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# COMPILATION OF RADIATION DAMAGE TEST DATA

PART II, 2nd edition:
Thermoset and thermoplastic resins, composite materials

# INDEX DES RÉSULTATS D'ESSAIS DE RADIORÉSISTANCE

IIe PARTIE, 2e édition :
Résines thermodurcies et thermoplastiques, matériaux composites

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## ABSTRACT

This catalogue summarizes radiation damage test data on thermoplastic and thermoset resins and composites. Most of them are epoxy resins used as insulator for magnet coils. Many results are also given for new engineering thermoplastics which can be used either for their electrical properties or for their mechanical properties.

The materials have been irradiated either in a $^{60}Co$ source, up to integrated absorbed doses between 200 kGy and a few megagrays, at dose rates of the order of 1 Gy/s, or in a nuclear reactor at dose rates of the order of 50 Gy/s, up to doses of 100 MGy.

The flexural strength, the deformation and the modulus of elasticity have been measured on irradiated and non-irradiated samples, according to the recommendations of the International Electrotechnical Commission. The results are presented in the form of tables and graphs to show the effect of the absorbed dose on the measured properties.



## RÉSUMÉ

Ce catalogue donne les résultats d'essais sur la résistance aux rayonnements ionisants de résines thermodurcies et thermoplastiques, et de composites. Pour la plupart, il s'agit de résines époxydes utilisées comme isolant de bobines d'électro-aimants. De nombreux résultats sont aussi donnés sur des thermoplastiques d'engineering récents pouvant être utilisés soit pour leurs propriétés électriques, soit pour leurs propriétés mécaniques.

Les matériaux ont été irradiés soit en source de $^{60}Co$, à des doses comprises entre 200 kGy et quelques mégagrays, à un débit de dose de l'ordre de 1 Gy/s, soit en réacteur nucléaire à un débit de dose de 50 Gy/s, jusqu'à des doses de 100 MGy.

La résistance en flexion, la déformation et le module d'élasticité sont mesurés sur des échantillons irradiés et non irradiés, conformément aux recommandations de la Commission Electrotechnique Internationale. Les résultats sont présentés sous forme de tableaux et de graphiques qui montrent l'effet de la dose absorbée sur ces propriétés.

**CONTENTS**

## 1. INTRODUCTION

Investigations into the degradation of materials and components which are exposed to ionizing radiation have been carried out in many applications, such as nuclear reactors, fusion reactors, high-energy accelerators, medical and industrial irradiation facilities, space projects, etc. At the European Organization for Nuclear Research (CERN), radiation damage test studies have been centred on organic and inorganic materials, electronic and optical components and devices, and other materials that are used in the construction and operation of high-energy accelerators and particle detectors.

Apart from electronic and optical devices, the organic materials are the ones most sensitive to radiation. As a consequence of this, a large number of radiation tests have been made on these materials and the results are extensively documented [e.g. 1–23]. Design engineers are, however, often faced with the problem of finding the desired information quickly within the available literature. We therefore decided to publish our radiation damage test results on organic materials in the form of catalogues.

The first catalogue, published more than fifteen years ago, concerned organic materials used as insulation and sheathing for electric cables [24].

The second dealt with thermosetting and thermoplastic resins, the majority being epoxies used for magnet coil insulations [25].

The third contained information on miscellaneous materials and components used around high-energy accelerators [26].

A second edition of the first catalogue was published in 1989 and concerns halogen-free cable-insulating materials [27].

The present volume is the second edition of the second part and concerns result of thermoset and thermoplastic resins and composite materials which were tested in the meantime.

As in the previous editions, the materials are presented in alphabetical order.

## 1. INTRODUCTION

Des essais sur la dégradation des matériaux due aux rayonnements ionisants ont été effectués dans plusieurs domaines d’application, par exemple autour des réacteurs nucléaires et de fusion, des accélérateurs à haute énergie, dans les installations industrielles ou médicales, dans les centres d’études spatiales, etc. A l’Organisation Européenne pour la Recherche Nucléaire (CERN), les essais de radiorésistance ont été concentrés sur des matériaux organiques et inorganiques, des composants électroniques et optiques, et d’autres matériaux qui sont utilisés pour la construction et l’opération des accélérateurs à haute énergie et les détecteurs de particules.

A part les composants électroniques et optiques, les matériaux organiques sont parmi les plus sensibles aux rayonnements ionisants. Par conséquent, une grande quantité de ces matériaux ont été soumis à des essais d’irradiation, et les résultats peuvent être trouvés dans de nombreuses publications [par exemple 1–23]. Toutefois, les ingénieurs rencontrent souvent des difficultés pour trouver, dans la littérature, l’information voulue. C’est pour cette raison que nous avons décidé de publier nos résultats d’essais de radiorésistance des matériaux organiques sous forme de catalogues.

Le premier catalogue, paru il y a plus de quinze ans, concernait les matériaux utilisés comme isolants, ainsi que pour les gaines de câbles électriques [24].

Le deuxième concernait des résines thermodurcies et thermoplastiques dont la plupart sont des époxydes utilisées dans l’isolation de bobines d’aimants [25].

Le troisième concernait divers matériaux et composants utilisés autour des accélérateurs de particules [26].

Une seconde édition du premier catalogue, publiée en 1989 portait sur les matériaux pour isolations et gaines de câbles exempts d’halogène [27].

Le présent volume est une seconde édition du deuxième ; il contient des informations sur des résines thermoplastiques et thermodurcies, ainsi que sur des matériaux composites.

Comme dans chaque édition, les matériaux sont présentés dans l’ordre alphabétique suivant leur nom anglais.

We first present some characteristic properties of the materials, and define our end-point criteria for the selection of radiation-resistant materials. We then list the tests and test methods, and give the irradiation conditions. In Section 5 we explain the presentation of the data. It should be noted that most of the data have been obtained from tests after accelerated irradiations, and that all tests were made at ambient temperature. After long exposures and ageing in other environments, a variation in the data presented may be expected; this is mainly the case for thermoplastic materials [9, 12, 18–23]. Test results at cryogenic temperatures can be found in Refs. [30–35].

## 2. MATERIALS, CHARACTERISTIC PROPERTIES, AND END-POINT CRITERIA

With a few exceptions, which are marked in the catalogue, all the test data given here have been obtained, over the past fifteen years, from commercially-available materials. Some of these materials may no longer be available and this is indicated in the tables when known. The most common materials that are dealt with here are:

– epoxy resins,
– polyester resins,
– polyurethanes,
– rigid and high performance thermoplastics.

The materials were usually supplied by European manufacturers involved in submitting offers and/or supplying components for the construction at CERN of the Large Electron–Positron storage ring (LEP), and for the Large Hadron Collider (LHC) project.

Some characteristic physical, mechanical, and electrical properties of thermoset resins are summarized in Table 1. These values are only a general indication since they depend on numerous parameters such as the composition and quantity of the base resin, the hardener, the accelerator, the filler, and other additives, as well as on the curing conditions, etc.

Most of the materials presented in this catalogue and all of the thermoplastics unless

Nous commençons par exposer quelques propriétés caractéristiques des matériaux présentés dans ce catalogue ; nous définissons les critères de dégradation de ces propriétés, qui servent à sélectionner les matériaux radiorésistants. Nous décrivons ensuite les méthodes d’essais, ainsi que les conditions d’irradiation. Dans la Section 5 nous expliquons la présentation des données. Il faut noter que les résultats ont généralement été obtenus par des irradiations accélérées, et que tous les essais ont été faits à température ambiante. Après une longue période d’irradiation et un vieillissement sous d’autres conditions, on peut s’attendre à un changement dans les résultats que nous avons obtenus, surtout pour les thermoplastiques [9, 12, 18–23]. Des résultats de tests à température cryogénique peuvent être trouvés aux références [30–35].

## 2. LES MATÉRIAUX, LEURS PROPRIÉTÉS CARACTÉRISTIQUES ET LES CRITÈRES DE DÉGRADATION DE CES PROPRIÉTÉS

A part quelques exceptions, qui sont indiquées dans le catalogue, tous les résultats donnés ont été obtenus, au cours des quinze dernières années, sur des matériaux disponibles dans le commerce. Il est possible que quelques-uns ne soient plus sur le marché, et nous l’avons noté dans les tableaux, pour les cas où nous l’avons su. Les plus courants de ces matériaux sont :

– résines époxydes
– résines polyestères
– polyuréthanes
– thermoplastiques rigides et hautes performance.

En général, les matériaux ont été fournis par des fournisseurs européens qui ont été engagés dans des offres ou des fournitures de matériels pour la construction au CERN du Large Electron-Positron Collider (LEP), ou pour le projet LHC (Large Hadron Collider), grand collisionneur de protons, supraconducteur.

Le tableau 1 donne un résumé des quelques propriétés mécaniques, électriques et physiques des résines thermodurcies. Ces valeurs peuvent seulement servir d’indication générale, puisqu’elles dépendent de nombreux paramètres tels que la composition et la quantité de la résine de base, du durcisseur et de l’accélérateur, ainsi que les charges et d’autres additifs.

otherwise stated, are halogen-free and contain little or no sulphur and phosphorus. They have passed the IEC 754–2 test which defines the maximum acidity and the maximum conductivity of combustion gases [28].

It is clear that when selecting and classifying materials according to their radiation resistance, not all of the properties listed in Table 1 could be tested, and we had to restrict ourselves to a few of the most characteristic and representative ones. For our purposes the mechanical properties were chosen. This choice can be justified by our own experience and that of others [10, 22, 29]. In general the mechanical degradation of plastic insulating materials due to ionizing radiation occurs before the degradation of the electrical and physical properties. Also, no important change in flammability was observed with radiation.

It should be noted that the mechanical properties of polymeric materials depend strongly on the temperature; at cryogenic temperature the stiffness and the brittleness are increased, and the plasticity and the impact strength are reduced. Irradiation of these materials either at low temperature or at room temperature does not influence their degradation: the mechanical properties of polymer-based materials are more influenced by the test temperature than by the irradiation temperature. A characteristic case is that of materials sensitive to oxido-degradation: the degradation is lower if they are irradiated in a cryogenic fluid rather than in air [30–35].

## 3. TESTS AND TEST METHODS

Whenever possible, the tests were carried out according to international norms [29]. Sometimes exceptions had to be made for practical or technical reasons, e.g. sample size, dose rate during irradiation, etc. The test samples, usually five per test, were cut from 2–6 mm thick plates molded from the respective materials.

Flexion tests were performed on an Instron testing machine to determine the breaking-strength and deflection at the breaking point.

Soulignons que la plupart des matériaux présentés dans ce catalogue, et en tout cas les thermoplastiques, sauf mention contraire sont exempts d’halogène et ne contiennent que peu ou pas de soufre ou de phosphore. Ils passent le test IEC 754–2 qui définit une acidité et une conductivité maximales des gaz de combustion [28].

Il est évident que, pour la sélection et la classification des matériaux selon leur résistance aux rayonnements, on ne peut pas tester toutes les propriétés citées dans le tableau 1, il faut se limiter à quelques-unes des plus représentatives. Dans le cas présent, nous avons choisi les propriétés mécaniques. Ce choix se justifie par notre propre expérience, et celle d’autres auteurs, qui nous a appris que la dégradation, due à l’irradiation, des propriétés mécaniques des isolants plastiques intervient généralement avant celle de leurs propriétés électriques et physiques [10, 22, 29]. D’autre part, les rayonnements n’ont que peu d’effet sur l’inflammabilité de ces matériaux.

Remarquons que les propriétés mécaniques des matériaux polymériques dépendent fortement de la température d’utilisation ; à température cryogénique la rigidité et la fragilité sont accrues, la plasticité et la résistance au chocs sont diminuées. Le fait d’irradier ces matériaux à basse température ou à température ambiante n’influe pas sur leur dégradation : les propriétés mécaniques des matériaux polymériques sont plus influencées par la température de test que par la température d’irradiation. Un cas particulier est celui des matériaux sensibles à l’oxydo-dégradation : lorsqu’ils sont irradiés dans un fluide cryogénique, leur dégradation est moindre que lorsqu’ils sont irradiés dans l’air [30–35].

## 3. ESSAIS ET MÉTHODES D’ESSAIS

Nous avons exécuté nos essais selon les normes internationales [29] dans tous les cas où cela était possible. Pour des raisons pratiques ou techniques, quelques exceptions étaient inévitables, par exemple dimension d’échantillons, débit de dose pendant l’irradiation, etc.

Les matériaux ont été fournis sous forme de plaques de 2 à 6 mm d’épaisseur, dans lesquelles, en général, cinq échantillons ont été coupés pour chaque essai.

From these measurements, the ultimate flexural strength, the deformation at break and the modulus of elasticity were calculated.

The testing method was a three-point loading system utilizing a centre load on the supported sample according to ASTM norm D790. The distance between the two supports was 67.0 mm and the speed of the central point was 2 mm/min for most of the materials. It was 5 mm/min for some very supple materials which undergo an important deformation. Some of these latter materials did not break during the test (the maximum value of the deformation appears in the tables). In this case, the flexural strength is the maximum recorded value, and not at the breaking point.

According to the recommendations of the International Electrotechnical Commission (IEC) [29], the most radiation-sensitive property is chosen as the reference critical property. For most of the thermoset resins and composites this critical property is the flexural strength, while for most of the thermoplastics it is the deflection [36]. The end-point criterion is 50% of the initial value of the critical property.

The Radiation Index (RI) is defined in IEC 544–4 as the logarithm, base 10, of the absorbed dose in grays (rounded down to two significant digits) at which the critical property is reduced to 50% of its initial value, under specified conditions of irradiation and tests.

## 4. IRRADIATION CONDITIONS AND DOSIMETRY

Most of the samples were irradiated in the ASTRA reactor at Seibersdorf (Austria) to doses between $5 \times 10^6$ Gy and $10^8$ Gy, at dose rates of about $2 \times 10^5$ Gy/h.

In this 7 MW pool reactor, the irradiation position ‘Ebene 1’ is in the pool about 26 cm away from the reactor core. The neutron dose is less than 5% of the total dose to the samples. The irradiation medium is air, and the temperature is kept below 60°C.

More sensitive samples were irradiated with a $^{60}$Co source, at Ionisos in Dagneux (France),

Des essais de flexion ont été effectués sur une machine Instron qui ont permis de déterminer la force ainsi que la déflexion à la rupture. Ensuite nous avons calculé la résistance à la flexion, la déformation et le module d’élasticité.

La méthode d’essai était un système d’appui à trois points : la force est appliquée sur le point central, selon la norme ASTM D790. La distance entre les deux points d’appui était de 67,0 mm, et la vitesse d’avancement du point central était de 2 mm/min pour la plupart des matériaux, elle était de 5 mm/min pour certains matériaux particulièrement souples à forte déformation. Certains de ces derniers n’ont pas subi de rupture lors des tests. La valeur maximale de la déformation apparait dans les tables. Dans ce cas, la résistance à la flexion n’est pas calculée à la rupture, mais est la valeur maximale enregistrée au cours de l’essai.

Conformément aux recommandations de la Commisssion Electrotechnique Internationale (CEI) [29], on choisit comme propriété critique de référence celle qui est la plus sensible aux radiations. Pour les thermodurcies et les composites, il s’agit en général de la résistance à la flexion ; pour les thermoplastiques, il s’agit plutôt de la déflexion [36]. Le critère de fin de vie est 50 % de la valeur initiale de la propriété critique.

La publication CEI 544–4 définit un indice de rayonnement (RI) déterminé par le logarithme, en base 10, de la dose absorbée en grays (arrondi à deux chiffres significatifs) au-dessus de laquelle la valeur de la propriété critique a atteint 50 % de sa valeur initiale, dans les conditions spécifiques d’irradiation et de test.

## 4. CONDITIONS D’IRRADIATION ET DOSIMÉTRIE

La plupart des échantillons ont été irradiés au réacteur ASTRA, à Seibersdorf (Autriche), à des doses de $5 \times 10^5$ Gy à $10^8$ Gy, où le débit de dose est de l’ordre de $2 \times 10^5$ Gy/h.

Dans ce réacteur-piscine de 7 MW, la position “Ebene 1” se trouve à 26 cm du coeur ; la dose en neutrons intégrée par les échantillons est inférieure à 5 % de la dose totale. Le milieu d’irradiation est l’air, et la température maximale est de 60°C.

Les échantillons plus sensibles ont été irradiés par une source de $^{60}$Co, à la société Ionisos à with doses of $2 \times 10^5$ Gy, $5 \times 10^5$ Gy, and $10^6$ Gy, at a dose rate of about 4000 Gy/h. In a cobalt source, the radiation comes from pure gamma rays of 1.17 and 1.25 MeV.

Some samples were irradiated in the CERN accelerators, either close to the magnet coils which are insulated with the material concerned (we call this 'live irradiation'), or around converting targets. Under these conditions, the neutron dose may be of the order of several tens of per cents of the total dose.

More details about irradiation conditions and dosimetry in the ASTRA reactor are given in Ref. [37] and for other sources in Ref. [38]. (Note that 1 Gy = 1 gray = 1 J/kg = 100 rad.)

