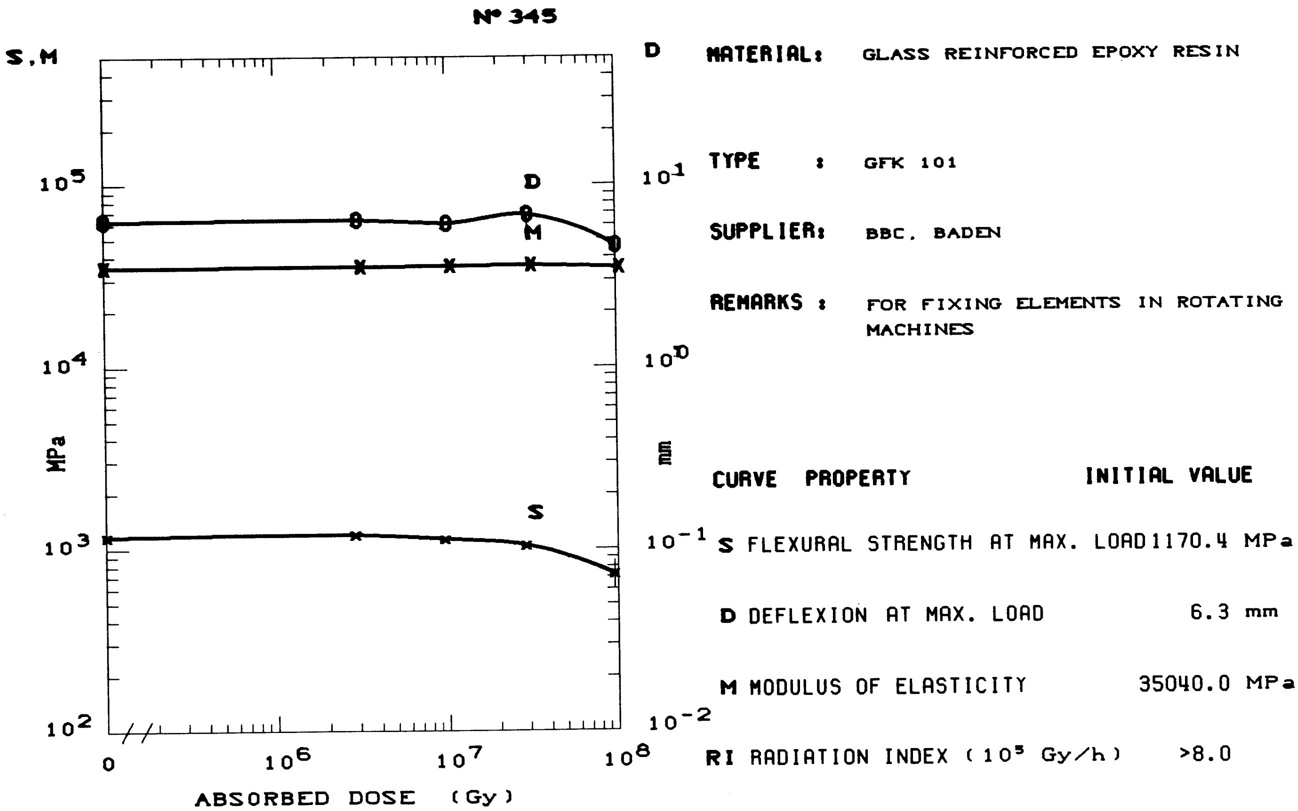
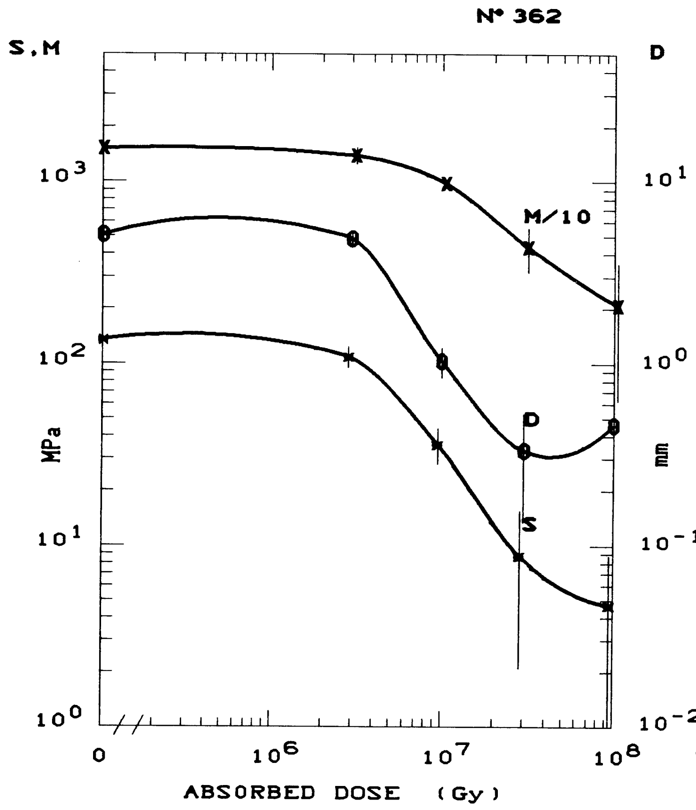

N° 345
S,M
D
D
M
S
MPa
mm
10⁵
10⁴
10³
10²
10¹
10⁰
10⁻¹
10⁻²
0
10⁶
10⁷
10⁸
ABSORBED DOSE (Gy)
MATERIAL: GLASS REINFORCED EPOXY RESIN
TYPE : GFK 101
SUPPLIER: BBC, BADEN
REMARKS : FOR FIXING ELEMENTS IN ROTATING MACHINES
CURVE PROPERTY INITIAL VALUE
S FLEXURAL STRENGTH AT MAX. LOAD 1170.4 MPa
D DEFLEXION AT MAX. LOAD 6.3 mm
M MODULUS OF ELASTICITY 35040.0 MPa
RI RADIATION INDEX (10⁵ Gy/h) >8.0

Fig. 32



MATERIAL: EPOXY (CYCLOALIPHATIC) + GLASS ROVING

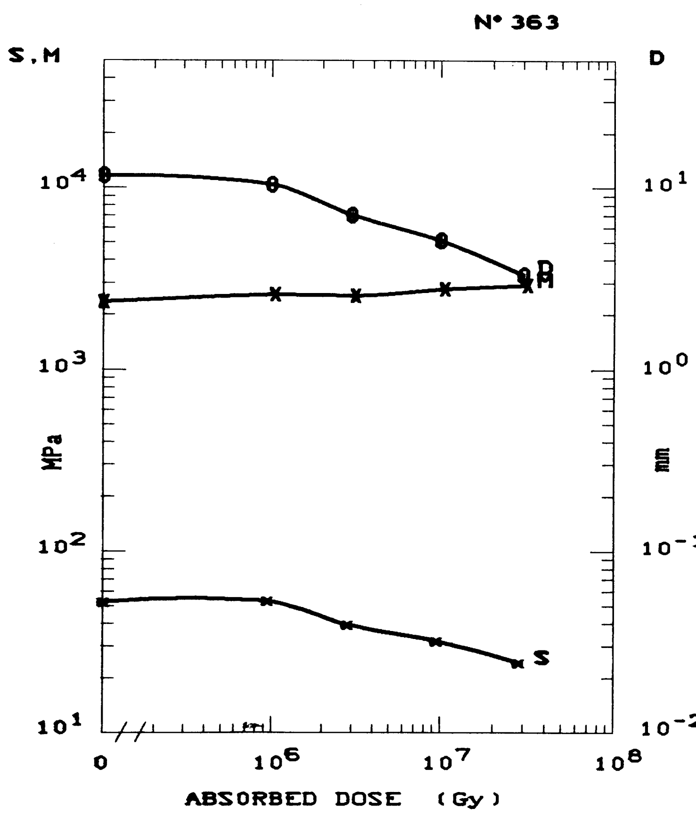
TYPE : VETRONIT 7310

SUPPLIER: ISOLA

REMARKS : AS FILAMENT WINDING TUBES TRACKING-RESISTANT

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	135.2 MPa
D	DEFLEXION AT MAX. LOAD	5.1 mm
M	MODULUS OF ELASTICITY	15080.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	6.7