## 5. PRESENTATION OF THE DATA

The lists of the materials that are presented in this catalogue and in the preceding volumes are given in Appendix 1.

Appendix 2 gives the chemical structures of some commercial products.

Appendix 3 is the alphabetical compilation of data where the materials are sorted according to their chemical name. Under each letter, the following information can be found:

– A generic page with the chemical names of the materials, as well as their usual and commercial names (with as many cross-references as possible). If specific results are not given in this volume, an indication of the radiation resistance is given by the value of the radiation index.
– On the verso of this generic page, the list of the materials classified under the given letter, together with their CERN identification number.
– In the individual pages of results, a header gives the TIS reference number, the description of the material and the name of the supplier (Appendix 5). If available, an indication of the fire behaviour is also given. The results are presented in the form of a table and graph. The mean values (and the standard deviation) of the mechanical properties, flexural strength (S), deformation at break (ε) and flexural modulus (M) appear in the table

Dagneux, France, à des doses de $2 \times 10^5$ Gy, $5 \times 10^5$ Gy et $10^6$ Gy, à un débit de dose de l'ordre de 4000 Gy/h. Dans une source cobalt, l'irradiation est purement electromagnétique, avec des gammas de 1,17 et 1,25 MeV.

Certains échantillons ont été irradiés dans des accélérateurs du CERN, soit près des bobines d'aimants dont les bobines sont isolées avec le matériau concerné (test avec irradiation à long terme). Dans ces conditions, la dose-neutron peut atteindre plusieurs dizaines de pourcents de la dose totale.

Plus de détails sur les conditions d'irradiation et de dosimétrie peuvent être trouvés dans les références [37] pour le réacteur ASTRA et [38] pour les autres sources. (Pour mémoire : 1 Gy = 1 gray = 1 J/kg = 100 rad.)

## 5. PRÉSENTATION DES RÉSULTATS

Les listes des matériaux pour lesquels nous donnons des résultats ainsi que ceux présentés dans les volumes précédants constituent l'appendice 1.

L'appendice 2 donne les structures chimiques de quelques composés commerciaux.

L'appendice 3 est la compilation alphabétique des résultats où les matériaux sont classés suivant leurs noms chimiques en Anglais. Sous chaque lettre on peut trouver les informations suivantes :

– La page générique avec les noms chimiques des matériaux, mais aussi leurs noms usuels ou commerciaux (nous avons fait autant de recoupements que possible). Si des résultats spécifiques ne sont pas présentés dans ce volume, une indication de la radiorésistance est donnée par l'indice de rayonnement.
– Au verso de cette page générique, la liste avec les numéros d'identification CERN des matériaux classés sous cette lettre.
– Viennent ensuite les pages individuelles de résultats, sur lesquelles on trouve en entête le numéro d'identification TIS, la description du matériaux et le nom du fournisseur (Annexe 5), ainsi qu'une éventuelle indication sur son comportement au feu. Les résultats sont présentés sous forme de tableau et de graphique. Dans le tableau apparraissent les doses absorbées avec les débits de dose correspondants, puis les valeurs moyennes (et l'écart type) des propriétés mécaniques, la

together with the absorbed doses and the corresponding dose rates. (The formulae for the calculation of these properties are given in Appendix 4. In some cases, the samples are too flexible to break during the test, the values given are then the maximum flexural strength and the maximum possible deformation in the cage.) Below the table are given the critical property for the calculation of the radiation index (RI) and its value for the corresponding dose rate. The graph presents the evolution of the flexural strength and of the deformation with respect to the absorbed dose.

Appendix 4 gives the main abbreviations used in the tables of results.

Appendix 5 is a list of the suppliers of the materials and/or components who contributed to this catalogue.

## 6. CLASSIFICATION OF MATERIALS

Tables 2a and 2b are a classification of the material in decreasing order of their radiation resistance. We have separated the thermoplastics from the thermosets because their conditions of use are usually different, though high-performance thermoplastics have properties as good as the ones of thermosets today.

This classification gives an order of magnitude of the maximum dose of usability of the materials; it corresponds to long-term irradiations. In particular, thermoplastics (Table 2a) may be very sensitive to oxidation and hence to dose-rate effect; during long-term irradiation in the presence of oxygen, their degradation starts at much lower doses [17–23]. An indication of this appears as a longer ‘mild to moderate’ zone on the bar graph.

All of these materials may be reinforced with fibres, long or short, oriented (1D, 2D, 3D) or not, woven or not, etc. The fibres usually increase the radiation resistance of the materials. The properties of some composites reinforced with glass fibres or carbon fibres may be kept up to doses above 100 MGy. A laminate will undergo degradation following delamination, showing the higher sensitivity of the matrix.

résistance en flexion (S), la déformation à la rupture (ε) et le module de flexion (M) (Les formules de calcul de ces grandeurs sont données en appendice 4. Dans certains cas, les échantillons sont trop flexibles pour subire une rupture, la valeur maximale de la défromation atteinte dans la cage est alors donnée, ainsi que la valeur maximale mesurée pour la résistance.) Sous le tableau sont donnés la propriétés de référence pour le calcul de l’indice de rayonnement (RI) et la valeur de celui-ci au débit de dose correspondant. Le graphique présente l’évolution de la résistance et de la déformation en fonction de la dose absorbée.

L’appendice 4 explique les principales abréviations utilisées dans les tableau de résultats.

L’appendice 5 est une liste des fournisseurs des matériaux de base et/ou de composants qui ont collaboré à ce catalogue.

## 6. CLASSIFICATION DES MATÉRIAUX

Les tableaux 2a et 2b sont un classement des matériaux par ordre décroissant de leur résistance aux radiations. Nous avons séparé les thermoplastiques des thermosets, car ils ont en général des conditions d’utilisation différentes, bien que les thermoplastiques à hautes performances aient aujourd’hui des propriétés comparables à celles des thermosets.

Ce classement donne un ordre de grandeur de la dose limite d’utilisation d’un matériau, il correspond à des irradiations accélérées. En particulier, les thermoplastiques (Tableau 2a) peuvent être très sensible à l’oxydation et donc à l’effet du débit de dose ; en irradiation à long terme en présence d’oxygène, leur dégradation intervient pour des doses nettement plus faibles [17–23]. Une indication de ceci apparait comme une zone de “dégradation modérée” plus longue sur le graphique.

Tous ces matériaux peuvent être renforcés par des fibres, courtes ou longues, orientées (1D, 2D ou 3D) ou non, tissées ou non, etc. Les fibres ont en général un effet bénéfique sur la résistance aux radiation d’un matériaux. Les propriétés de certains composites renforcés aux fibres de verre ou de carbone peuvent être conservées à des doses de plus de 100 MGy. Un composite laminé subira une dégradation par délamination, mettant ainsi en évidence la plus grande sensibilité de la matrice.

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Our particular thanks are due to K. Goebel, K. Potter and B. de Raad at CERN who throughout the years have supported radiation-damage studies.

Most of the materials tested were used or proposed for the SPS and LEP, as well as for the LHC project at CERN. We thank the European manufacturers who supplied the test samples, both for their interest in the subject and for the useful discussions that we had with many of them.

The irradiations were carried out in the ASTRA reactor of the Forschungszentrum Seibersdorf in Austria, where the collaboration of A. Burtscher and J. Casta was greatly appreciated. We would also like to thank Mrs M-A. Mirvault and Mrs M.-O. Bachelier from Ionisos in Dagneux, France.

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La plus grande partie des matériaux testés ont été utilisés ou proposés pour le SPS et pour le LEP, ainsi que pour le projet LHC du CERN. Nous remercions les fabricants européens qui ont fourni des échantillons d'essais ; nous avons eu des discussions utiles avec les représentants de nombreuses firmes.

Les irradiations ont été effectuées au réacteur ASTRA du Forschungszentrum Seibersdorf en Autriche, où nous avons apprécié la collaboration que nous ont offerte J. Casta et F. Böheim, et à Ionisos, à Dagneux, France où nous remercions Mmes M.A. Mirvault et M.-O. Bachelier.

Nous voudrions enfin exprimer notre appréciation de l'aide et l'attention du Service de publication assistée par ordinateur du CERN.

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**Table 1**
Characteristic properties of thermoset and thermoplastic materials

| Properties | Polymers | EPOXY RESINS | | | | | | PEEK | |
|---|---|---|---|---|---|---|---|---|---|
| | | BISPHENOL A | | | EPOXY NOVOLAC | | | | |
| | | No filler | Glass | Mineral | No filler | Glass | Mineral | Unfilled | 30% G.F. |
| Specific gravity ($g/cm^3$) | ISO 1183 | 1.15 | 2.0–2.1 | 1.8–2.0 | 1.2 | 1.97 | 1.7 | 1.32 | 1.48 |
| Water absorption (%) | ISO 62 | 0.1–0.2 | 0.02–0.8 | 0.30–0.80 | – | 0.04–0.06 | 0.11–0.20 | 0.06–0.2 | 0.14 |
| Thermal conductivity (k cal/m.h. °C) | ASTM D325 | 0.15–0.45 | 1 | – | – | – | – | – | – |
| Thermal coefficient of expansion ($10^{-5}$/°C) | ASTM D 696 | 6 | 0.6 | – | 3 | – | – | 5 | 2.5 |
| Tensile strength (MPa) | ISO R37 | 70–80 | 350–400 | 70 | 70 | 350–400 | 38 | 95 | 170 |
| Elongation (%) | ISO R37 | 4.4 | – | – | 2–5 | – | – | >25 | 2 |
| Tensile modulus (GPa) | ISO R37 | 3.5 | 30 | 10–15 | 3.5 | 21–22 | – | 3.6 | 9.7 |
| Flexural strength (MPa) | ISO 178 | 80–130 | 360 | 150–170 | 60–100 | 390 | 70–80 | 180 | – |
| Impact strength (notched) (kg cm/cm) | ASTM D 256 | 1.1–2.7 | 6.4–8.2 | 2.2–2.7 | 2.7 | 7.0–9.2 | 2.2–2.7 | – | – |
| Volume resistivity ($\Omega$ cm) | IEC 93 | $6.1 \times 10^{15}$ | – | $1.5 \times 10^{15}$ | $2.1–10^{14}$ | – | $1.4–5.5 \times 10^{14}$ | $10^{16}$ | – |
| Dielectric strength (kV/mm) | IEC 243 | > 16 | 18–22 | 15–16 | – | – | 12–16 | 30 | – |
| Power factor (tg) at $10^6$ Hz | IEC 250 | 0.032 | 0.024 | 0.013 | 0.029 | 0.015 | – | 0.003 | – |
| Dielectric constant at $10^6$ Hz | IEC 250 | 3.4 | 4.7–4.8 | 4.1–4.6 | 3.5 | 5.1 | 4.3–4.8 | 3.3 | – |
| Heat distortion temperature (°C) | ISO 75 | 110 | – | – | 150–200 | – | – | 340 | 340 |

**Table 1** (cont.)

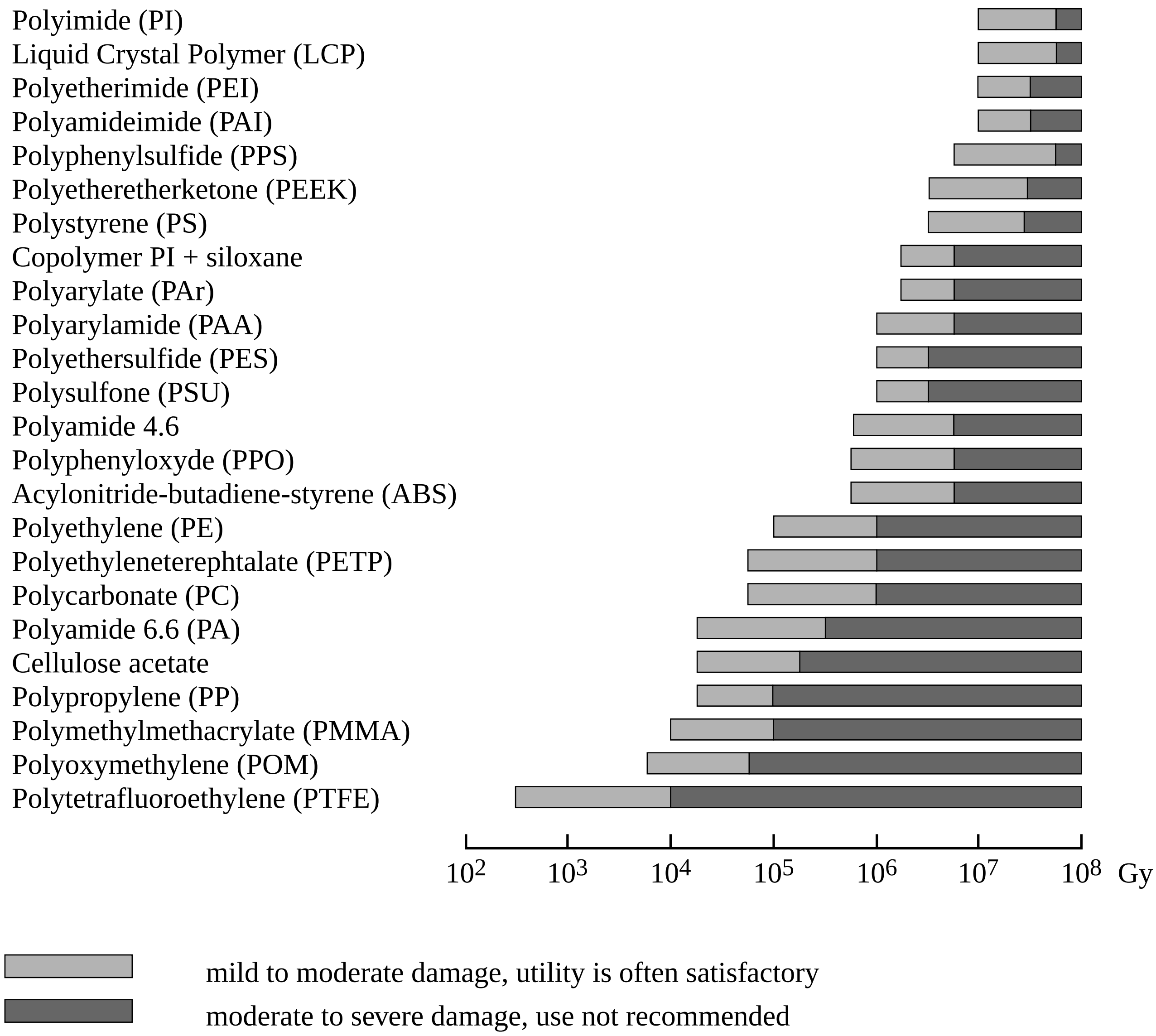
| Polymers | | PHENOLICS | | | | | | POLYMIDES | |
|---|---|---|---|---|---|---|---|---|---|
| Properties | | No filler | Wood flour | Asbestos | Fibre and fabric | Mineral | Nylon | Unfilled | Glass |
| Specific gravity ($g/cm^3$) | ISO 1183 | 1.30–1.32 | 1.29–1.51 | 1.78–2.00 | 1.3–1.4 | 1.5–1.9 | 1.2–1.5 | 1.47 | 1.90 |
| Water absorption (%) | ISO 62 | 0.30–0.40 | 0.70–1.20 | 0.03–0.30 | 0.50–1.6 | 0.04–0.25 | 0.25–0.4 | 0.68 | 0.20 |
| Thermal conductivity (k cal/m.h. °C) | ASTM D325 | – | 0.15–0.45 | 0.15–0.25 | 0.3 | 0.3 | – | 0.60 | – |
| Thermal coefficient of expansion ($10^{-5}$/°C) | ASTM D 696 | 4.3 | 3.6 | – | 3 | 1.8 | – | 5.4 | 1.5 |
| Tensile strength (MPa) | ISO R37 | 14–63 | 38–63 | 21–49 | 31–63 | 14–59 | 31–63 | 74 | 210 |
| Elongation (%) | ISO R37 | ~ 5 | ~ 5 | ~ 5 | ~ 5 | 4–9 | – | < 1.5 | < 1 |
| Tensile modulus (GPa) | ISO R37 | 1.4–3.1 | 4.9–14.0 | 11–20.0 | 5.6–10.0 | 9.5–21.0 | 2.8–14.0 | 3.2 | 28–30 |
| Flexural strength (MPa) | ISO 178 | 84–100 | 60 | 45–77 | 49–110 | 56–84 | 42–91 | 100 | 350 |
| Impact strength (notched) (kg cm/cm) | ASTM D 256 | 2.7–4.3 | 1–2.8 | 0.8–16 | 2–36 | 0.97–3.9 | 1.4–2.8 | 5 | 17 |
| Volume resistivity ($\Omega$ cm) | IEC 93 | $2.5 \times 10^{10}$–$10^{12}$ | $10^{9}$–$10^{13}$ | $10^{8}$–$10^{13}$ | $10^{8}$–$10^{12}$ | $10^{10}$–$10^{14}$ | $10^{11}$–$10^{14}$ | $10^{16}$–$10^{17}$ | $9.2 \times 10^{15}$ |
| Dielectric strength (kV/mm) | IEC 243 | 10–16 | 0.6–10 | 0.4–10 | 0.4–7 | 3–16 | 1–11 | 22 | – |
| Power factor (tg) at $10^6$ Hz | IEC 250 | 0.04–0.05 | 0.015–0.06 | 0.03–0.25 | 0.03–0.08 | 0.007–0.08 | 0.15–0.2 | 0.005 | 0.0055 |
| Dielectric constant at $10^6$ Hz | IEC 250 | 4–9.7 ($10^3$ c/s) | 3.9–6.5 | 5–6 | 4.8–7 | 4–6 | 3.7–4.5 | 3.4 | 4.7 |
| Heat distortion temperature (°C) | ISO 75 | 150–180 | 130–180 | – | 250 | 180–200 | – | 300 | 350 |

**Table 1** (cont.)

| Properties | Polymers | POLYESTERS | | | | POLYURETHANES | SILICONES | |
|---|---|---|---|---|---|---|---|---|
| | | α Cellulose | Mineral | Glass | No filler | | Glass | Mineral |
| Specific gravity ($g/cm^3$) | ISO 1183 | 1.35–1.40 | 1.70–2.20 | 1.20–2.00 | 1.20–1.40 | 1.21 | 1.88 | 1.88–2.8 |
| Water absorption (%) | ISO 62 | 0.01–1 | – | 0.1–2 | 0.03–0.4 | 0.30–0.90 | 0.10–0.30 | 0.05–0.22 |
| Thermal conductivity (k cal/m.h. °C) | ASTM D325 | – | – | 1.8–2.2 | 0.15 | – | 0.27 | 0.50 |
| Thermal coefficient of expansion ($10^{-5}$/°C) | ASTM D 696 | – | – | 2 | 7 | – | 6 | 5 |
| Tensile strength (MPa) | ISO R37 | 42–50 | 21–46 | 42–90 | 35–81 | 45–60 | 28–56 | 17–31 |
| Elongation (%) | ISO R37 | – | – | 0.3–0.5 | 1.7–2.6 | > | < 3 | < 3 |
| Tensile modulus (GPa) | ISO R37 | – | 9.8–19.0 | 4.2–12.0 | 2.8–4.6 | 3.3–8.4 | 14.7–17.5 | 8.7–15.9 |
| Flexural strength (MPa) | ISO 178 | 70–84 | 17–63 | 84–150 | 45–91 | – | 91<br>133 | 49<br>70 |
| Impact strength (notched) (kg cm/cm) | ASTM D 256 | 1.6–2.5 | 1–4 | 40–54 | 1.6–10 | > 5.4 | 50 | 2 |
| Volume resistivity (Ω cm) | IEC 93 | $> 10^{14}$ | $> 10^{14}$ | $10^{12}$–$10^{15}$ | $2.7 \times 10^{14}$<br>$2 \times 10^{15}$ | $6 \times 10^{12}$–$10^{14}$ | $3 \times 10^{14}$ | $10^{14}$ |
| Dielectric strength (kV/mm) | IEC 243 | 10–14 | 10–17 | 6–14 | 10–17 | 20 | 10–11 | 11–16 |
| Power factor (tg) at $10^6$ Hz | IEC 250 | 0.03–0.05 | 0.013–0.04 | 1.1–0.04 | 0.01–0.03 | 0.03–0.05 | 0.003–0.02 | 0.002–0.01 |
| Dielectric constant at $10^6$ Hz | IEC 250 | 3.5–5.5 | 4.5–6.0 | 4.5–6.0 | 3.0–4.01 | 3.3–3.9 | 4.35 | 3.4–4.5 |
| Heat distortion temperature (°C) | ISO 75 | – | – | 200 | 50–200 | – | > 450 | 270–450 |

**Table 2a**

General classification of rigid thermoplastics with respect to their radiation resistance

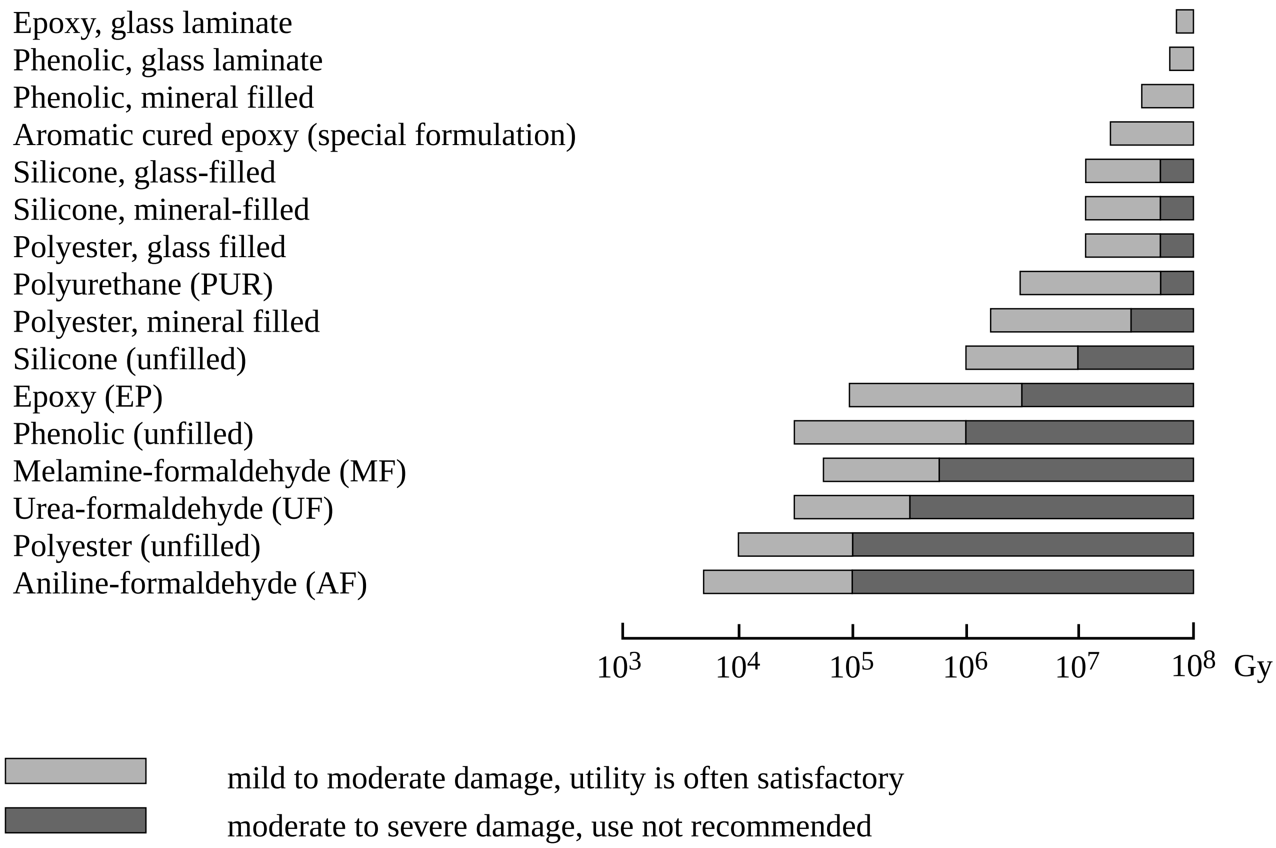



These appreciations can only serve as a general guideline; environmental conditions such as temperature, humidity and dose rate, as well as additives influence the radiation behaviour of materials.

Fibre reinforced composites based on these resins can be at least one order of magnitude better.

**Table 2b**

General classification of thermoset resins and composites with respect to their radiation resistence




These appreciations can only serve as a general guideline; environmental conditions such as temperature, humidity and dose rate, as well as additives influence the radiation behaviour of materials.

Fibre reinforced composites based on these resins can be at least one order of magnitude better (see Appendix 3).

## APPENDIX 1

**List of materials presented in the previous volumes**
(Trade names in italics)

### Volume I: Cable insulating materials (Ref. [24])

Butyl rubber
*Chlorostop*
Chlorosulfonated polyethylene (CSP)
Cross-linked polyethylene (XLPE)
*Desmopan*
Ethyl-acrylate rubber (EAR)
Ethylene-propylene diene rubber (EPDM)
Ethylene-propylene rubber (EPR)
Ethylene vinyl acetate (EVA)
*Flamtrol*
Fluoropolymer
*Halar*
*Hypalon*
*Hytrel*
*Kapton*
*Lupolen*
*Neoprene*
*Nordel*
Polychloroprene
Polyethylene (PE)
Polyurethane (PUR)
Polyvinyl chloride (PVC)
*Pyrofil*
*Radox*
Semiconducting polyethylene
Silicone rubber
*Silythene*
*Stilan*
*Teflon*
*Tefzel*
*Viton*
XLPE

### Volume I, 2nd edition: Halogen-free cable-insulating materials (Ref. [27])

*Acorad*
*Afumex*
*Cogegum*
*Elastollan*
Ethyl acrylate rubber (EAR)
Ethylene ethyl acrylate (EEA)
Ethylene-propylene diene monomer rubber (EPDM)
Ethylene-propylene rubber (EPR)
Ethylene-vinyl acetate copolymer (EVA)
*Lupolen*
*Megolon*
Polyethylene (PE)
Polyolefin (PO)
Polyurethane (PUR)
*Radox*
*Rheyhalon*
Semiconducting PE
*Silanpex*
Silicone rubber (SiR)
*Silythene*
*Sioplas*
Thermoplastic rubber (TPR)
*Toxfree*
*VAC*
*Vamac*
XLPE

**Volume II: Thermoplastic and thermosetting resins (Ref. [25])**

*Araldite* B
*Araldite* D
*Araldite* F and other *Araldite* resins
*Araldite* F + epoxy *Novolac*
*Birakrit*
*Cevolit*
*Crystic*
*Dobeckan* IF
*Dobeckot*
*Epikote*
Epoxy resins
Epoxy resins + epoxy *Novolac*
*Etronax*
*Isoval*
*Kerimid*
*Kinel*
*Makrolon*
*Novolac*
*Orlitherm*
Phenolic resins
Polycarbonate resins
Polymide resins
*Polylite*
Polyurethane resins
*Resofil*
*Ryton*
*Samicanit*
*Samicatherm*
Silicone resins
*Veridur*
*Vetresit*
*Vetronite*

**Volume III: Accelerator engineering materials and components (Ref. [26])**

Adhesive tape
Aluminium oxide
*Araldite*
Asbestos cement
Askarel
*Buna*
Cable insulation
Cable tie
Ceramic
Cerium-doped glass
Connector
Copper wire
*Diala C*
Diester oil
Electronic components
Epoxy resin
Ethylene-propylene rubber (EPR) and (EPDM)
Ethylene-tetrafluoroethylene copolymer (ETFE)
Fluorinated oil
Fluorinated polymer
Foam
Glass
Glass fibre
Heating element
HF absorber
Hoses
*Hostalen*
*Hypermalloy*
*Hytrel*
Insulated wire
Insulating oil
Insulating sleeve
Insultaing tape
Iron
Joint
*Kapton*
*Kevlar*
*Kynar*
Lighting
Lithium polysilicate
Lubricating oil
Luminous paint
*Lupolen*
Magnet coil insulation
Magnetic material
*Makrolon*
*Micatherm*
Microswitch
Mineral oil
Motor, electric
*Mylar*
*Neoprene*
Nitrile-butadiene rubber
*Nomex*

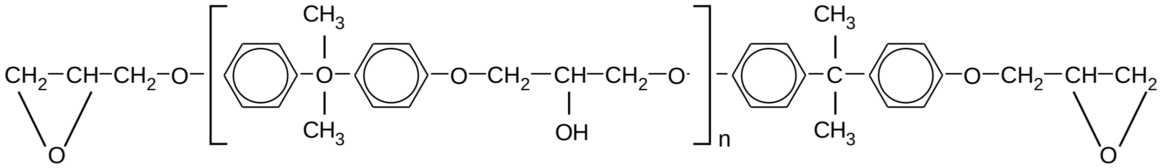
*Noryl*
*Novolac*
*Nylon*
Oil
Optical fibre
O-ring
Pain
Paper
Particle detector
*Pertinax*
*Plexiglas*
Polyacrylate
Polyamide
Polybutylene terephthalate (PBTP)
Polycarbonate
Polychloroprene (*Neoprene*)
Polyester resin
Polyethylene (PE) and (XLPE)
Polyethylene terephthalate (PETP)
Polyhydantoin
Polyimide
Polyolefin
Polyphenylene oxide (PPO)
Polyphenylene sulfide (PPS)
Polypropylene (PP)
Polysiloxane
Polytetrafluoroethylene (*Teflon* PTFE)
Polyurethane resin (PUR)
Polyvinyl chloride (PVC)
Polyvinyl toluene
Quartz
Relay
Resin
*Resistofol*
Rubber
*Ryton*
Scintillator
*Scotchcal*
Seal (O-ring)
Silica
Silicon detector
Silicone oil
Silicone rubber
Sleeve
Styrene-butadiene rubber (SBR)
Switch
Tape
*Teflon* (PTFE)
*Tefzel*
Terminal board
Textile
Thermoplastic resin
Thermosetting resin
Thermoshrinking sheath
Vacuum chamber tube
Vacuum gasket
Vacuum pump accessory
Vacuum seal
Vacuum valve
*Valvata*
Valve
*Vestolene*
*Viton*
Wire
Wood

## APPENDIX 2

### Chemical structures of some commercial products

$BF_3$MEA Boron trifluoride monoethylamine: $BF_3–NH_2–CH_2–CH_3$

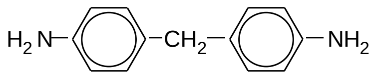
CT 200 (CIBA–GEIGY), Araldite B, solid, unmodified epoxy resin based on Bisphenol A:



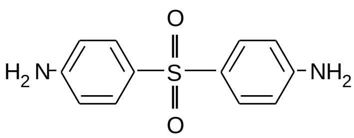
CY 205 (CIBA – GEIGY) Liquid, unmodified epoxy resin based on Bisphenol A
CY 208 (CIBA – GEIGY) Liquid, modified epoxy resin based on Bisphenol A
CY 221 (CIBA – GEIGY) Liquid, modified epoxy resin based on Bisphenol A
CY 222 (CIBA – GEIGY) Liquid, modified epoxy resin based on Bisphenol A

} Chemical formula see CT 200 ($n \hat{=} 0.15$)

DDM (CIBA–GEIGY) Hardener – 4,4' – Diaminodiphenylmethane (methylenedianiline MDA):

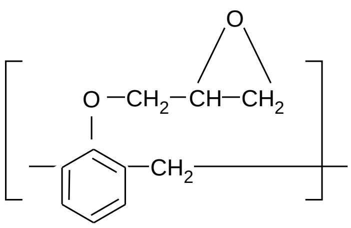


DDS Hardener – Diaminodiphenyl sulphone:

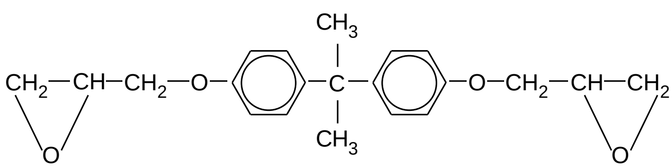


DEN (DOW) Dow Epoxy Novolac

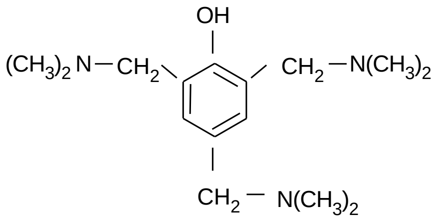
431
438 } Polyglycidyl ether of phenol formaldehyde novolac



DGEBA Diglycidyl ether of Bisphenol A:



DMP 30 Accelerator – 2, 4, 6–tris[N,N–(dimethylamino)methyl]phenol



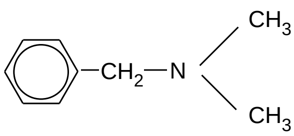
DX 126 (SHELL)
DX 127 (SHELL) } Curing agent – anhydride

DX 125 (SHELL)

DY 040 (CIBA–GEIGY) flexibilizer – polypropyleneglycol

061 accelerator – aminophenol

062 accelerator – benzyldimethylamine



063 accelerator

064 accelerator – aminophenol

065 accelerator unmodified sodium alkoxide

067 accelerator modified " "

EP (SHELL) EPIKOTE

154 } Polyglycidyl ether of phenol formaldehyde novolac
827 } (Chemical formulae see DEN)

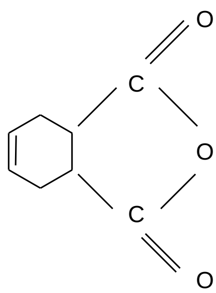
828 Diglycidyl ether of Bisphenol A (see DGEBA)

EPN (CIBA–GEIGY) Epoxy Phenol Novolac

1138 } Polyglycidyl ether of phenol formaldehyde novolac
1139 } (Chemical formulae see DEN)

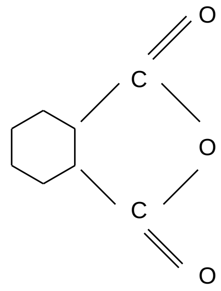
HT 903 (CIBA–GEIGY) Acid anhydride hardener, solid, modified