Fig. 33



MATERIAL: EPOXY + GLASS ROVING

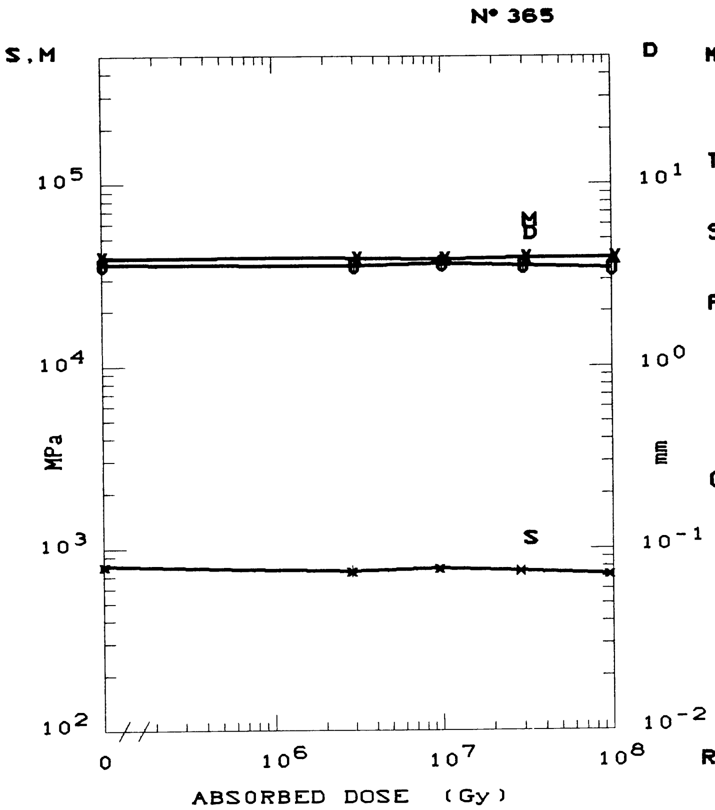
TYPE : FLUORIDIT 22

SUPPLIER: ISOLA

REMARKS : AS FILAMENT WINDING TUBES

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	52.8 MPa
D	DEFLEXION AT MAX. LOAD	11.7 mm
M	MODULUS OF ELASTICITY	2360.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	7.3

Fig. 34



MATERIAL: POLYESTER + GLASS ROVING

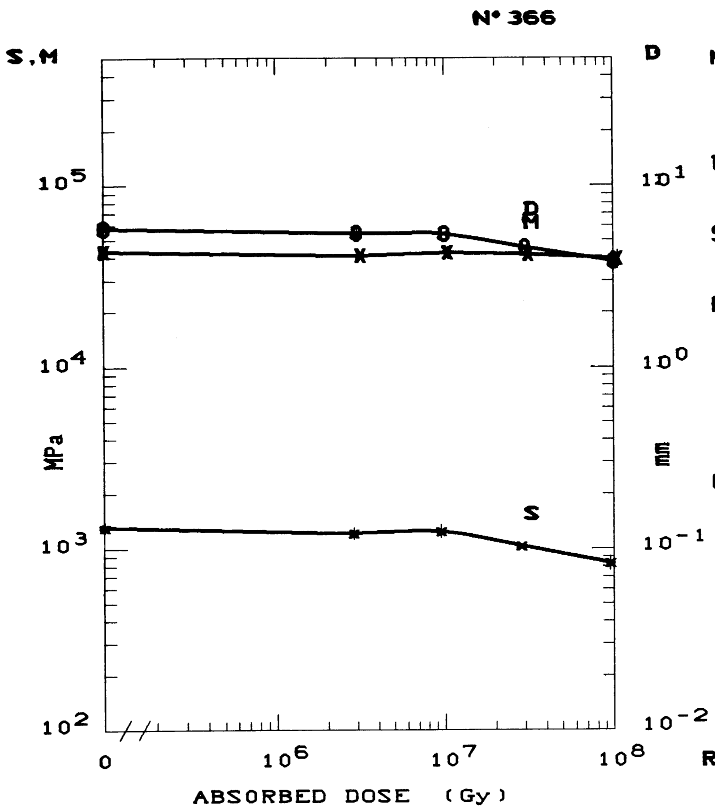
TYPE : POLYGLASS 31

SUPPLIER: ISOLA

REMARKS : TAPE FOR WINDINGS

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	802.0 MPa
D	DEFLEXION AT MAX. LOAD	3.6 mm
M	MODULUS OF ELASTICITY	39250.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	>8.0

Fig. 35



MATERIAL: POLYESTER + GLASS ROVING

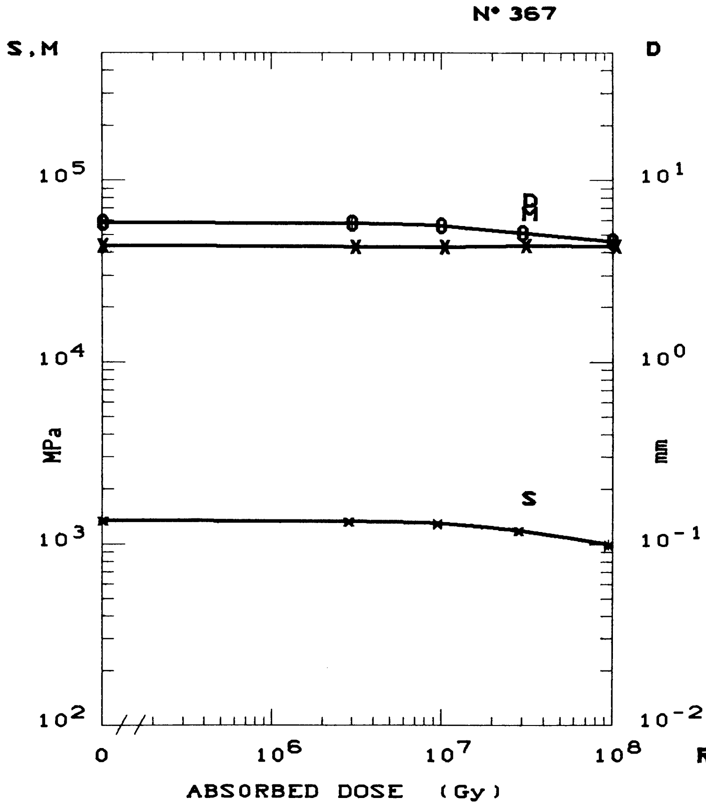
TYPE : POLYGLASS H-200

SUPPLIER: ISOLA

REMARKS : TAPE FOR WINDINGS FOR CLASS H MACHINES

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	1311.0 MPa
D	DEFLEXION AT MAX. LOAD	5.8 mm
M	MODULUS OF ELASTICITY	43100.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	>8.0

Fig. 36



MATERIAL: POLYESTERIMIDE + GLASS ROVING

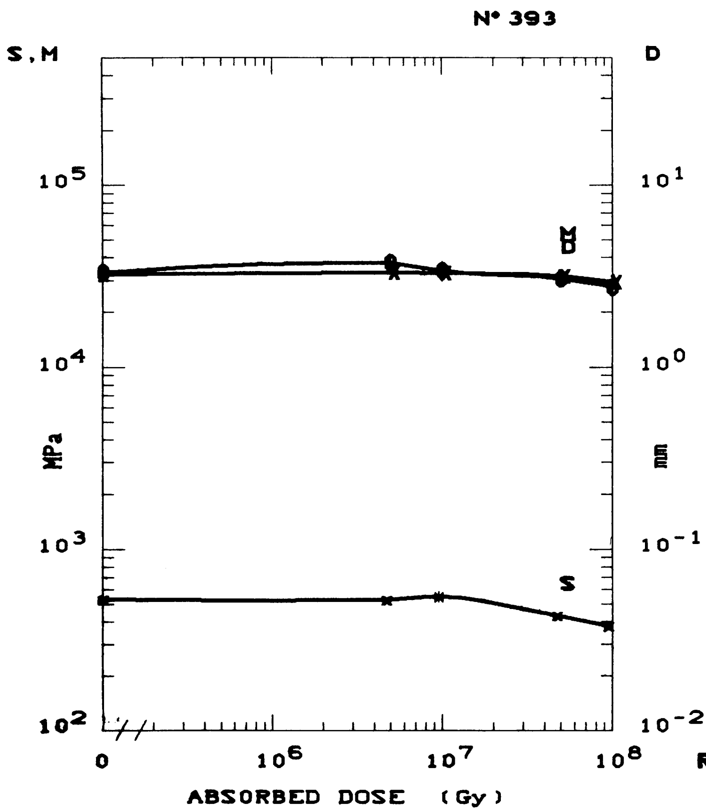
TYPE : POLYGLASS H-220

SUPPLIER: ISOLA

REMARKS : TAPE FOR WINDINGS AT HIGHER TEMPERATURES

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	1344.0 MPa
D	DEFLEXION AT MAX. LOAD	5.8 mm
M	MODULUS OF ELASTICITY	43470.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	>8.0