Tetrahydrophthalic anhydride



HT 907 (CIBA–GEIGY) Acid anhydride hardener, solid, unmodified

Hexahydrophthalic anhydride

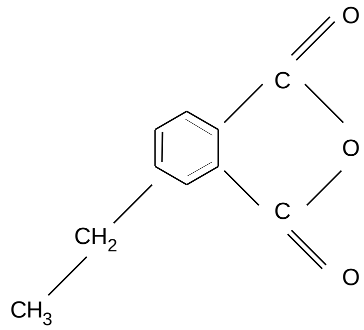


HT 972 (CIBA–GEIGY) Amine hardener, solid, unmodified (see DDM)

HY 905 (CIBA–GEIGY) Acid anhydride hardener, liquid, modified
Hexahydrophhalic anhydride (see HT 907)

HY 906 (CIBA–GEIGY) Acid anhydride hardener, liquid, unmodified

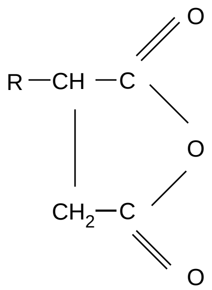
Methyl nadic anhydride (MNA)



HY 956 (CIBA–GEIGY) Amine hardener, liquid, modified
Triethylenetetramine $H_2N\ [CH_2 - CH_2 - NH]\ CH_2 - CH_2 - NH_2$

HY 964 (CIBA–GEIGY) Acid anhydride hardener

Dodecenyl succinic anhydride



R = $C_{12}H_{23}$

MDA Hardener
Methylenedianiline (see DDM)

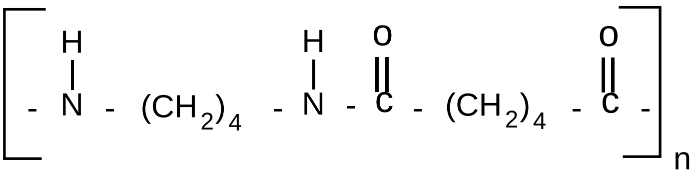
MNA Hardener
Methyl nadic anhydride (formula see HY 906)

MY 720 (CIBA–GEIGY) Liquid, unmodified, epoxy resin
Tetrafuncional glycidyl compound of diamines (TGDM)

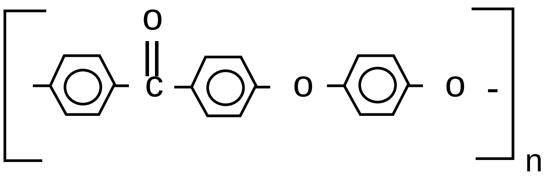
MY 740 (CIBA–GEIGY) Liquid, modified epoxy resin based on Bisphenol A
(see CY 205)

MY 745 (CIBA–GEIGY) Liquid, modified epoxy resin based on Bisphenol A
(see CY 208, 221 and 222)

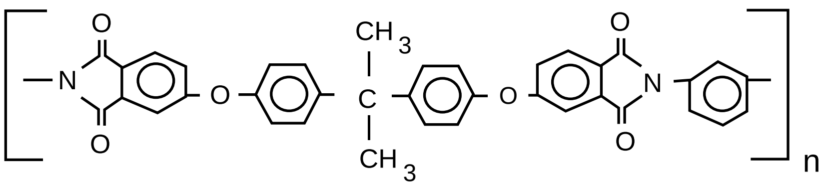
PA 4.6



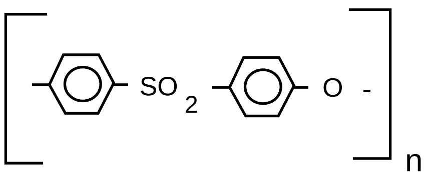
PEEK



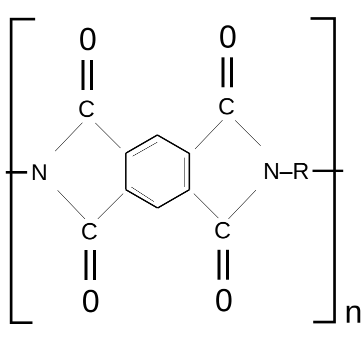
PEI



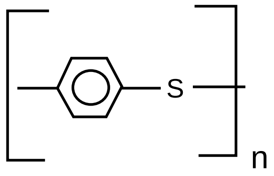
PES



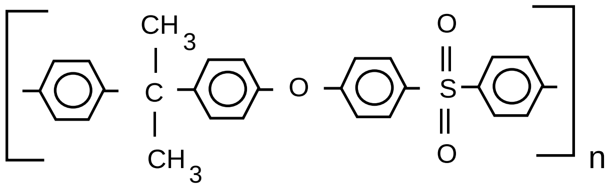
PI



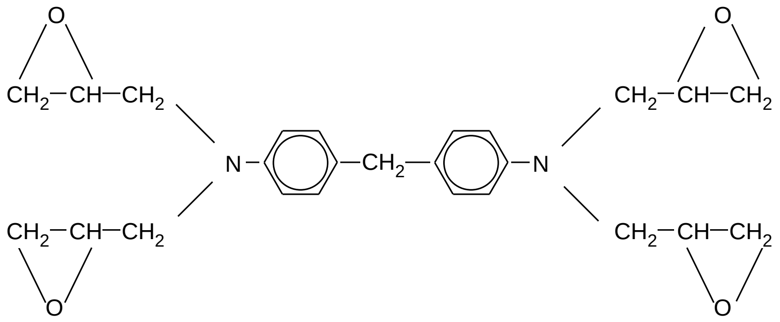
PPS



PSU



TGDM N,N´-tetraepoxypropyl-4,4´-methylene-dianiline



XB 2687 (CIBA–GEIGY) Accelerator, liquid modified, replacement for DY 063
Amine-phenol salt

# APPENDIX 3

## Alphabetic compilation of data

# A

| | |
|---|---|
| Acetal resin | see polyoximethylene (POM) |
| Adiprene | trade name for polyurethane, polyester |
| Araldite | trade name of CIBA-GEIGY for epoxy resins, for behaviour under cryogenic irradiation, see Ref. [35] |
| | Araldite B = unmodified epoxy resin based on Bisphenol A; base resin = CT200<br>Araldite D<br>Araldite F; base resin = CY205<br>Araldite MY720 = liquid unmodified epoxy resin based on TGDM |
| Arenka | trade name of ENKA for Epikote reinforced with aramid fibers, see epoxy composite |
| Arocy | trade name of CIBA-GEIGY for cyanate ester based resins, see cyanate ester |

## List of materials classified under letter A

| TIS number | Material name | Base material | Mechanical properties | | | |
|---|---|---|---|---|---|---|
| | | | UTS (MPa) | Deform. (%) | Modulus (MPa) | RI |
| 439 | Araldite NU 460 | epoxy moulding compound | 138 | 1.04 | 13.7 | < 6.7 |
| 441 | Araldite NU 461 | epoxy moulding compound | 117 | 0.90 | 18.5 | > 8 |
| 443 | Araldite NU 471 | epoxy moulding compound | 96.5 | 0.96 | 12.8 | 7.8 |
| 447 | Araldite NU 481 | epoxy moulding compound | 87.3 | 0.98 | 11.8 | 7.7 |
| 449 | Araldite NU 505 | epoxy moulding compound | 115 | 0.90 | 17.6 | > 8 |
| 453 | Araldite NU 511 | epoxy moulding compound | 158 | 1.08 | 17.4 | > 8 |
| 483 | Araldite F | CY 205 | 89.8 | 2.61 | 3.6 | 7 |
| 486 | Araldite F | epoxy HY905-DY040-DY061 | 82.4 | 2.60 | 3.30 | 7.1 |
| 492 | Araldite NU 514 | epoxy moulding compound | 115 | 1.17 | 12.7 | 7.9 |
| 493 | Araldite NU 487 | epoxy moulding compound | 150 | 1.19 | 15.7 | 7.8 |
| 566 | Araldite | Av/HV 158GB | 60.8 | 0.53 | 15.2 | 6.6 |

| | | |
|---|---|---|
| Type Material: | **Araldite NU 460** **Epoxy moulding compound** | TIS No. **R 439** |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | standard curing | LOI: |

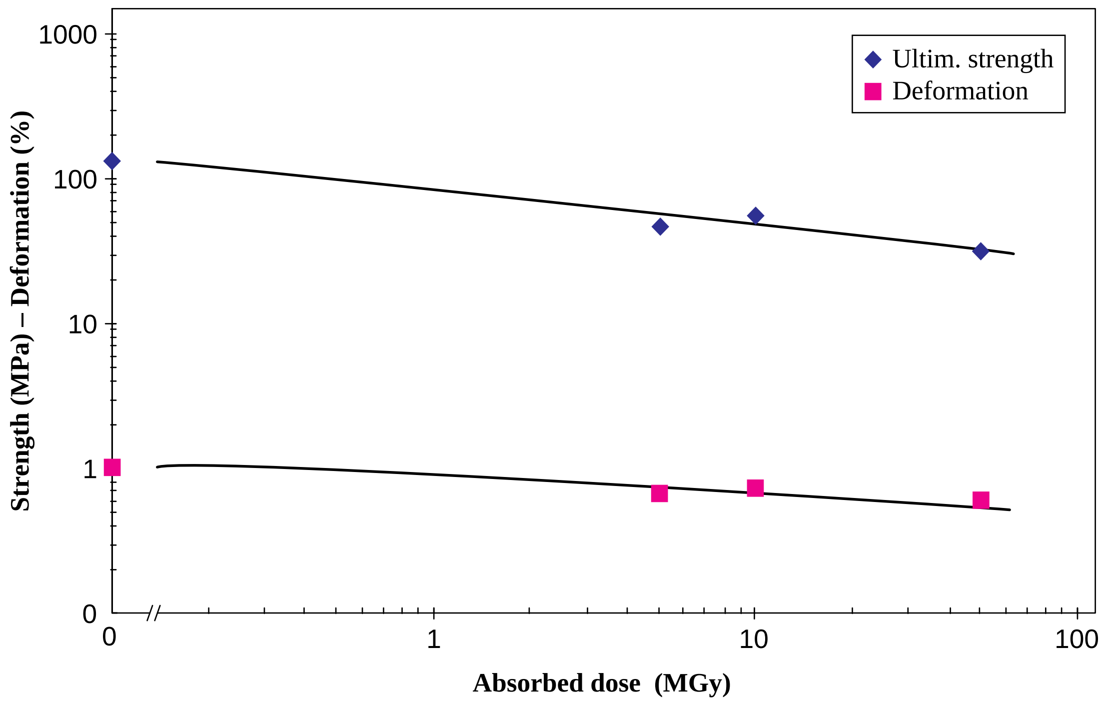
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **138**±9 | **1.04**±0.06 | **13.7**±6.8 |
| **220** | **5** | **49**±6 | **0.67**±0.03 | **9.9**±1.5 |
| **220** | **10** | **58**±3 | **0.73**±0.04 | **10.6**±0.6 |
| **220** | **50** | **32**±7 | **0.61**±0.06 | **6.3**±1.9 |

Critical property = flexural strength

Radiation index (RI) = < 6.7 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 439**



| | | |
|---|---|---|
| Type Material: | **Araldite NU 461** **Epoxy moulding compound** | TIS No. **R 441** |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | VPI product | LOI: |

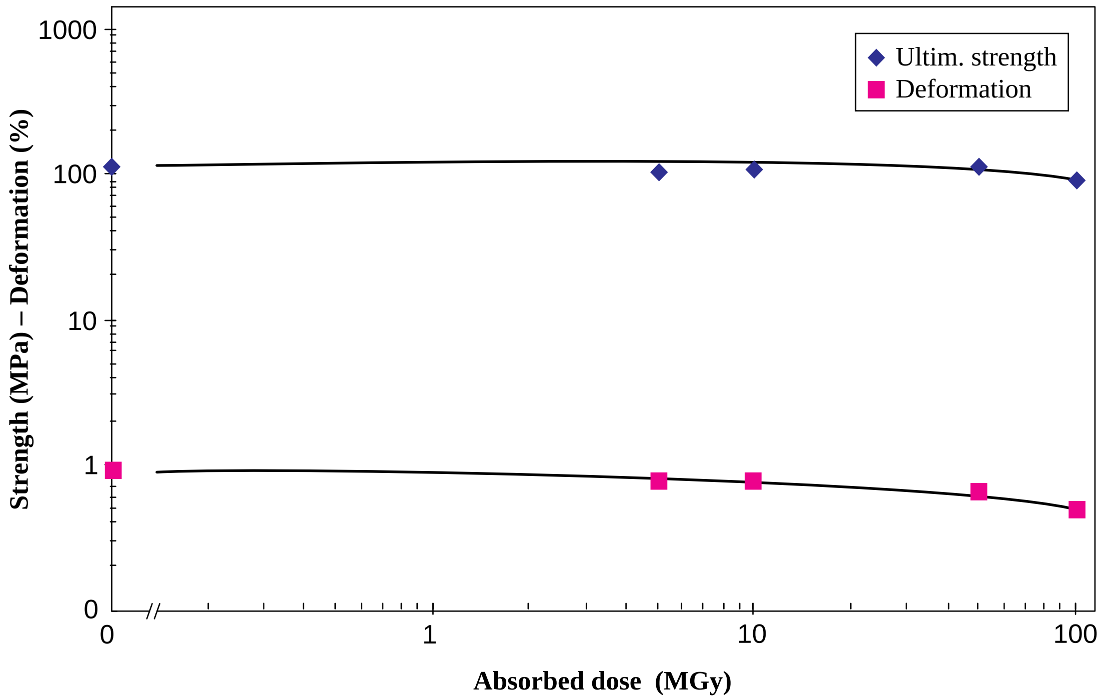
### Radiation test results according to IEC Standard 544 (and ISO 178

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **117**±5 | **0.90**±0.06 | **18.5**±0.7 |
| **220** | **5** | **105**±5 | **0.76**±0.04 | **18.3**±0.7 |
| **220** | **10** | **112**±8 | **0.77**±0.08 | **18.4**±0.4 |
| **220** | **50** | **115**±4 | **0.64**±0.03 | **21.4**±0.4 |
| **220** | **100** | **92**±10 | **0.50**±0.05 | **20.1**±1.1 |

Critical property = deformation

Radiation index (RI) = > 8 at a mean dose rate of 220 kGy/h

### Radiation effect on insulating resin R 441



| | | |
|---|---|---|
| Type Material: | **Araldite NU 471** **Epoxy moulding compound** | TIS No. **R 443** |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | VPI product, not cured | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **97**±3 | **0.96**±0.03 | **12.8**±0.3 |
| **0.1** | **0.5** | **88**±3 | **0.80**±0.04 | **13.7**±0.2 |
| **0.1** | **2.5** | **78**±1 | **0.63**±0.01 | **15.2**±0.7 |
| **220** | **5** | **74**±2 | **0.62**±0.02 | **12.9**±1.3 |
| **10** | **6.4** | **87**±2 | **0.72**±0.01 | **14.4**±0.1 |
| **220** | **10** | **74**±7 | **0.57**±0.08 | **15.1**±0.4 |
| **220** | **50** | **75**±3 | **0.51**±0.03 | **16.6**±0.3 |
| **220** | **100** | **51**±2 | **0.36**±0.02 | **17.8**±1.7 |

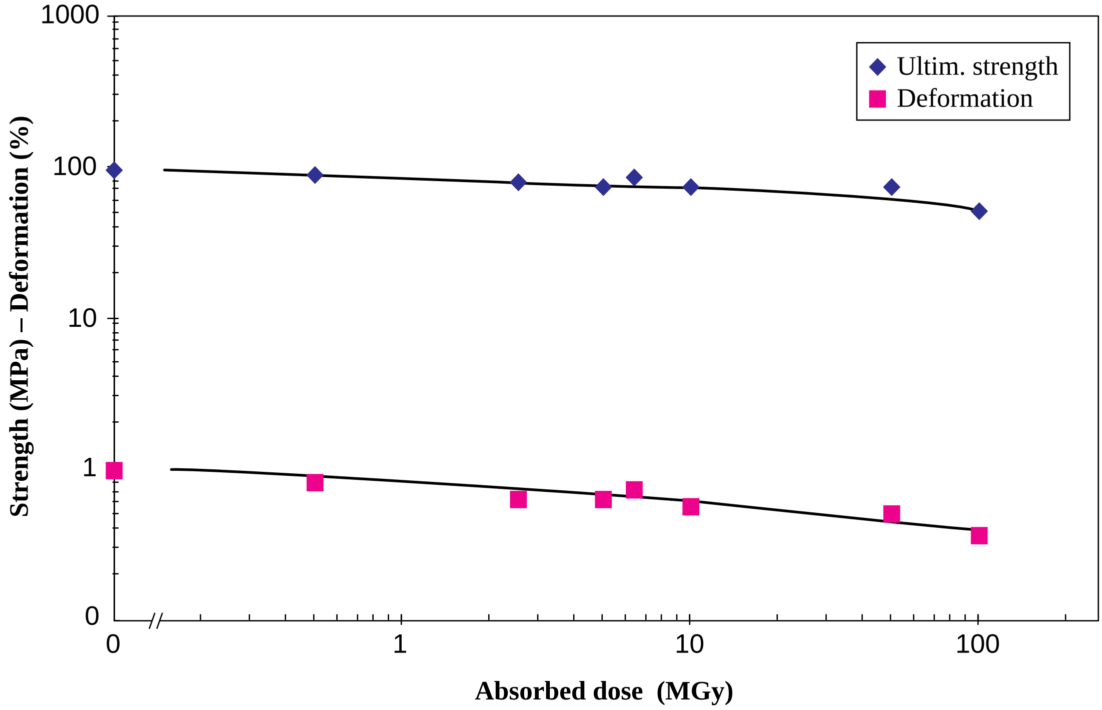
Critical property = deformation

Radiation index (RI) = 7.8 at a mean dose rate of 220 kGy/h

Radiation index (RI) = > 6.8 at a mean dose rate of 10 kGy/h

Radiation index (RI) = > 6.4 at a mean dose rate of 100 Gy/h

**Radiation effect on Epoxy  R 443**



| | | |
|---|---|---|
| Type | **Araldite NU 481** | TIS No. **R 447** |
| Material: | **Epoxy moulding compound** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | VPI product | LOI: |

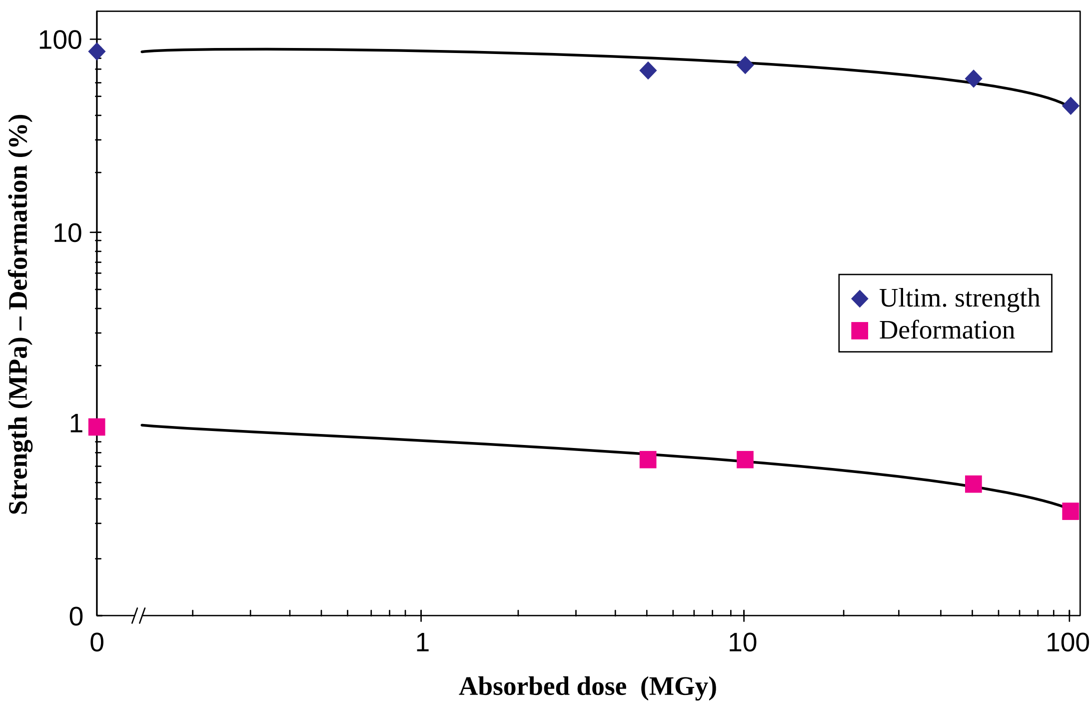
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **87**±2 | **0.98**±0.02 | **11.8**±0.2 |
| **220** | **5** | **70**±1 | **0.67**±0.02 | **12.7**±0.2 |
| **220** | **10** | **75**±2 | **0.67**±0.02 | **13.5**±0.4 |
| **220** | **50** | **63**±3 | **0.49**±0.03 | **15.6**±0.2 |
| **220** | **100** | **46**±1 | **0.36**±0.01 | **15.4**±0.7 |

Critical property = deformation

Radiation index (RI) = 7.7 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 447**



| | | |
|---|---|---|
| Type Material: | **Araldite NU 505** **Epoxy moulding compound** | TIS No. **R 449** |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | VPI product | LOI: |

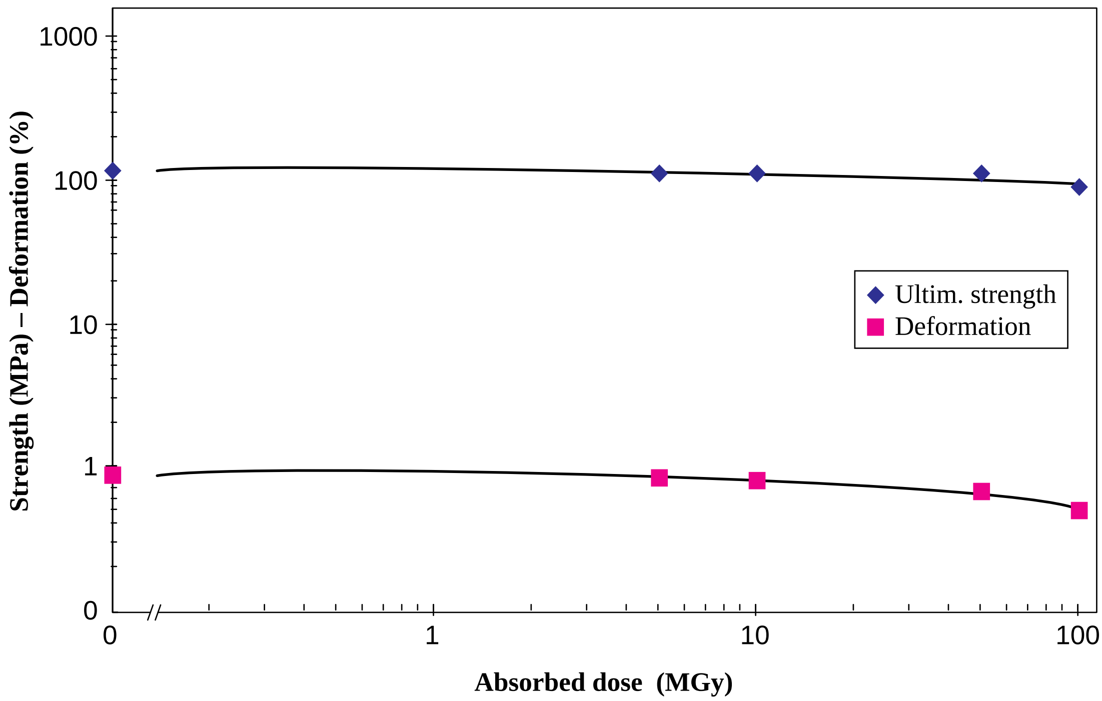
### Radiation test results according to IEC Standard 544 (and ISO 178)

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **115**±12 | **0.9**±0.1 | **17.6**±0.5 |
| **220** | **5** | **113**±4 | **0.84**±0.02 | **17.7**±0.7 |
| **220** | **10** | **111**±7 | **0.81**±0.04 | **17.3**±0.5 |
| **220** | **50** | **111**±3 | **0.67**±0.01 | **20.0**±0.6 |
| **220** | **100** | **91**±4 | **0.51**±0.04 | **18.7**±1.0 |

Critical property = deformation

Radiation index (RI) = > 8 at a mean dose rate of 220 kGy/h

### Radiation effect on insulating resin R 449



| | | |
|---|---|---|
| Type Material: | **Araldite NU 511** **Epoxy moulding compound** | TIS No. **R 453** |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | VPI product | LOI: |

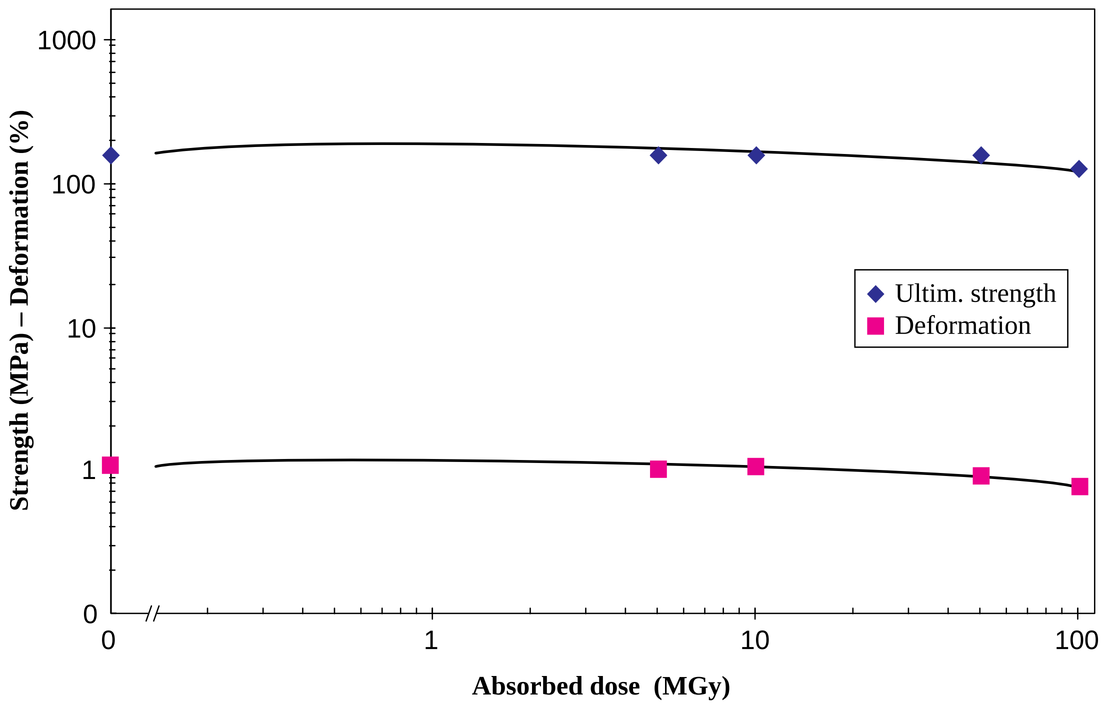
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **158**±20 | **1.08**±0.13 | **17.4**±0.6 |
| **220** | **5** | **163**±8 | **1.06**±0.06 | **17.7**±0.4 |
| **220** | **10** | **159**±12 | **1.06**±0.09 | **16.8**±0.3 |
| **220** | **50** | **162**±6 | **0.94**±0.03 | **18.6**±0.7 |
| **220** | **100** | **128**±5 | **0.78**±0.04 | **18.1**±0.4 |

Critical property = deformation

Radiation index (RI) = > 8 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 453**



Material: **Araldite F** TIS No. **R 483**
Type **CY 205**

Supplier: **ABB Augsburg** UL 94: n.m.
Remarks: Insulation of LEP quadrupole coils LOI:

**Radiation test results according to IEC Standard 544 (and ISO 178)**

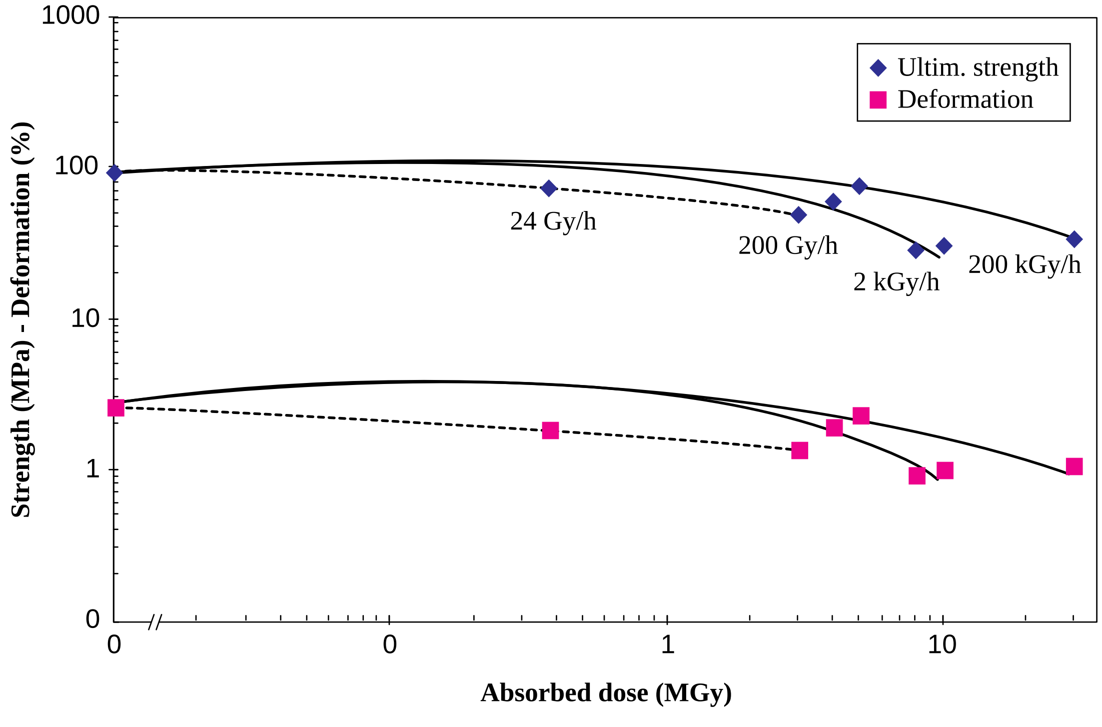
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **90**±12 | **2.61**±0.38 | **3.6**±0.05 |
| **0.02** | **0.37** | **73**±15 | **1.81**±0.42 | **3.8**±0.07 |
| **0.2** | **3** | **48**±9 | **1.35**±0.20 | **3.6**±0.29 |
| **2** | **4** | **59**±10 | **1.86**±0.50 | **3.2**±0.20 |
| **200** | **5** | **76**±20 | **2.24**±0.53 | **3.5**±0.14 |
| **2** | **8** | **28**±4 | **0.91**±0.10 | **3.2**±0.80 |
| **2** | **10** | **30**±2 | **0.96**±0.10 | **3.2**±0.10 |
| **200** | **30** | **33**±11 | **1.03**±0.25 | **3.5**±0.44 |

Critical property = flexural strength

Radiation index (RI) = 7.3 at a mean dose rate of 220 kGy/h

Radiation index (RI) = 6.7 at a mean dose rate of 200 Gy/h

**Radiation effect on Araldite F - R 483**




Comment: Low-dose rate irradiations (dotted lines) correspond to life irradiation in LEP.

| | | |
|---|---|---|
| Material: | **Araldite F** | TIS No. **R 486** |
| Type | **HY 905 + DY 040 + DY 061** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | via Ansaldo<br>this resin is used for LEP QA magnets | LOI: |

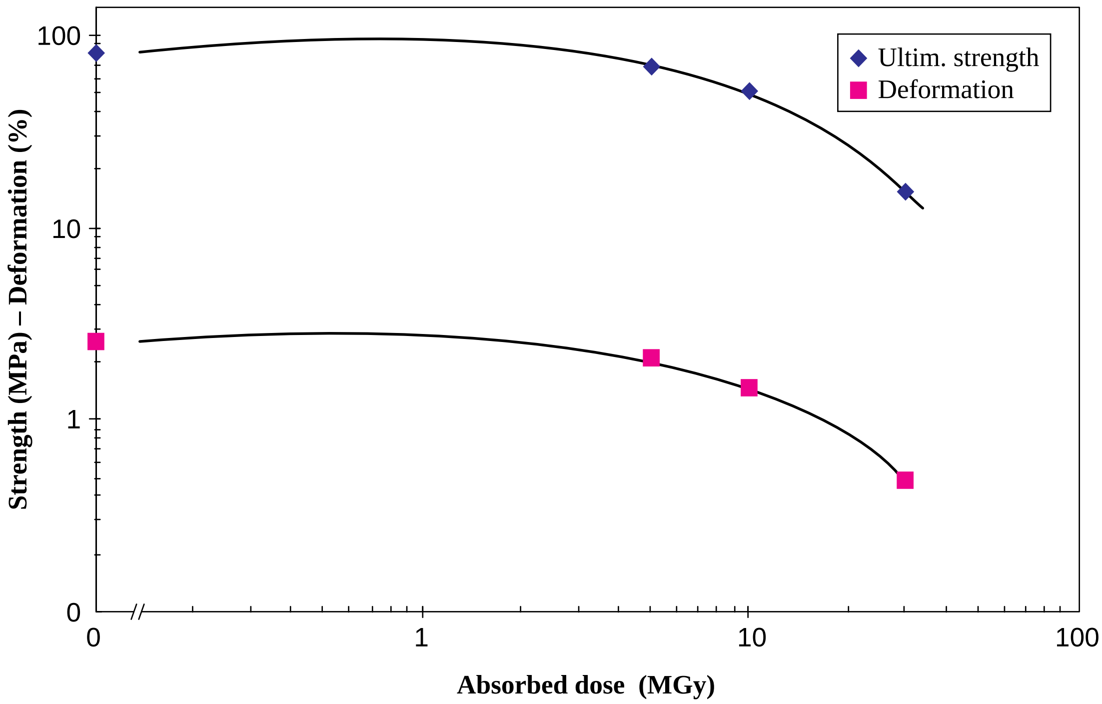
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **82**±11 | **2.6**±0.38 | **3.3**±0.09 |
| **220** | **5** | **71**±13 | **2.1**±0.4 | **3.5**±0.10 |
| **220** | **10** | **51**±6 | **1.5**±0.18 | **3.6**±0.07 |
| **220** | **50** | **15**±2 | **0.5**±0.04 | **3.3**±0.13 |