Fig. 37



MATERIAL: EPOXY + GLASS CLOTH (PREPREG)

TYPE : ART. NO. 251.70

SUPPLIER: ISOLA

REMARKS : FOR MAGNET COIL INSULATION

CURVE	PROPERTY	INITIAL VALUE
S	FLEXURAL STRENGTH AT MAX. LOAD	531.0 MPa
D	DEFLEXION AT MAX. LOAD	3.3 mm
M	MODULUS OF ELASTICITY	32250.0 MPa
RI	RADIATION INDEX (10^5 Gy/h)	>8.0

Fig. 38

Table 8
Conductor insulating tapes with and without mica content

No.	Material Type Supplier Remarks	Dose (Gy)	Breakdown voltage[1)] (kV) Straight	Bent 45	RI[2)] IEC 544-4 at 10^5 Gy/h
E 01	Polyurethane + Samica glass cloth	0.0	1.60 ± 0.15	1.20 ± 0.18	> 7.7
	Art. No. 366.10	5.0×10^6	1.90 ± 0.30	0.0 ± 0.0 (0)	
	Isola	9.2×10^6	1.40 ± 0.30	0.0 ± 0.0 (0)	
	Insulating tape for Class F HV machines	5.0×10^7	1.40 ± 0.20	0.0 ± 0.0 (0)	
E 02	Silicone + Samica + glass cloth	0.0	1.40 ± 0.30	1.40 ± 0.44	>7.7
	Art. No. 366.16	5.0×10^6	1.40 ± 0.35	1.00 ± 0.13 (4)	
	Isola	9.2×10^6	1.70 ± 0.40	1.10 ± 0.15 (3)	
	Insulating tape for class H HV machines	5.0×10^7	1.70 ± 0.35	1.30 ± 0.23 (2)	
E 03	Silicone + Samica + glass cloth	0.0	3.10 ± 0.40	1.70 ± 0.37	> 7.7
	Art. No. 366.19	5.0×10^6	3.10 ± 0.40	1.30 ± 0.15 (3)	
	Isola	9.2×10^6	2.60 ± 0.50	1.30 ± 0.13 (4)	
	Insulating tape (polymerizable) for Class H HV machines	5.0×10^7	2.50 ± 0.30	1.10 ± 0.10 (2)	
E 04	Acryl + Samica + glass cloth + PETP film	0.0	6.40 ± 0.20	6.00 ± 0.43	6.8
	Art. No. 326.02	5.0×10^6	4.40 ± 1.10	1.20 ± 0.17 (4)	
	Isola	9.2×10^6	2.30 ± 0.40	1.20 ± 0.17	
	Insulating tape for Class F HV machines	5.0×10^7	2.30 ± 0.45	0.0 ± 0.0 (0)	
E 05	Epoxy + Samica + glass cloth + PC film	0.0	6.30 ± 0.40	3.80 ± 0.76	
	Art No. 326.06	5.0×10^6	2.60 ± 0.60	0.90 ± 0.12	
	Isola	9.2×10^6	2.60 ± 0.35	0.90 ± 0.08 (4)	
	Insulating tape for Class F HV machines	5.0×10^7	3.40 ± 0.90	0.0 ± 0.0 (0)	
E 06	Polyurethane + Samica + glass cloth + PC film	0.0	6.20 ± 0.25	5.20 ± 1.20	6.8
	Art. No. 326.11	5.0×10^6	3.30 ± 0.55	0.0 ± 0.0 (0)	
	Isola	9.2×10^6	2.90 ± 0.50	0.0 ± 0.0 (0)	
	Insulating tape for Class F HV machines	5.0×10^7	2.40 ± 0.50	0.0 ± 0.0 (0)	

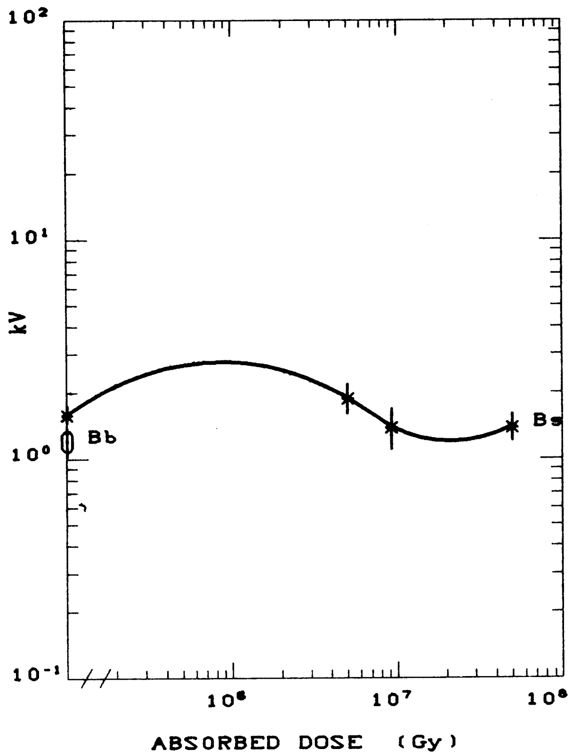
1) Mean value consists of five specimens; in brackets, the number of samples untorn.
2) RI for breakdown-voltage measurement on straight sample.

Table 8 (Cont.)

No.	Material Type Supplier Remarks	Dose (Gy)	Breakdown voltage[1](kV)		RI[2] IEC 544-4 at 10^5 Gy/h
			Straight	Bent 45	
E 07	Silicone + Samica + glass cloth + PC film	0.0	5.10 ± 0.30	4.50 ± 0.54	<6.0
	Art. No. 326.15	5.0×10^6	1.80 ± 0.10	0.90 ± 0.07 (2)	
	Isola	9.2×10^6	1.90 ± 0.45	1.00 ± 0.10 (1)	
	Insulating tape for Class F HV machines	5.0×10^7	1.70 ± 0.25	1.00 ± 0.10 (1)	
E 08	Epoxy + Samica + PETP film	0.0	6.40 ± 0.20	4.50 ± 0.31	>7.7
	Art. No. 315.10	5.0×10^6	6.70 ± 0.85	0.0 ± 0.0 (0)	
	Isola	9.2×10^6	6.30 ± 0.80	0.0 ± 0.0 (0)	
	Insulating tape (polymerizable) for Class F HV machines	5.0×10^7	5.40 ± 0.70	0.0 ± 0.0 (0)	
E 09	Epoxy + Samica polyimide film	0.0	6.50 ± 0.30	6.20 ± 0.26	>7.7
	Art. No. 315.95-20X	5.0×10^6	6.70 ± 0.70	0.0 ± 0.0 (0)	
	Isola	9.2×10^6	5.60 ± 0.60	0.0 ± 0.0 (0)	
	Insulating tape (polymerizable) for Class F HV machines	5.0×10^7	6.00 ± 0.35	0.0 ± 0.0 (0)	
E 10	Epoxy + polyester mat	0.0	7.20 ± 0.80	6.30 ± 0.67	>7.7
	Epoflex 215.01	5.0×10^6	6.00 ± 1.60	5.60 ± 1.28	
	Isola	9.2×10^6	6.60 ± 0.65	5.60 ± 0.71	
	Insulating tape (polymerizable) as sealing layer in class F HV machines	5.0×10^7	3.80 ± 0.50	0.0 ± 0.0 (0)	

1) Mean value consists of five specimens; in brackets, the number of samples untorn.
2) RI for breakdown-voltage measurement on straight sample.