Critical property = flexural strength

Radiation index (RI) = 7.1 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 486**



| | | |
|---|---|---|
| Type Material: | **Araldite NU 514** **Epoxy moulding compound** | TIS No. **R 492** |
| Supplier: Remarks: | **Ciba-Geigy** | UL 94: n.m. LOI: |

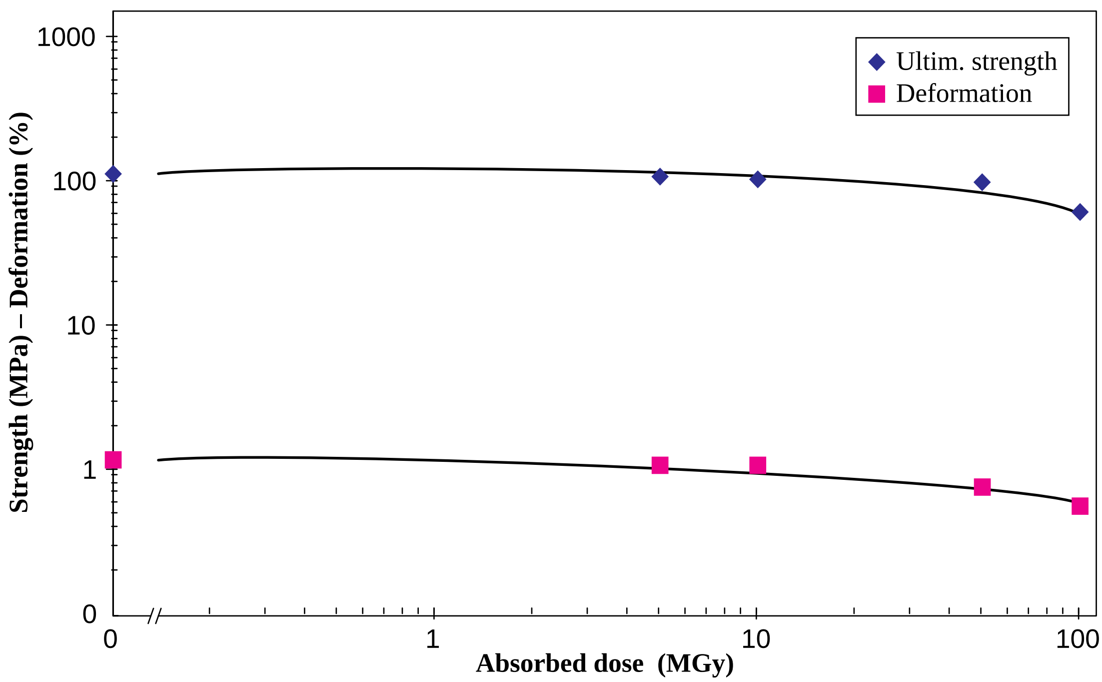
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **115**±9 | **1.17**±0.10 | **12.7**±0.2 |
| **170** | **5** | **110**±10 | **1.07**±0.13 | **13.6**±0.3 |
| **170** | **10** | **103**±3 | **1.10**±0.04 | **13.5**±0.2 |
| **170** | **50** | **98**±2 | **0.77**±0.02 | **15.6**±0.2 |
| **170** | **100** | **63**±12 | **0.6**±0.1 | **12.7**±0.7 |

Critical property = deformation

Radiation index (RI) = 7.9 at a mean dose rate of 170 kGy/h

**Radiation effect on insulating resin R 492**



| | | |
|---|---|---|
| Type<br>Material: | **Araldite NU 487**<br>**Epoxy moulding compound** | TIS No. **R 493** |
| Supplier:<br>Remarks: | **Ciba-Geigy** | UL 94: n.m.<br>LOI: |

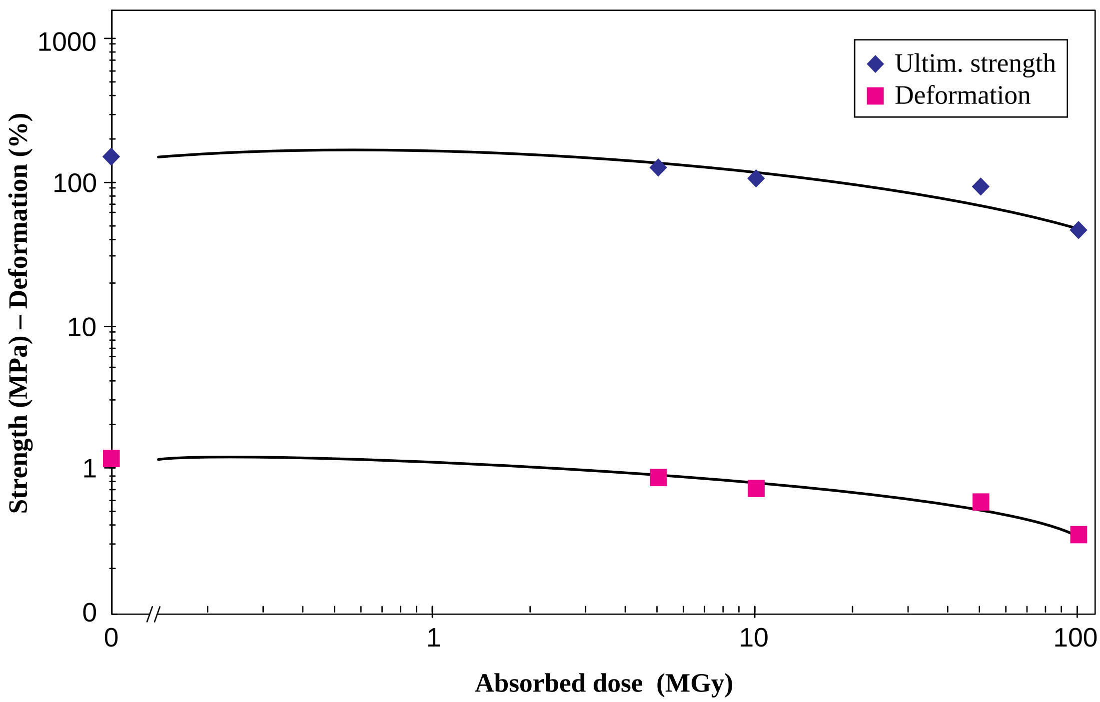
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **150**±9 | **1.19**±0.05 | **15.7**±0.5 |
| **170** | **5** | **127**±11 | **0.89**±0.08 | **16.5**±0.4 |
| **170** | **10** | **108**±12 | **0.74**±0.08 | **17.1**±0.5 |
| **170** | **50** | **96**±13 | **0.59**±0.08 | **18.9**±0.5 |
| **170** | **100** | **47**±2 | **0.36**±0.01 | **15.7**±0.5 |

Critical property = deformation

Radiation index (RI) = 7.8 at a mean dose rate of 170 kGy/h

**Radiation effect on insulating resin R 493**



| | | |
|---|---|---|
| Type Material: | **Araldite AV/HV 1580 GB** **Epoxy resin putty** | TIS No. **R 566** |
| Supplier: Remarks: | **Ciba-Geigy** | UL 94: n.m. LOI: |

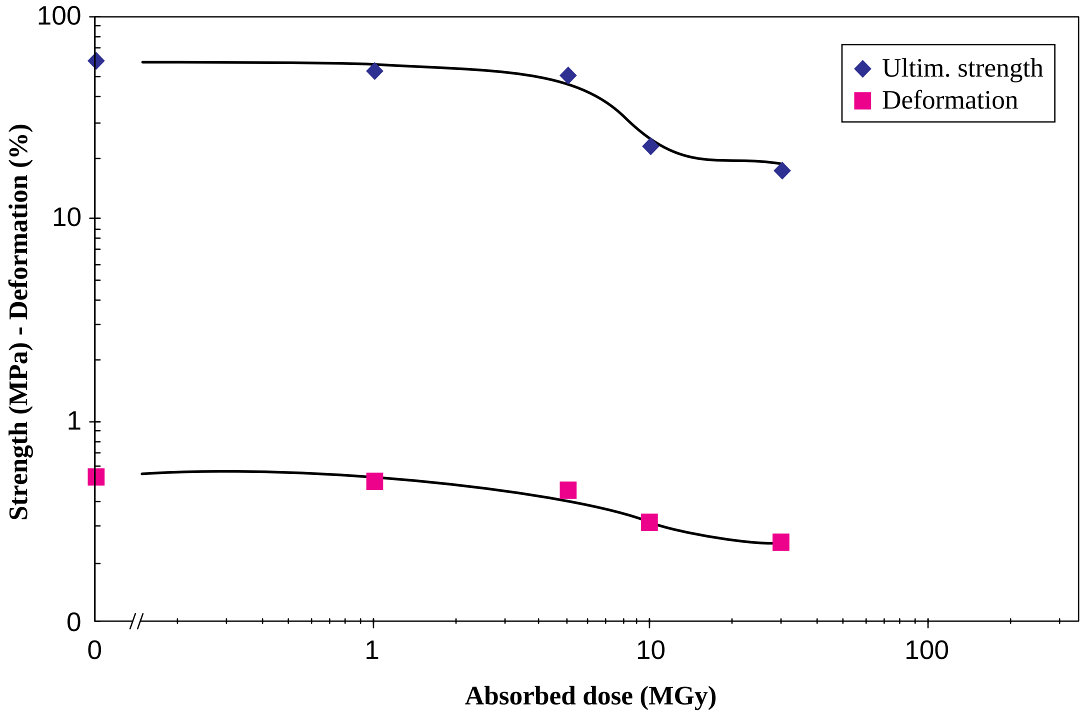
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **61**±2 | **0.53**±0.04 | **15.2**±0.3 |
| **0.1** | **1** | **54**±3 | **0.50**±0.01 | **14.5**±0.9 |
| **65** | **5** | **51**±7 | **0.45**±0.04 | **10.6**±2.5 |
| **240** | **10** | **23**±3 | **0.31**±0.02 | **8.5**±0.8 |
| **225** | **30** | **18**±2 | **0.25**±0.03 | **8.6**±1.2 |

Critical property = flexural strength

Radiation index (RI) = 6.6 at a mean dose rate of 240 kGy/h

**Radiation effect on Araldite AV/HV 1580 - R 566**



# B

| | |
|---|---|
| Bakelite | trade name for Phenol-Formaldehyde (PF) resins |
| Birakrit | trade name for glass-fibre epoxy laminate, see Ref. [25], RI = 7.3 |
| Bisphenol A | base product for epoxy resins, see Araldite and epoxy resins |
| Borolene | trade name by DSM for polyethylene; see PE |

# C

Cestidur — trade name of DSM EPP for polyethylene, see PE

Cestilene — trade name of DSM EPP for polyethylene, see PE

Cestitech — trade name of DSM EPP for polyethylene, see PE

Cevolit — trade name for glass-fibre reinforced polyester resin, see Ref. [25]; RI = 6.7

CFRP — Carbon-fibre-reinforced plastics (composites) for behaviour under cryogenic irradiation, see Ref. [35]

Copolymer polyimide and silicone — see silicone-polyimide copolymer

Cross-linked styrene copolymer — see styrene

Crystic — trade name for glass-fibre reinforced unsatured polyester resin, see Ref. [25]; RI = 7.3

Cyanate-ester resins (type of polyurethane resins), see also CFRP

## List of materials classified under letter C

| TIS number | Material name | Type | Mechanical properties | | | |
|---|---|---|---|---|---|---|
| | | | UTS (MPa) | Deform. (%) | Modulus (MPa) | RI |
| 550 | Carbon-fibre-reinforced epoxy | MY720/MT976 | 1674 | 1.54 | 112 | > 7.7 |
| 552 | Carbon-fibre-reinforced epoxy | LY556/HY917/DY070 | 929 | 1.17 | 80.5 | 8.1 |
| 553 | Carbon-fibre-reinforced epoxy | LY556/HY2954 | 884 | 1.10 | 81.1 | 6.6 |
| 555 | Carbon-fibre-reinforced epoxy | Fibredux | 1208 | 1.80 | 70.5 | > 8.1 |
| 556 | Carbon-fibre-reinforced epoxy | Vicotex | 841 | 1.93 | 47.0 | 7.2 |
| 558 | Cyanate ester resin | Arocy | 125 | 4.53 | 3.20 | 7.5 |
| 559 | Cyanate ester resin + epoxy | | 139 | 5.82 | 3.30 | 7.3 |
| 561 | Cyanate ester resin | RS-3 | 94.7 | 3.95 | 2.80 | 7.3 |
| 562 | Cyanate ester resin + carbon fibre | RS-3 + XM50A | 304 | 0.64 | 66.1 | > 7.7 |

| | | |
|---|---|---|
| Material: | **Carbon-fibre-reinforced epoxy** | TIS No. **R 550** |
| Type | **MY720/HT976 + 67.8% fibres** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | unidirectional fibres orientation | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

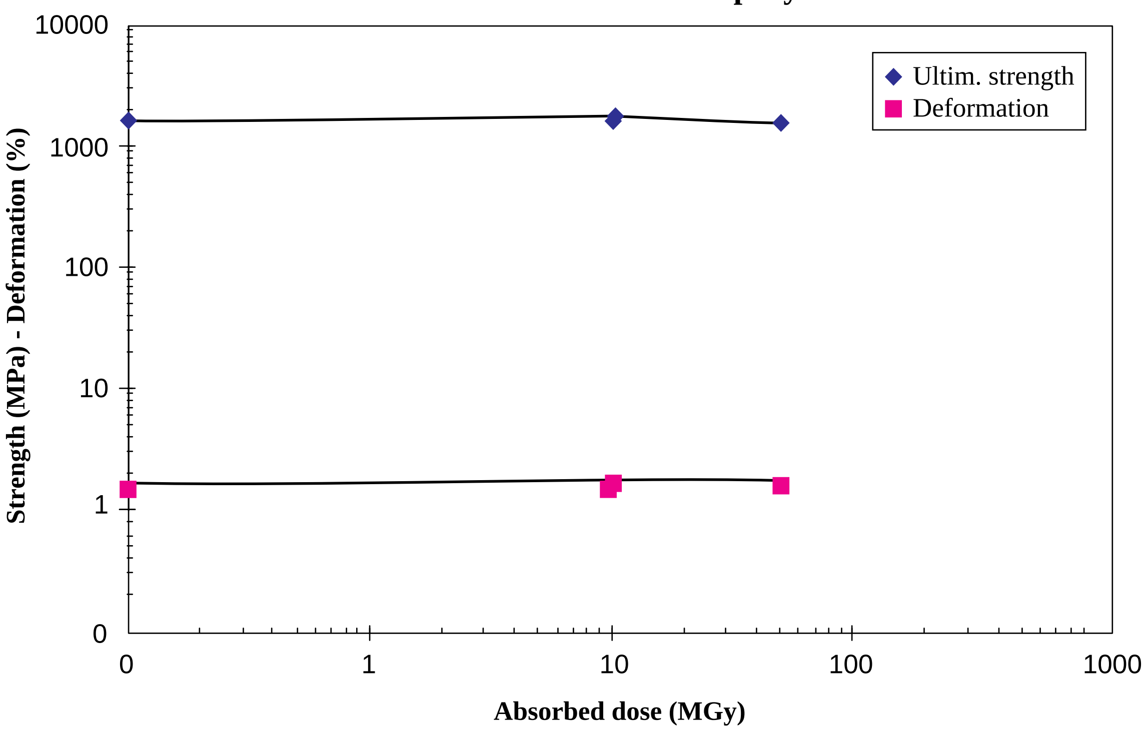
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **1674**±134 | **1.54**±0.05 | **112**±3 |
| **10** | **9** | **1535**±94 | **1.50**±0.06 | **102**±8 |
| **200** | **10** | **1681**±122 | **1.65**±0.09 | **106**±2 |
| **200** | **50** | **1579**±76 | **1.56**±0.06 | **106**±1 |

Critical property = flexural strength

Radiation index (RI) = > 7 at a mean dose rate of 10 kGy/h

Radiation index (RI) = > 7.7 at a mean dose rate of 220 kGy/h

**Radiation effect on carbon-epoxy  R 550**



| | | |
|---|---|---|
| Material: | **Carbon-fibre-reinforced epoxy** | TIS No. **R 552** |
| Type | **LY 556/HY 917/DY 070** | |
| Supplier: | **Ciba-Geigy** | UL 94: |
| Remarks: | 8 layers of fibre mat | LOI: |