N° E 01



MATERIAL: POLYURETHANE + SAMICA GLASS CLOTH

TYPE : ART. NO. 366.10

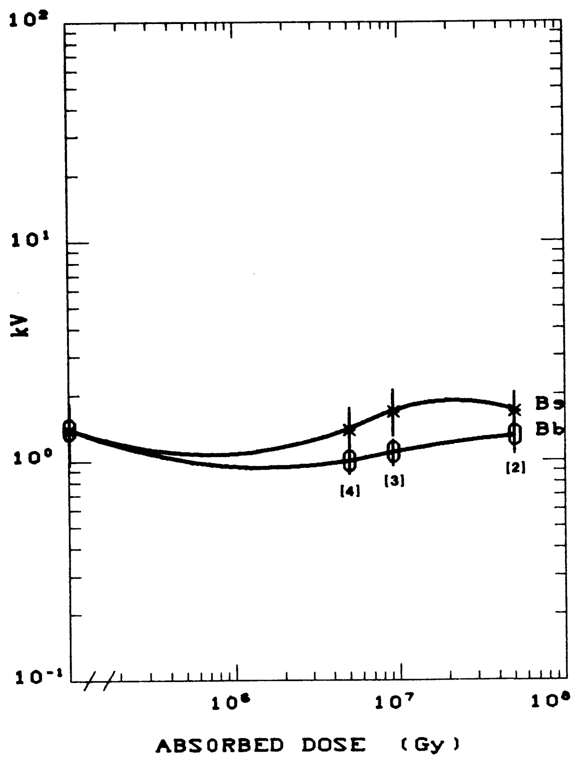
SUPPLIER: ISOLA

REMARKS : INSULATING TAPE FOR CLASS F HV MACHINES

CURVE	PROPERTY	INITIAL VALUE
Bs	BREAKDOWN VOLTAGE STRAIGHT	1.6 kV
Bb	BREAKDOWN VOLTAGE BENT 45°	1.2 kV
RI	RADIATION INDEX (10^5 Gy/h)	>7.7

Fig. 39

N° E 02



MATERIAL: SILICONE + SAMICA + GLASS CLOTH

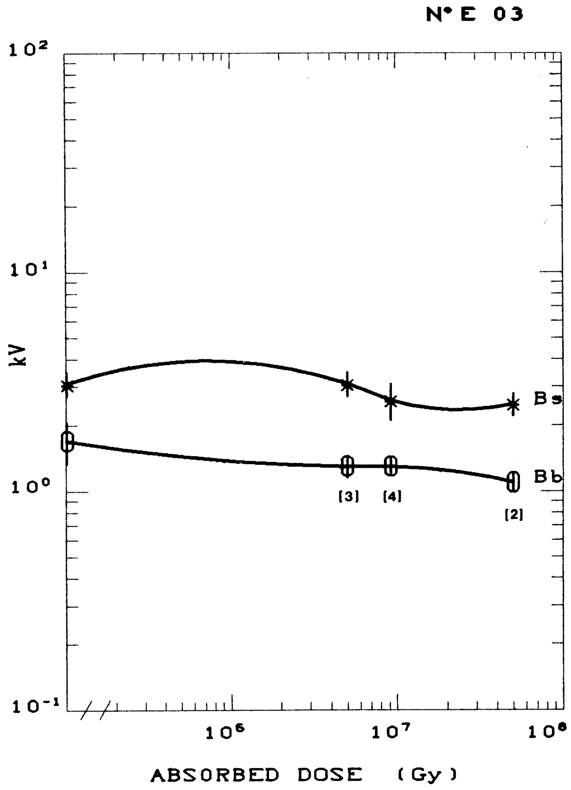
TYPE : ART. NO. 366.16

SUPPLIER: ISOLA

REMARKS : INSULATING TAPE FOR CLASS H HV MACHINES

CURVE	PROPERTY	INITIAL VALUE
Bs	BREAKDOWN VOLTAGE STRAIGHT	1.4 kV
Bb	BREAKDOWN VOLTAGE BENT 45°	1.4 kV
RI	RADIATION INDEX (10^5 Gy/h)	>7.7

Fig. 40



MATERIAL: SILICONE + SAMICA + GLASS CLOTH

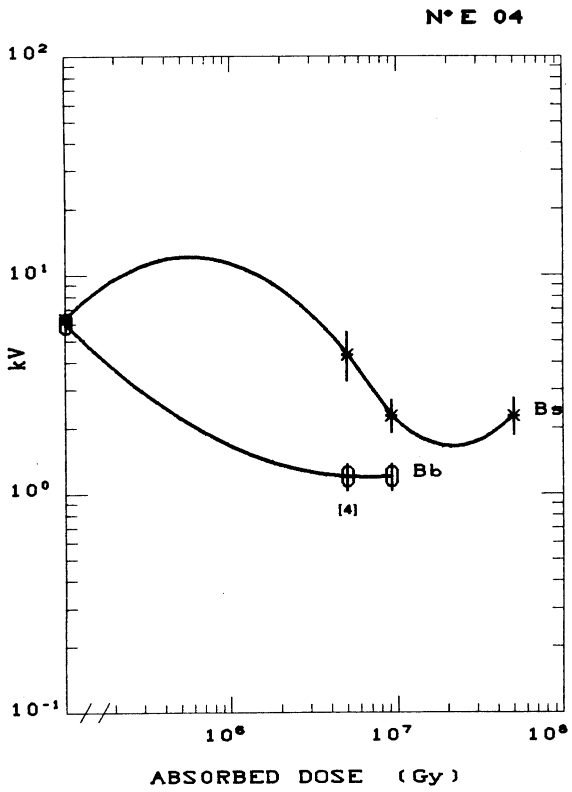
TYPE : ART. NO. 366.19

SUPPLIER: ISOLA

REMARKS : INSULATING TAPE (POLYMERIZABLE) FOR CLASS H HV MACHINES

CURVE	PROPERTY	INITIAL VALUE
Bs	BREAKDOWN VOLTAGE STRAIGHT	3.1 kV
Bb	BREAKDOWN VOLTAGE BENT 45°	1.7 kV
RI	RADIATION INDEX (10^5 Gy/h)	>7.7

Fig. 41



MATERIAL: ACRYL + SAMICA + GLASS CLOTH + PETP FILM

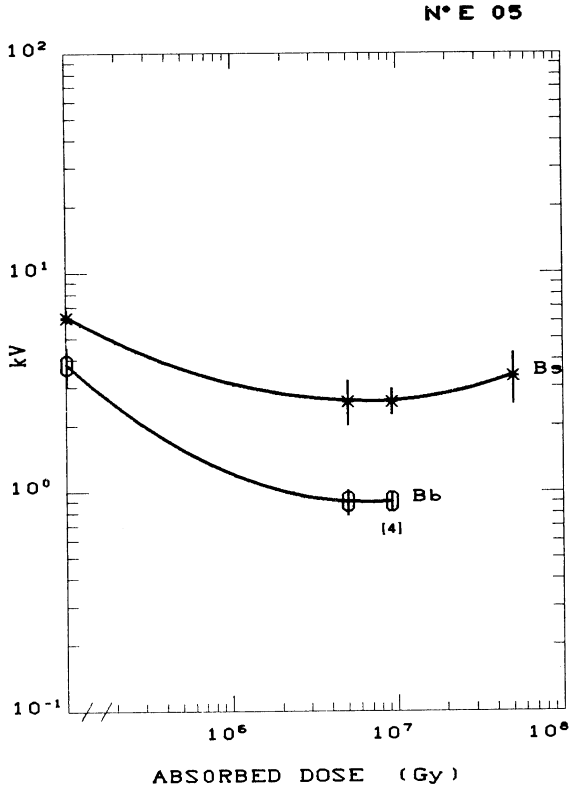
TYPE : ART. NO. 326.02

SUPPLIER: ISOLA

REMARKS : INSULATING TAPE FOR CLASS F HV MACHINES

CURVE	PROPERTY	INITIAL VALUE
Bs	BREAKDOWN VOLTAGE STRAIGHT	6.4 kV
Bb	BREAKDOWN VOLTAGE BENT 45°	6.0 kV
RI	RADIATION INDEX (10^5 Gy/h)	6.8

Fig. 42



MATERIAL: EPOXY + SAMICA + GLASS CLOTH + PC FILM

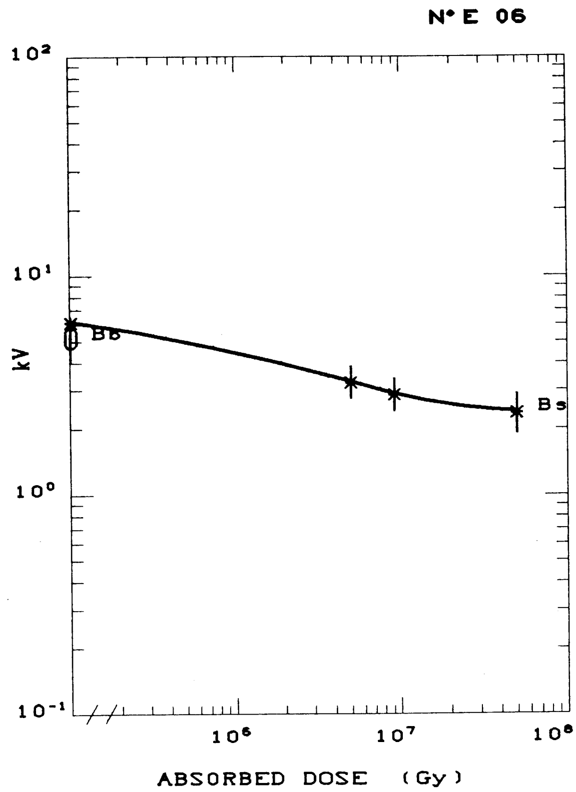
TYPE : ART. NO. 326.06

SUPPLIER: ISOLA

REMARKS : INSULATING TAPE FOR CLASS F HV MACHINES

CURVE	PROPERTY	INITIAL VALUE
Bs	BREAKDOWN VOLTAGE STRAIGHT	6.3 kV
Bb	BREAKDOWN VOLTAGE BENT 45°	3.8 kV
RI	RADIATION INDEX (10^5 Gy/h)	

Fig. 43



MATERIAL: POLYURETHANE + SAMICA + GLASS CLOTH + PC FILM

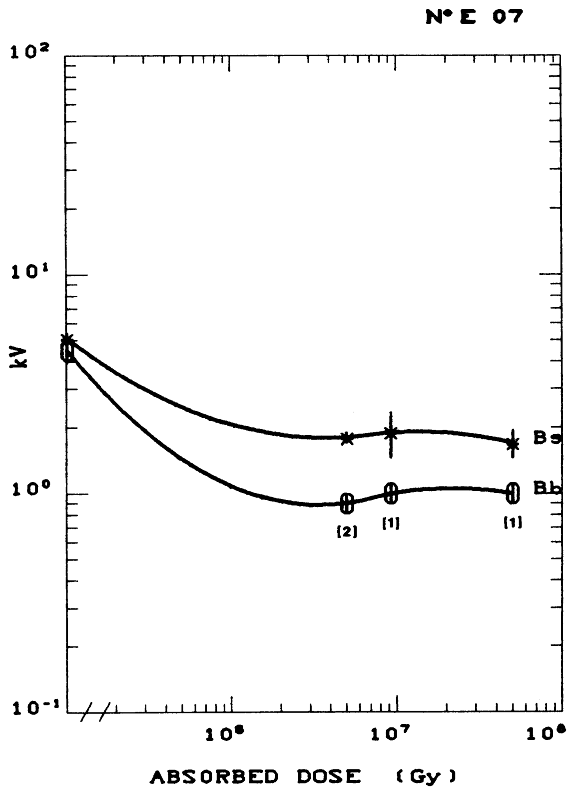
TYPE : ART. NO. 326.11

SUPPLIER: ISOLA

REMARKS : INSULATING TAPE FOR CLASS F HV MACHINES

CURVE	PROPERTY	INITIAL VALUE
Bs	BREAKDOWN VOLTAGE STRAIGHT	6.2 kV
Bb	BREAKDOWN VOLTAGE BENT 45°	5.2 kV
RI	RADIATION INDEX (10^5 Gy/h)	6.8

Fig. 44



MATERIAL: SILICONE + SAMICA + GLASS CLOTH + PC FILM

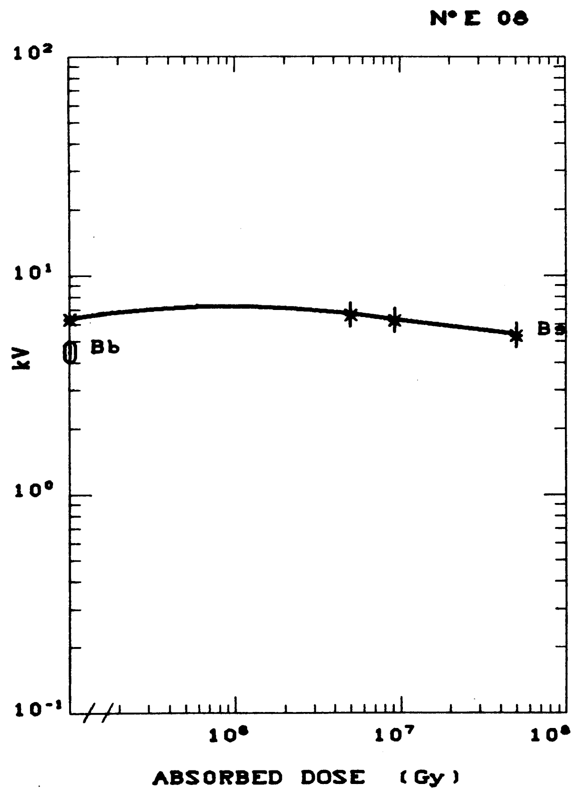
TYPE : ART. NO. 326.15

SUPPLIER: ISOLA

REMARKS : INSULATING TAPE FOR CLASS F HV MACHINES

CURVE	PROPERTY	INITIAL VALUE
Bs	BREAKDOWN VOLTAGE STRAIGHT	5.1 kV
Bb	BREAKDOWN VOLTAGE BENT 45°	4.5 kV
RI	RADIATION INDEX (10^5 Gy/h)	<6.0

Fig. 45



MATERIAL: EPOXY + SAMICA + PETP FILM

TYPE : ART. NO. 315.10

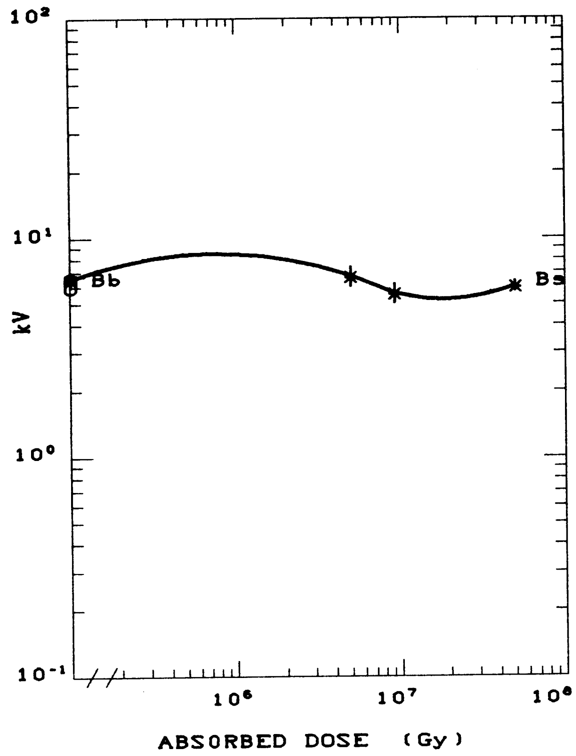
SUPPLIER: ISOLA

REMARKS : INSULATING TAPE (POLYMERIZABLE) FOR CLASS F HV MACHINES

CURVE	PROPERTY	INITIAL VALUE
Bs	BREAKDOWN VOLTAGE STRAIGHT	6.4 kV
Bb	BREAKDOWN VOLTAGE BENT 45°	4.5 kV
RI	RADIATION INDEX (10^5 Gy/h)	>7.7

Fig. 46

N° E 09



MATERIAL: EPOXY + SAMICA POLYIMIDE FILM

TYPE : ART. NO. 315.95-20X

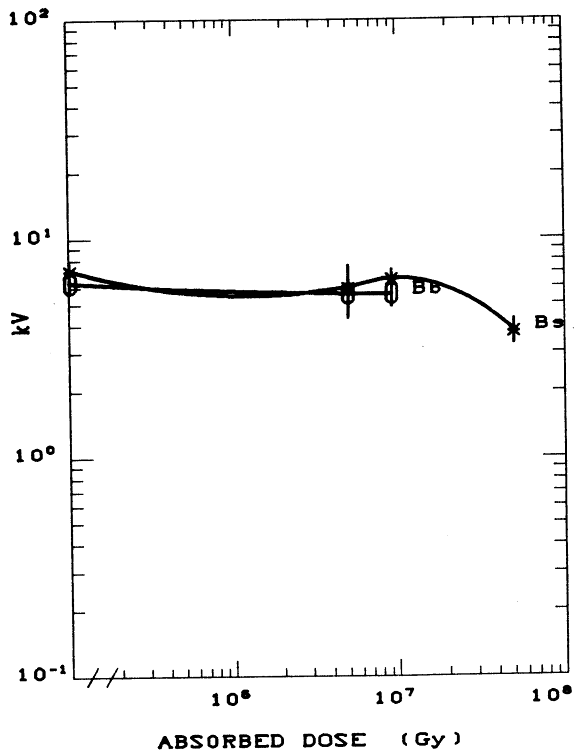
SUPPLIER: ISOLA

REMARKS : INSULATING TAPE (POLYMERIZABLE) FOR CLASS F HV MACHINES

CURVE	PROPERTY	INITIAL VALUE	
Bs	BREAKDOWN VOLTAGE STRAIGHT	6.5	kV
Bb	BREAKDOWN VOLTAGE BENT 45°	6.2	kV
RI	RADIATION INDEX (10^5 Gy/h)	>7.7	