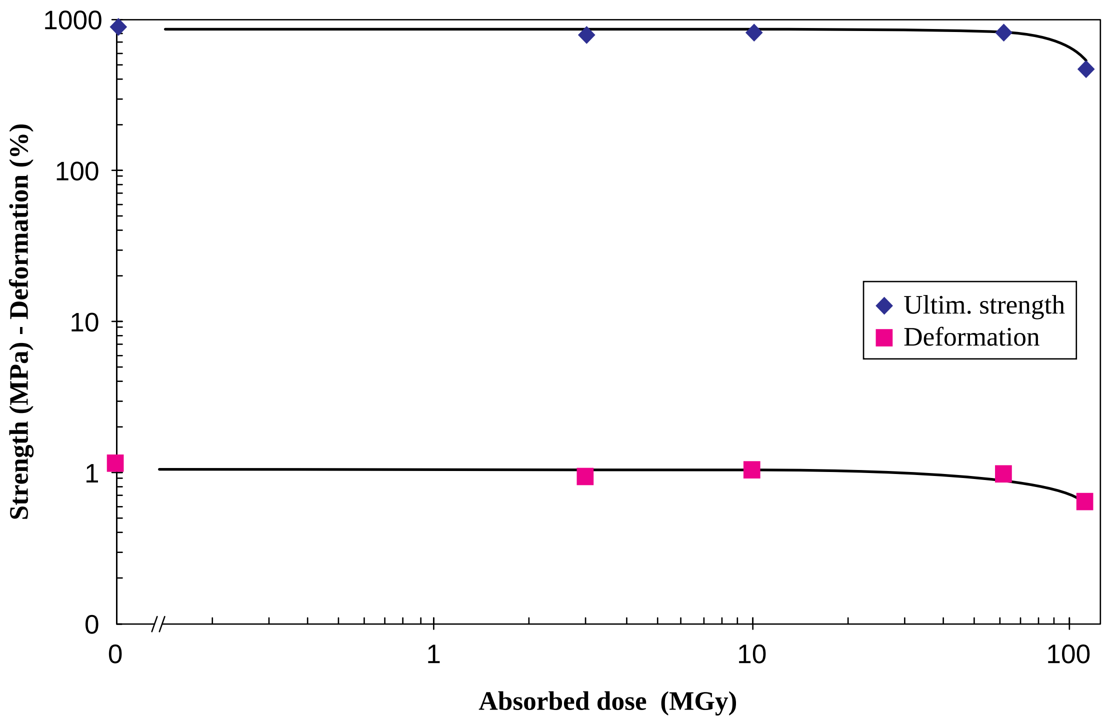
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **929**±187 | **1.17**±0.23 | **80.5**±2.6 |
| **230** | **3** | **816**±99 | **0.97**±0.16 | **81.5**±2.1 |
| **230** | **10** | **857**±114 | **1.06**±0.13 | **82.2**±1.4 |
| **230** | **62** | **837**±90 | **1.02**±0.12 | **83.0**±1.2 |
| **230** | **112** | **487**±29 | **0.64**±0.05 | **81.3**±3.9 |

Critical property = flexural strength

Radiation index (RI) = 8.1 at a mean dose rate of 230 kGy/h

**Radiation effect on epoxy laminate R 552**



| | | |
|---|---|---|
| Material: | **Carbon-fibre-reinforced epoxy** | TIS No. **R 553** |
| Type | **LY 556/HY 2954** | |
| Supplier: | **Ciba-Geigy** | UL 94: |
| Remarks: | 8 layers of fibre mat | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **884**±98 | **1.10**±0.12 | **81.1**±1.0 |
| **230** | **3** | **860**±99 | **1.05**±0.11 | **83.3**±2.0 |
| **0.5** | **3** | **774**±113 | **0.39**±0.06 | **192**±17 |
| **230** | **10** | **190**±26 | **0.29**±0.03 | **79.7**±3.8 |
| **230** | **62** | **102**±5 | **0.18**±0.01 | **79.3**±1.1 |
| **230** | **112** | **114**±8 | **0.17**±0.02 | **84.9**±2.4 |

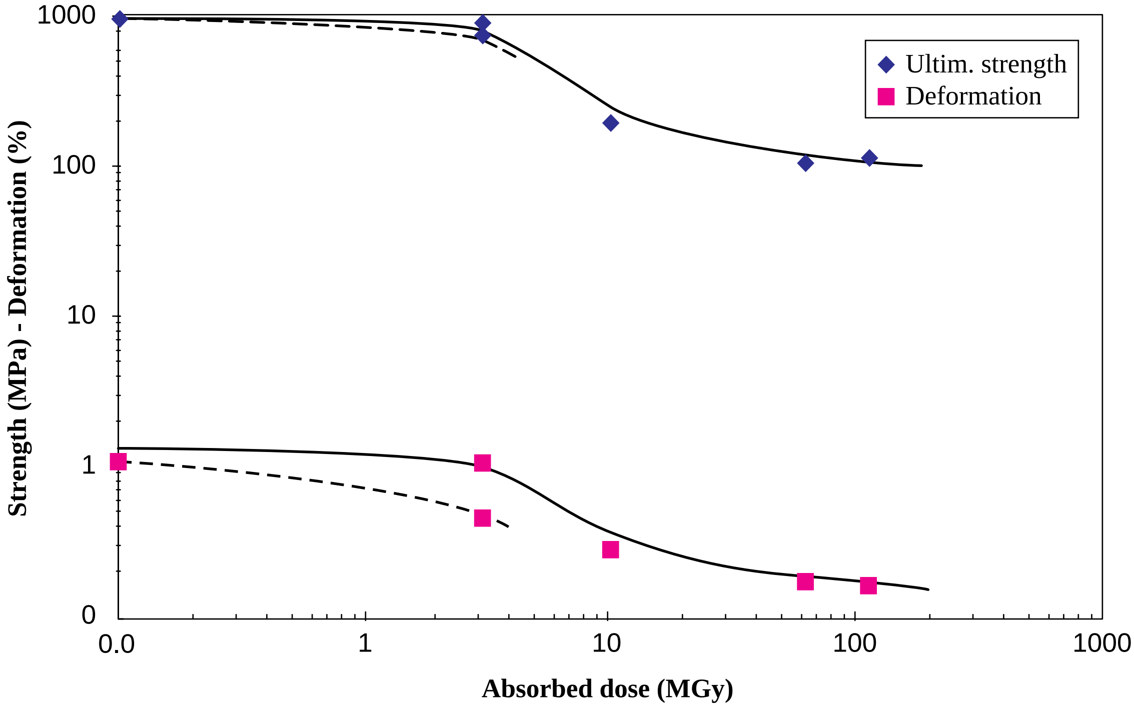
Critical property at a mean dose rate of 230 kGy/h = flexural strength

Radiation index (RI) = 6.6 at a mean dose rate of 230 kGy/h

Critical property at a mean dose rate of 0.5 kGy/h = deformation

Radiation index (RI) = 6.4 at a mean dose rate of 0.5 kGy/h

**Radiation effect on epoxy laminate  R 553**




Comment:  Dotted lines correspond to low dose rate irradiation.

| | | |
|---|---|---|
| Material: | **Carbon-fibre-reinforced epoxy** | TIS No. **R 555** |
| Type | **Fibredux 91 4c-TS(6K)-5-34%** | |
| Supplier: | **Ciba-Geigy** | UL 94: |
| Remarks: | 8 layers of prepreg | LOI: |

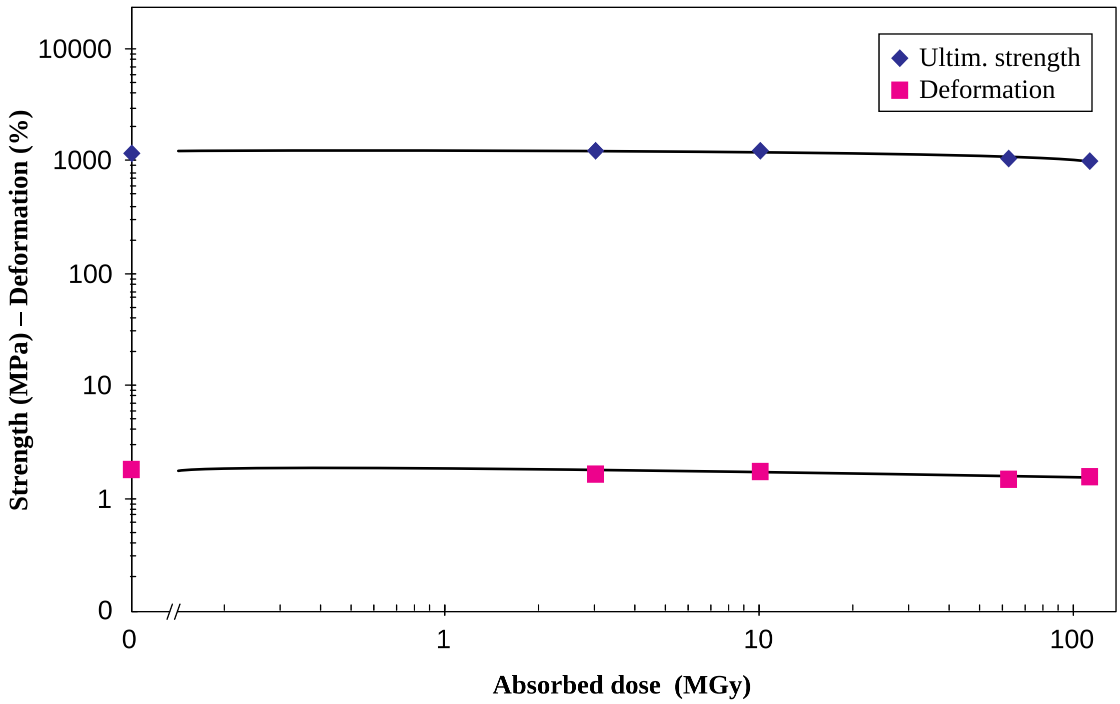
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **1208**±35 | **1.80**±0.04 | **70.5**±0.2 |
| **230** | **3** | **1239**±42 | **1.68**±0.09 | **76.1**±2.0 |
| **230** | **10** | **1255**±82 | **1.75**±0.12 | **75.9**±2.5 |
| **230** | **62** | **1077**±275 | **1.47**±0.22 | **75.2**±3.2 |
| **230** | **112** | **1013**±192 | **1.56**±0.31 | **67.6**±4.4 |

Critical property = flexural strength

Radiation index (RI) > 8.1 at a mean dose rate of 230 kGy/h

**Radiation effect on epoxy laminate R 555**



| | | |
|---|---|---|
| Material: | **Carbon-fibre-reinforced epoxy** | TIS No. **R 556** |
| Type | **Vicotex M 10 G 1071** | |
| Supplier: | **Ciba-Geigy** | UL 94: |
| Remarks: | | LOI: |

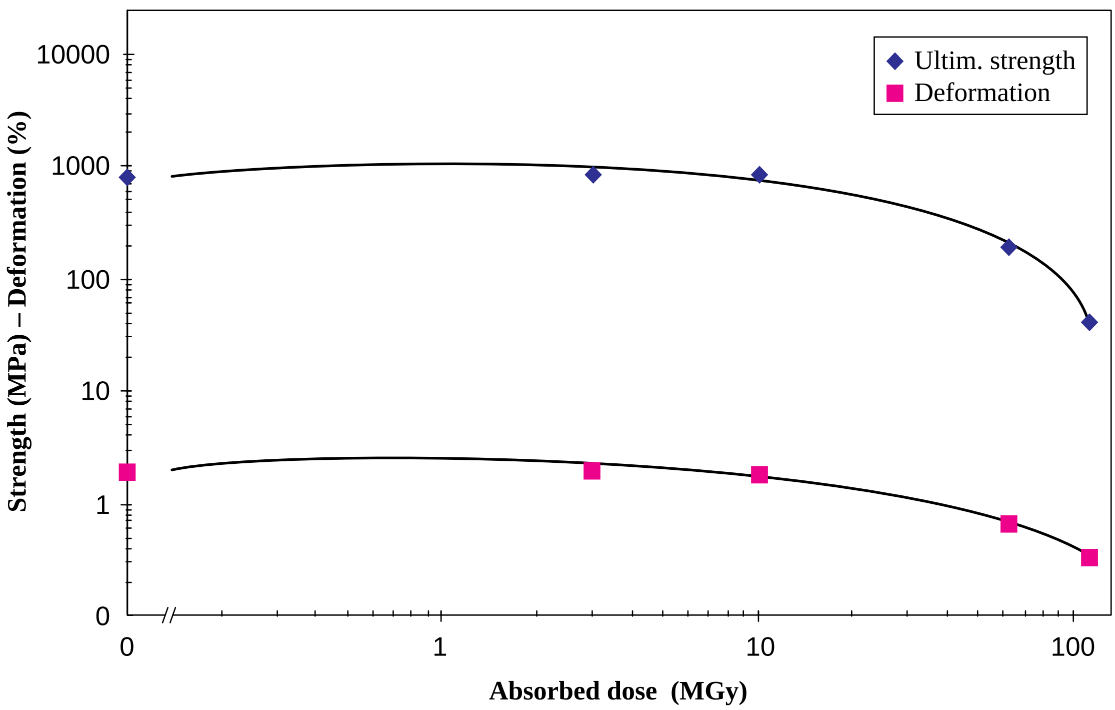
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **841**±31 | **1.93**±0.06 | **47.0**±1.0 |
| **230** | **3** | **865**±36 | **1.93**±0.05 | **48.0**±1.4 |
| **230** | **10** | **852**±32 | **1.83**±0.06 | **49.1**±1.6 |
| **230** | **62** | **201**±71 | **0.66**±0.26 | **39.4**±12 |
| **230** | **112** | **42**±10 | **0.33**±0.15 | **19.4**±4.8 |

Critical property = flexural strength

Radiation index (RI) = 7.2 at a mean dose rate of 230 kGy/h

**Radiation effect on epoxy laminate R 556**



| | | |
|---|---|---|
| Material: | **Cyanate ester resin** | TIS No. **R 558** |
| Type | **Arocy B 10 (M 7.009/9)** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | Bisphenol-Adicyanate ester | LOI: |

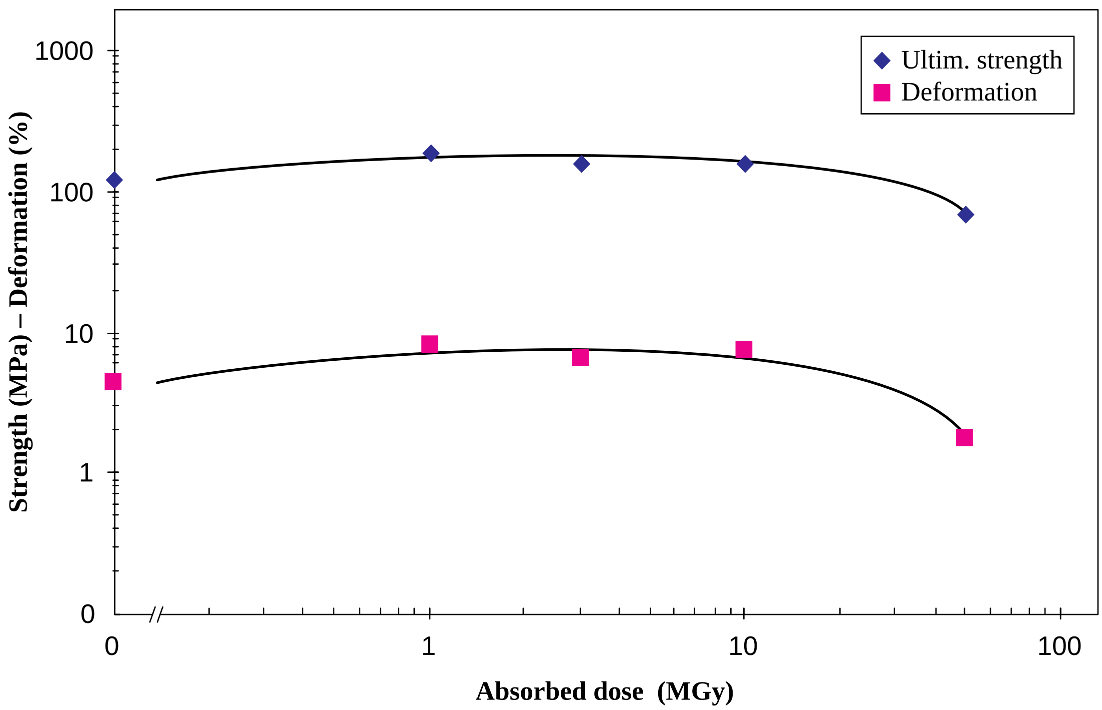
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **125**±11 | **4.53**±0.49 | **3.2**±0.02 |
| **6** | **1** | **189**±11 | **8.25**±1.53 | **4.2**±0.04 |
| **230** | **3** | **161**±5 | **6.62**±1.00 | **3.8**±0.05 |
| **230** | **10** | **160**±2 | **7.62**±1.24 | **3.8**±0.07 |
| **180** | **50** | **69**±4 | **1.76**±0.07 | **4.0**±0.06 |