Fig. 47

N° E 10



MATERIAL: EPOXY + POLYESTER MAT

TYPE : EPOFLEX 215.01

SUPPLIER: ISOLA

REMARKS : INSULATING TAPE (POLYMERIZABLE) AS SEALING LAYER IN CLASS F HV MACHINES

CURVE	PROPERTY	INITIAL VALUE	
Bs	BREAKDOWN VOLTAGE STRAIGHT	7.2	kV
Bb	BREAKDOWN VOLTAGE BENT 45°	6.3	kV
RI	RADIATION INDEX (10^5 Gy/h)	>7.7	

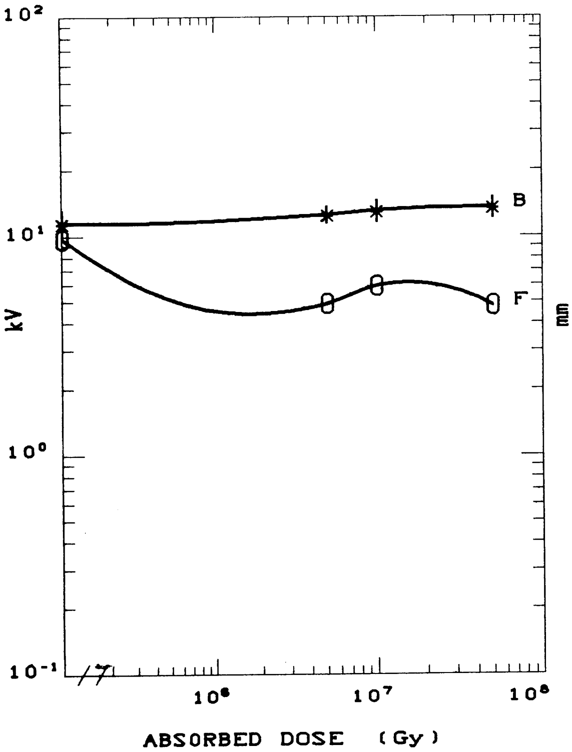
Fig. 48

Table 9
Impregnating and coating varnishes containing solvents

No.	Material Type Supplier Remarks	Dose (Gy)	Breakdown voltage (kV)	Flexibility (mm)	RI[3)] IEC 544-4 at 10^5 Gy/h
E 11	Impregnating varnish: alkyd-phenolic	0.0	11.50 ± 1.50	9.70 ± 0.0	
	Varnish 2005 (755)	5.0×10^6	12.50 ± 1.10	4.90 ± 0.0	
	Isola	1.0×10^7	13.00 ± 1.50	5.90 ± 0.0	
	Treatment of windings for Class F machines	5.0×10^7	13.50 ± 1.50	4.80 ± 0.0	
E 12	Impregnating varnish: polyester-imide	0.0	12.00 ± 1.30	> 10.00 ± 0.0	
	Varnish 2051 (757)	5.0×10^6	12.00 ± 1.40	> 10.00 ± 0.0	
	Isola	1.0×10^7	14.50 ± 1.50	> 10.00 ± 0.0	
	Treatment of windings for Class F machines	5.0×10^7	15.50 ± 1.00	3.50 ± 0.0	
E 13	Impregnating varnish: polyester-imide modified	0.0	11.50 ± 1.10	2.80 ± 0.0	
	Varnish 2053 (760)	5.0×10^6	10.50 ± 1.10	4.20 ± 0.0	
	Isola	1.0×10^7	11.50 ± 1.50	5.30 ± 0.0	
	Treatment of windings for Class H machines	5.0×10^7	13.00 ± 1.50	5.00 ± 0.0	
E 14	Impregnating varnish: silicone	0.0	6.60 ± 0.50	2.30 ± 0.0	
	Varnish IM 9791	5.0×10^6	7.00 ± 0.60	4.80 ± 0.0	
	Isola	1.0×10^7	8.00 ± 1.60	> 10.00 ± 0.0	
	Treatment of windings for Class H machines	5.0×10^7	9.00 ± 1.00	> 10.00 ± 0.0	
E 15	Impregnating varnish: phenolic	0.0	11.50 ± 1.10	5.80 ± 0.0	
	Varnish IM 2139	5.0×10^6	11.00 ± 1.20	3.60 ± 0.0	
	Isola	1.0×10^7	10.00 ± 2.40[1)]	0.0 ± 0.0[1)]	
	Treatment of windings for Class F machines	5.0×10^7	0.0 ± 0.0[2)]	0.0 ± 0.0[2)]	
E 16	Coating varnish: epoxy	0.0	13.50 ± 1.80	7.20 ± 0.0	
	Varnish IM 280	5.0×10^6	12.00 ± 2.80	1.60 ± 0.0	
	Isola	1.0×10^7	13.00 ± 2.20	1.60 ± 0.0	
	Overcoating of glass-reinforced tubes	5.0×10^7	12.00 ± 2.20	1.50 ± 0.0	

1) Varnish adheres only partly.
2) Varnish does not adhere.
3) Assessment of RI not possible; end-point not reached during test.

N° E 11



MATERIAL: IMPREGNATING VARNISH ALKYD-PHENOLIC

TYPE : VARNISH 2005 (755)

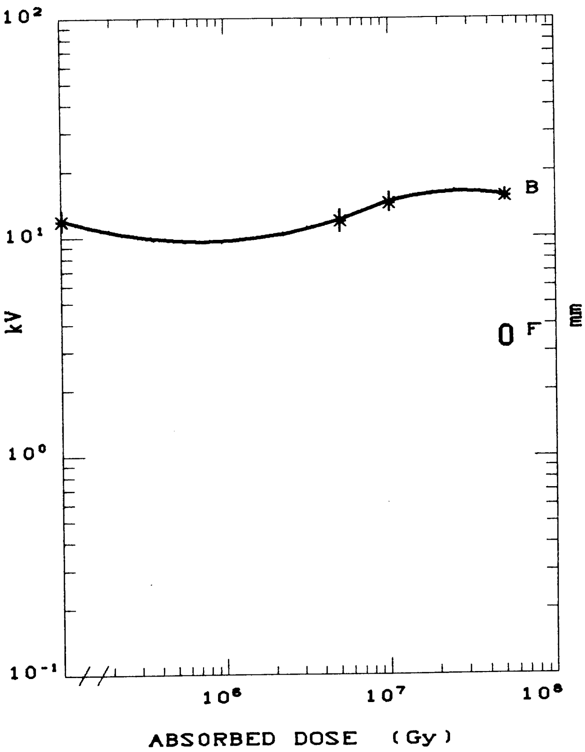
SUPPLIER: ISOLA

REMARKS : TREATMENT OF WINDINGS FOR CLASS F MACHINES

CURVE	PROPERTY	INITIAL VALUE	
B	BREAKDOWN VOLTAGE	11.5	kV
F	FLEXIBILITY	9.7	mm
RI	RADIATION INDEX (10^5 Gy/h)		

Fig. 49

N° E 12



MATERIAL: IMPREGNATING VARNISH POLYESTERIMIDE

TYPE : VARNISH 2051 (757)

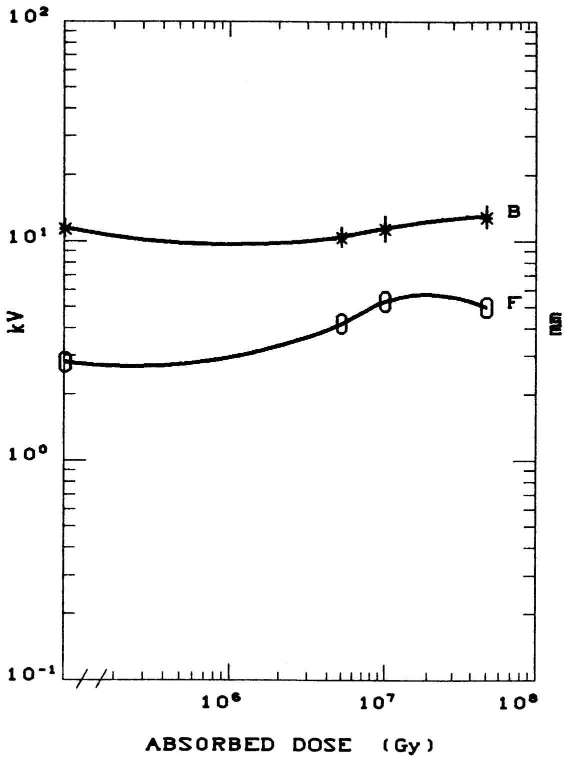
SUPPLIER: ISOLA

REMARKS : TREATMENT OF WINDINGS FOR CLASS F MACHINES

CURVE	PROPERTY	INITIAL VALUE	
B	BREAKDOWN VOLTAGE	12.0	kV
F	FLEXIBILITY	> 10.0	mm
RI	RADIATION INDEX (10^5 Gy/h)		

Fig. 50

N°E 13



MATERIAL: IMPREGNATING VARNISH POLYESTERIMIDE MODIFIED

TYPE : VARNISH 2053 (760)

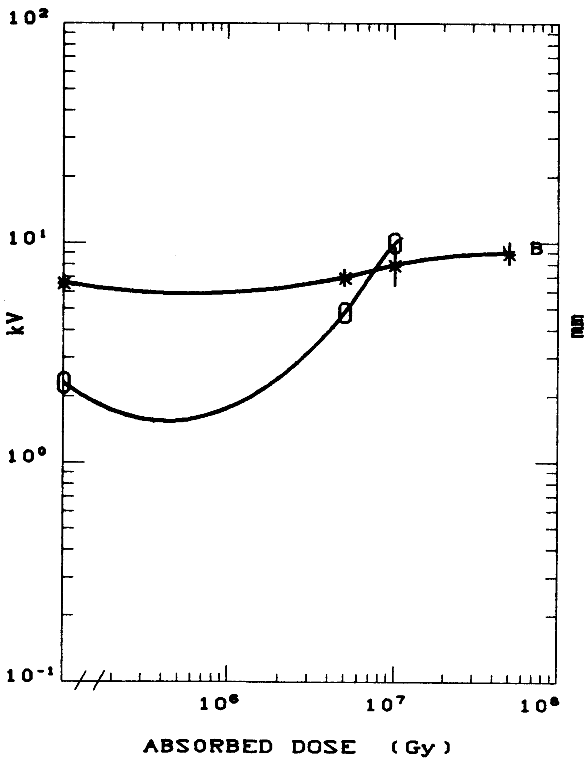
SUPPLIER: ISOLA

REMARKS : TREATMENT OF WINDINGS FOR CLASS H MACHINES

CURVE	PROPERTY	INITIAL VALUE	
B	BREAKDOWN VOLTAGE	11.5	kV
F	FLEXIBILITY	2.8	mm
RI	RADIATION INDEX (10^5 Gy/h)		

Fig. 51

N°E 14



MATERIAL: IMPREGNATING VARNISH SILICONE

TYPE : VARNISH IM 9791

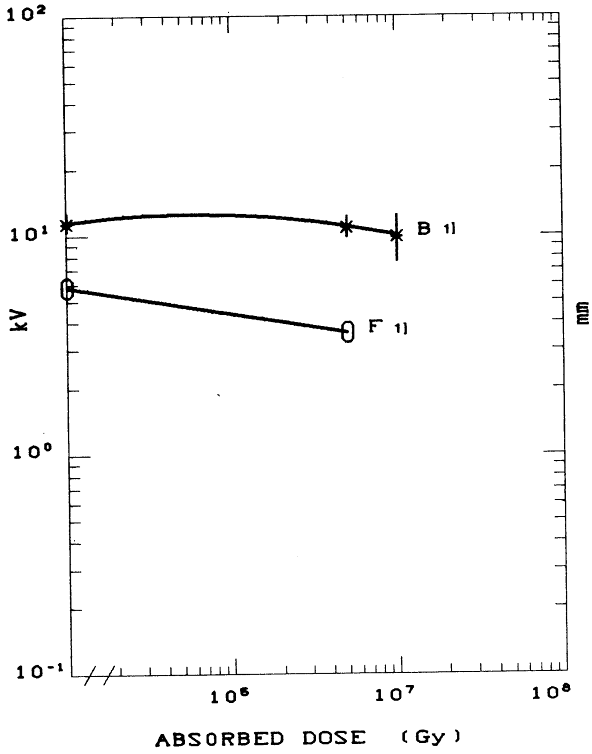
SUPPLIER: ISOLA

REMARKS : TREATMENT OF WINDINGS FOR CLASS H MACHINES

CURVE	PROPERTY	INITIAL VALUE	
B	BREAKDOWN VOLTAGE	6.6	kV
F	FLEXIBILITY	2.3	mm
RI	RADIATION INDEX (10^5 Gy/h)		

Fig. 52

N°E 15



MATERIAL: IMPREGNATING VARNISH PHENOLIC

TYPE : VARNISH IM 2139

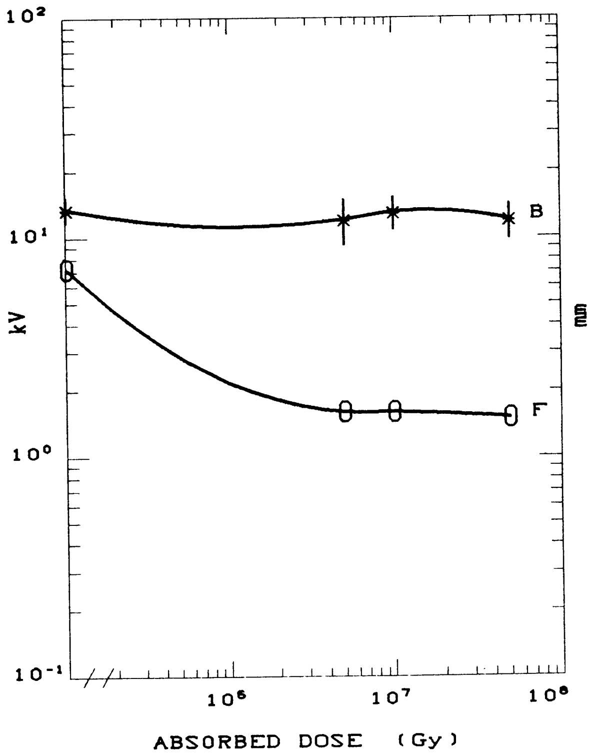
SUPPLIER: ISOLA

REMARKS : TREATMENT OF WINDINGS FOR CLASS F MACHINES

CURVE	PROPERTY	INITIAL VALUE	
B	BREAKDOWN VOLTAGE	11.5	kV
F	FLEXIBILITY	5.8	mm
RI	RADIATION INDEX (10^5 Gy/h)		

Fig. 53

N°E 16



MATERIAL: COATING VARNISH EPOXY

TYPE : VARNISH IM 280

SUPPLIER: ISOLA

REMARKS : OVERCOATING OF GLASS-REINFORCED TUBES

CURVE	PROPERTY	INITIAL VALUE	
B	BREAKDOWN VOLTAGE	13.5	kV
F	FLEXIBILITY	7.2	mm
RI	RADIATION INDEX (10^5 Gy/h)		

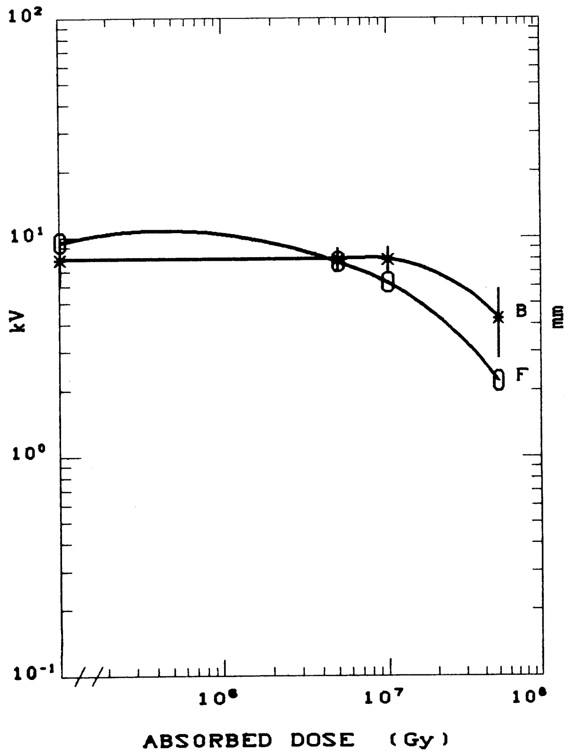
Fig. 54

Table 10
Impregnating and coating varnishes; solventless

No.	Material Type Supplier Remarks	Dose (Gy)	Breakdown Voltage (kV)	Flexibility (mm)	RI[1)] IEC 544-4 at 10^5 Gy/h
E 17	Impregnating varnish: epoxy modified Varnish 3405 (801) Isola Treatment of windings of heavy-duty machines, Class F	0.0 5.0×10^6 1.0×10^7 5.0×10^7	8.00 ± 1.90 8.00 ± 0.90 8.00 ± 1.00 4.30 ± 1.50	9.50 ± 0.0 7.70 ± 0.0 6.20 ± 0.0 2.20 ± 0.0	
E 18	Trickle resin: unsaturated polyesterimide Varnish 3021 (950) Isola For impregnation by trickle process	0.0 5.0×10^6 1.0×10^7 5.0×10^7	8.20 ± 0.50 8.00 ± 0.45 8.50 ± 1.10 9.50 ± 1.10	1.60 ± 0.0 4.10 ± 0.0 4.30 ± 0.0 2.70 ± 0.0	
E 19	Trickle resin: unsaturated polyesterimide Varnish 3022 (951) Isola For impregnation by trickle process, resistant to refrigerants	0.0 5.0×10^6 1.0×10^7 5.0×10^7	7.00 ± 0.70 6.80 ± 0.40 6.80 ± 0.40 7.20 ± 0.80	1.80 ± 0.0 4.40 ± 0.0 4.80 ± 0.0 3.30 ± 0.0	

1) Assessment of RI not possible, end-point not reached.

N° E 17



MATERIAL: IMPREGNATING VARNISH
EPOXY MODIFIED

TYPE : VARNISH 3405 (801)

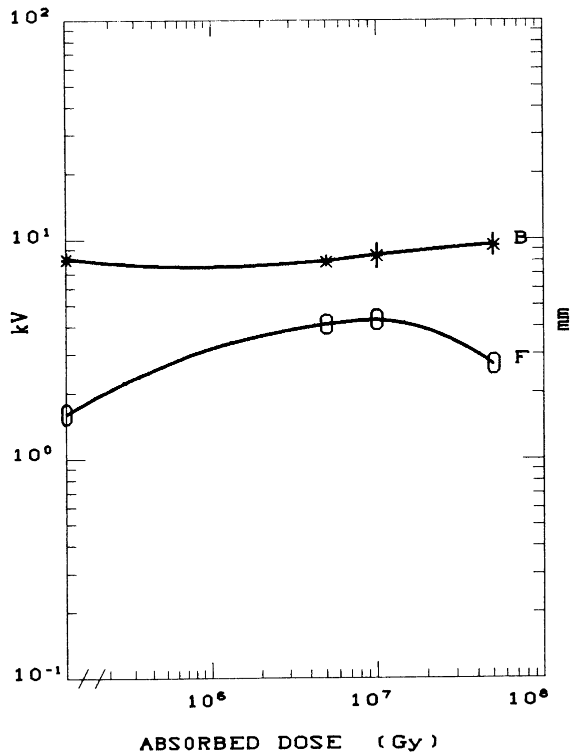
SUPPLIER: ISOLA

REMARKS : TREATMENT OF WINDINGS OF
HEAVY-DUTY MACHINES, CLASS F

CURVE	PROPERTY	INITIAL VALUE	
B	BREAKDOWN VOLTAGE	8.0	kV
F	FLEXIBILITY	9.5	mm
RI	RADIATION INDEX (10^5 Gy/h)		

Fig. 55

N° E 18



MATERIAL: TRICKLE RESIN
UNSATURATED POLYESTERIMIDE

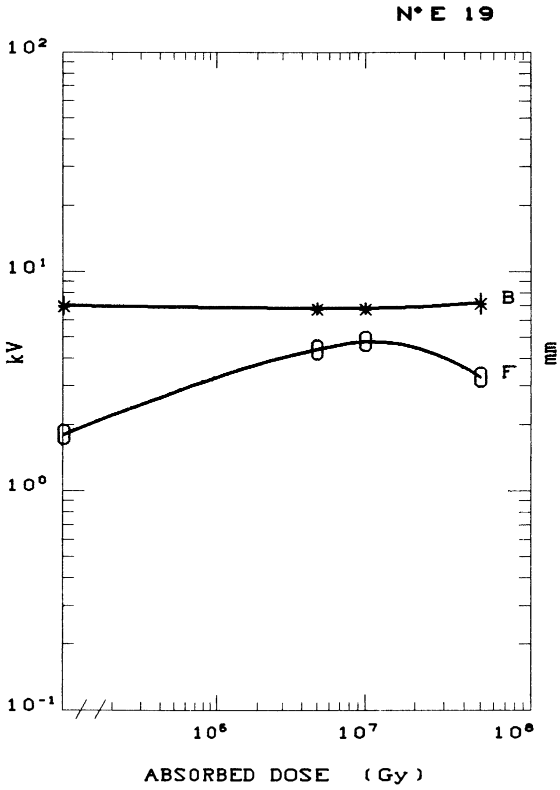
TYPE : VARNISH 3021 (950)

SUPPLIER: ISOLA

REMARKS : FOR IMPREGNATION BY
TRICKLE PROCESS

CURVE	PROPERTY	INITIAL VALUE	
B	BREAKDOWN VOLTAGE	8.2	kV
F	FLEXIBILITY	1.6	mm
RI	RADIATION INDEX (10^5 Gy/h)		

Fig. 56



MATERIAL: TRICKLE RESIN
UNSATURATED POLYESTERIMIDE

TYPE : VARNISH 3022 (951)

SUPPLIER: ISOLA

REMARKS : FOR IMPREGNATION BY TRICKLE PROCESS, RESISTANT TO REFRIGERANTS

CURVE	PROPERTY	INITIAL VALUE	
B	BREAKDOWN VOLTAGE	7.0	kV
F	FLEXIBILITY	1.8	mm
RI	RADIATION INDEX (10^5 Gy/h)		

Fig. 57

Table 11
Coating varnish

No.	Material Type Supplier Remarks	Dose (Gy)	Depth of penetration test Penetration (mm)	Hardness test Depth of penetration (mm)	Hardness test Remaining deformation (mm)
E20	Phenol–formaldehyde varnish	0	5.0	2.6	1.5
	LJ-E2	1.2×10^6	5.6	2.4	1.4
	BBC, Baden	1×10^7	2.7	2.3	1.4
	Coating application in rotating machines				

Table 12
Anticorona varnish

No.	Material Type Supplier Remarks	Dose (Gy)	Specific surface resistance at 5 kV/at 15 kV
E 21	Polyurethane resin filled with SiC	0.0	123
	LL5	5×10^6	125
	BBC, Baden	1.1×10^7	119
	Anticorona varnish in HV applications	3.1×10^7	116

Table 13
Adhesive

No.	Material Supplier	Dose (Gy)	Shear strength (Mpa)
E22	Epoxy resin 305 + primer DZ 80	0.0	29.0
		3.3×10^5	12.4
	BBC, Baden	3.4×10^6	5.3
		1.4×10^6	8.2
		1.2×10^7	6.0
E23	Epoxy resin 305 without primer	0.0	11.5
		1.2×10^6	5.2
	BBC, Baden	1.3×10^7	3.9
		5.2×10^6	4.8

Symmetrical lap-shear specimen

a_1: Piece $140 \times 25 \times 10$ mm^3 } copper treated
a_2: Piece $60 \times 25 \times 8$ mm^3 } with/without primer

b : Bonding: epoxy resin with glass fabric

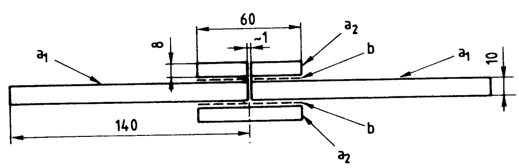


Table 14
Power cable

No.	Material Supplier Remarks	Dose (Gy)	50 Hz Breakdown voltage (r.m.s.) (kV)	50 Hz Min. dielectric strength (r.m.s.) (kV)
E24	Samicaflex, silicone	0.0		31.4
	BBC, Baden	3×10^5	25.0	23.0
	$U_n = 6.6$ kV, 50 mm^2 Al	1.2×10^6	18.0	16.5
		3.1×10^6	13.5	12.5
		1×10^7	13.5	12.5

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