Critical property = deformation

Radiation index (RI) = 7.5 at a mean dose rate of 180 kGy/h

**Radiation effect on cyanate ester R 558**



| | | |
|---|---|---|
| Material: | **Cyanate ester + Epoxy** | TIS No. **R 559** |
| Type | **Arocy B 10/LY556 / Zn (M 7.10/6)** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | | LOI: |

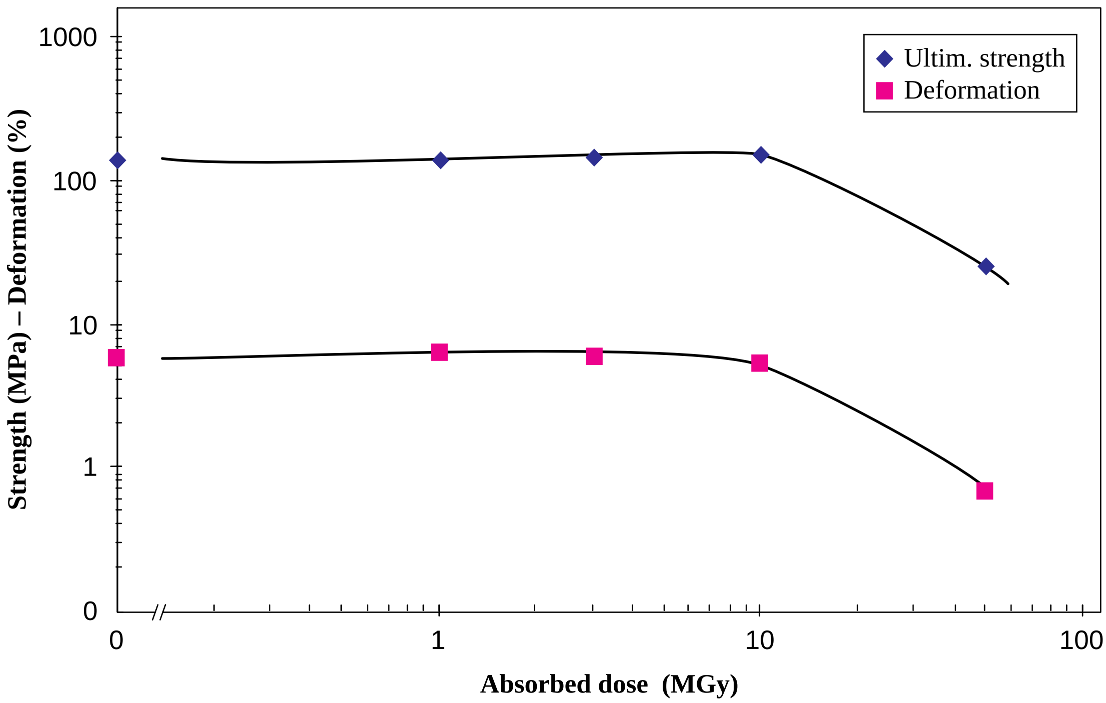
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **139**±9 | **5.82**±1.00 | **3.3**±0.09 |
| **6** | **1** | **141**±11 | **6.42**±1.93 | **3.5**±0.07 |
| **230** | **3** | **147**±6 | **6.04**±0.83 | **3.7**±0.03 |
| **230** | **10** | **150**±3 | **5.34**±0.34 | **3.9**±0.10 |
| **180** | **50** | **25**±12 | **0.68**±0.28 | **4.1**±0.09 |

Critical property = deformation

Radiation index (RI) ~ 7.3 at a mean dose rate of 180 kGy/h

**Radiation effect on cyanate ester + epoxy R 559**



| | | |
|---|---|---|
| Material: | **Cyanate ester resin** | TIS No. **R 561** |
| Type | **RS-3** | |
| Supplier: | **YLA** | UL 94: n.m. |
| Remarks: | | LOI: |

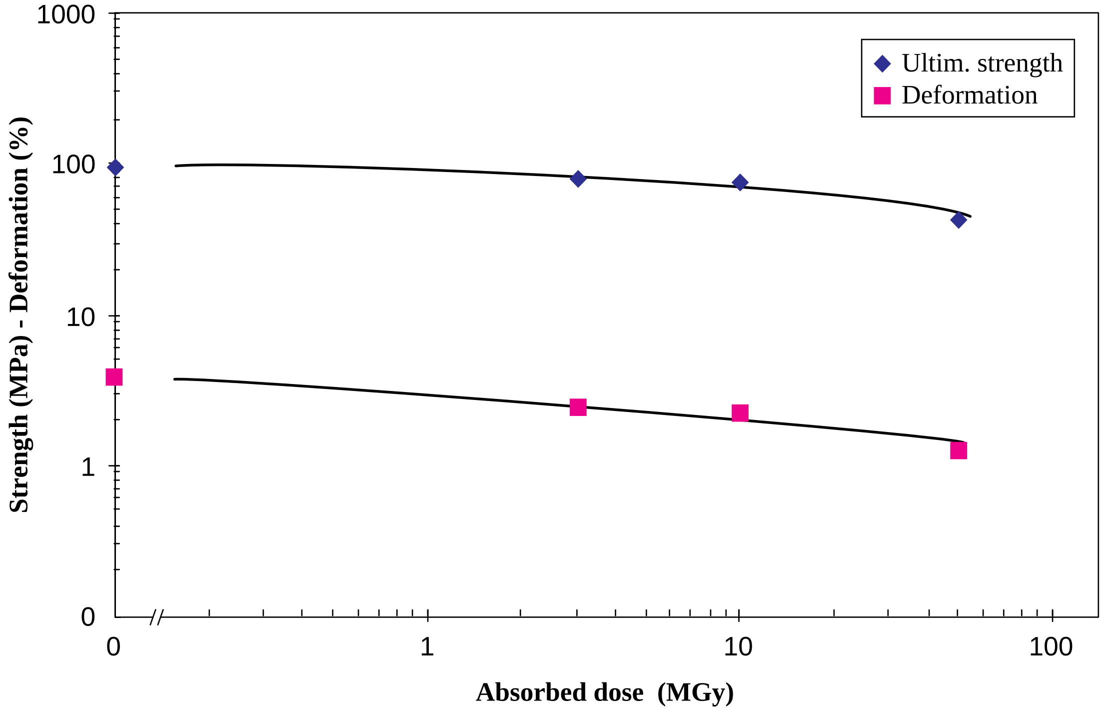
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **94.7**±13.1 | **3.95**±0.80 | **2.8**±0.13 |
| **18** | **3** | **80.8**±7.3 | **2.55**±0.51 | **3.4**±0.37 |
| **190** | **10** | **78.0**±8.8 | **2.30**±0.30 | **3.4**±0.13 |
| **230** | **50** | **42.9**±7.8 | **1.28**±0.21 | **3.5**±0.13 |

Critical property = deformation

Radiation index (RI) = 7.3 at a mean dose rate of 200 kGy/h

**Radiation effect on Cyanate ester resin R 561**



| | | |
|---|---|---|
| Material: | **Cyanate ester + carbon fibres** | TIS No. **R 562** |
| Type | **RS-3 + XN 50A** | |
| Supplier: | **YLA** | UL 94: n.m. |
| Remarks: | | LOI: |

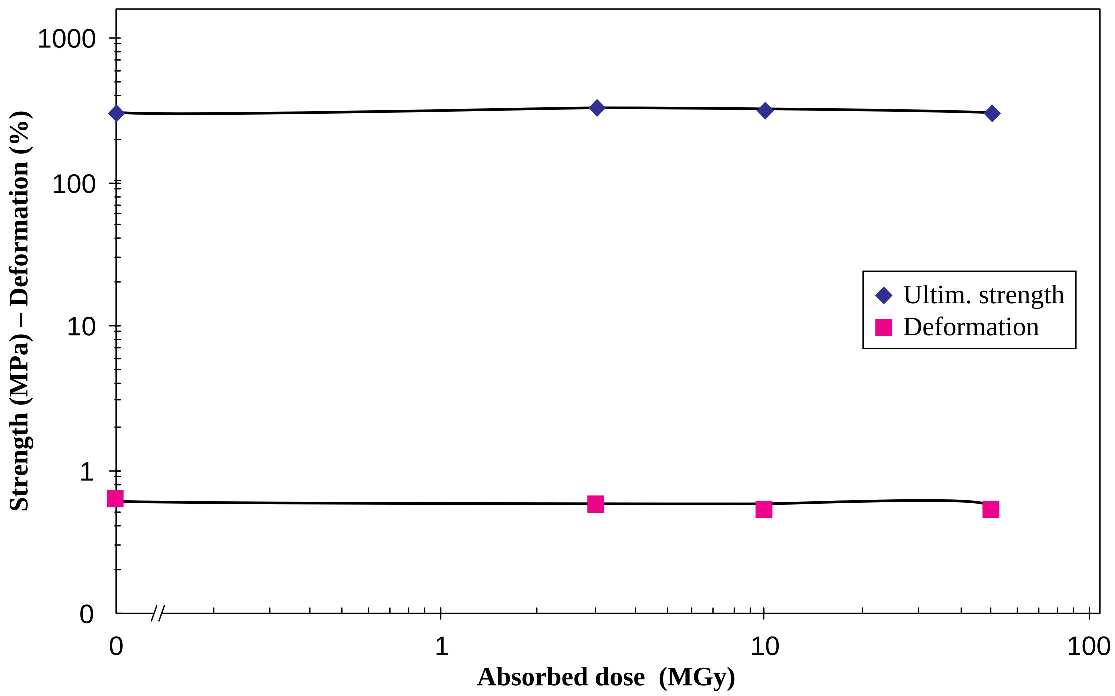
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **304**±26 | **0.64**±0.11 | **66.1**±11.9 |
| **18** | **3** | **330**±17 | **0.57**±0.05 | **77.6**±1.2 |
| **180** | **10** | **320**±26 | **0.54**±0.05 | **79.7**±5.3 |
| **180** | **50** | **313**±33 | **0.52**±0.06 | **76.9**±3.3 |

Critical property = deformation

Radiation index (RI) > 7.7 at a mean dose rate of 180 kGy/h

**Radiation effect on Cyanate ester laminate R 562**



# D

| | |
|---|---|
| Dacron | trade name of Dupont for polyester fibres, see Ref. [25]; RI = 5.5 |
| Delrin | trade name of DUPONT de Nemours for polyoxymethylene (POM), see polyoxymethylene (POM) |
| Dobeckan IF | trade name for polyurethane, see Ref. [25]; RI > 7 |
| Dobeckot | trade name for epoxy resins, see Ref. [25]; RI < 7 |
| Durotenax | trade name of ISOLA for bisphenol A epoxy, see epoxy resins |

| | |
|---|---|
| Envex | trade name for polyimide (PI) |
| Epikote | trade name of SHELL for epoxy resin |
| Epoxy resins | for chemical formulas, see Appendix 2 and Ref. [25]<br>Araldite B, D, F trade names of CIBA-GEIGY, see Araldite<br>Bisphenol A epoxy (BPA)<br>Durotenax<br>Epikote<br>Novolac, see Ref. [25]<br>Samicatherm<br>Scotchcast, epoxy base compound<br>Vetresit<br>for behaviour under cryogenic irradiation, see Ref. [35] |
| Epoxy based laminates, see also CFRP | |
| Epoxy based prepreg | |
| Epoxy moulding | compound<br>Araldite NU 460, 461, 471, 481, 487, 505, 511, 514. See Araldite<br>Neonit |
| Ertalon | trade name of ERTA-EPEC for polyamides, see polyamide |
| Ertalyte | trade name of ERTA for PETP, see PETP |
| Ertapeek | trade name of ERTA-EPEC for polyether-ether-ketone, see PEEK |
| Ertaxel | trade name of ERTA-EPEC for PPS, see PPS |
| Etronax | trade name of Elektro-Isola for phenolic resins, see phenolic resins |

## List of materials classified under letter E

| TIS number | Material name | Type | Mechanical properties UTS (MPa) | Deform. (%) | Modulus (MPa) | RI |
|---|---|---|---|---|---|---|
| 409 | Epoxy + glass mat | HGW 2372.4 | 453.3 | 2.3 | 22.08 | > 8 |
| 414 | Epoxy laminate – prepreg | Isopreg 0.28 VP 288 | 371.1 | 2.6 | 16.8 | > 7.7 |
| 417 | Epikote + Aramid fiber | Arenka 900 | 247.6 | 3.8 | 14.4 | > 6.7 |
| 422 | Epoxy resin MY745/EPN1138/CY221/HY905/DY073 | | 153 | 13.1 | 3.8 | 6.6 |
| 423 | Epoxy resin MY745/HY906/DY073 | | 148.1 | 8.8 | 3.8 | 7.1 |
| 424 | Epoxy resin (based on Bisphenol A) | Durotenax | 61.2 | 1.05 | 5.93 | 6.7 |
| 426 | Epoxy + glass fibres | Vetresit 1101 | 1341.5 | 3.2 | 42.8 | 7.9 |
| 427 | Epoxy (cycloaliphatic) + glass | Vetresit 312 | 547.4 | 1.88 | 31.03 | 7.7 |
| 428 | Epoxy (cycloaliphatic) + glass | Vetresit 300 | 388.4 | 2.33 | 18.75 | 7.9 |
| 433 | Epoxy resin (based on Bisphenol A) | Durotenax Art. 521-02 | 141.2 | 1.58 | 10.09 | 7.5 |
| 434 | Epoxy resin (based on Bisphenol A) + Methyl hexahydrophtal. anhydr. | | 78.3 | 2.19 | 3.6 | 6.5 |
| 437 | Epoxy moulding compound | Neonit EG61 | 92.9 | 1.03 | 10.77 | ~ 7.1 |
| 460 | Epoxy resin SIB3309 + tape:Samicapor 326.95-47X | | 116.7 | 0.54 | 31.7 | 7.3 |
| 461 | Epoxy resin SIB3309 + tape:Samicapor 326.96-86X | | 162.8 | 0.52 | 41.4 | > 8 |
| 465 | Epoxy resin + glass fabric | G-Etronax EP11 | 387.6 | 2.28 | 18.7 | > 7.5 |
| 466 | Epoxy moulding compound | MY790 + HY1102BD | 84 | 2.24 | 3.91 | 6.5 |
| 467 | Epoxy resin + Mica + GF | MY790 + HY1102BD | 544.7 | 2.87 | 23 | 7.4 |
| 468 | Epoxy – prepreg | Isopreg EP spess 0.33 | 354.8 | 1.79 | 22.6 | > 8 |
| 502 | Epoxy moulding compound | R112 + H232 | 57.6 | > 12 | 1.57 | 7.1 |
| 506 | Epoxy laminated + glass | ACO1+GLASS A | 408 | 1.96 | 22.98 | 7.3 |
| 507 | Epoxy laminated + glass | ACO2+GLASS A | 431.3 | 2.47 | 22.13 | 7.4 |
| 508 | Epoxy laminated + glass | ACO1+GLASS B | 404.7 | 2.1 | 23.1 | 7.5 |
| 509 | Epoxy laminated + glass | ACO2+GLASS B | 459.1 | 2.06 | 24.1 | 7.5 |
| 511 | Epoxy | Scotchcast 9 | 34.3 | > 12 | 1.5 | 6.8 |
| 512 | Epoxy | Scotchcast 281 | 32.9 | > 12 | 2.3 | < 6.5 |
| 514 | Epoxy | Scotchcast 804 | 90.5 | 5.44 | 2.4 | < 6.5 |
| 515 | Epoxy | Scotchcast 824 | 54.6 | 1.53 | 5.6 | 6.8 |
| 525 | Epoxy A + glass + Kevlar | Novolac resin | 376.5 | 2.05 | 33.3 | 6.9 |
| 539 | Epoxy resin | Vetronite | 362.9 | 2.1 | 20.9 | > 7.7 |
| 540 | Epoxy resin + mineral filler + glass mica + Dacron | Samicatherm | 143.5 | 1.14 | 19.8 | 7.6 |
| 541 | Epoxy resin | XNR 4153 / XNH 4153 | 111.5 | 1.18 | 11.34 | 6.8 |
| 554 | Epoxy resin | AS/37-3 | 126 | 8.4 | 2.9 | 6.1 |
| 557 | Epoxy moulding compound | Matramid 5292A/B | 165 | 6.27 | 3.9 | 7.6 |
| 564 | Epoxy laminate | Isopreg EP 0316 | 239 | 1.14 | n.m. | 7.8 |
| 565 | Epoxy laminate | Isopreg EP 1037/IDT | 552 | 2.46 | 30.3 | > 8 |

| | | |
|---|---|---|
| Material: | **Epoxy + glass mat** | TIS No. **R 409** |
| Type | **HGW 2372.4** | |
| Supplier: | **Elin Union** | UL 94: n.m. |
| Remarks: | LEP-QP insulations based on EPN 1138 from Ciba-Geigy | LOI: |

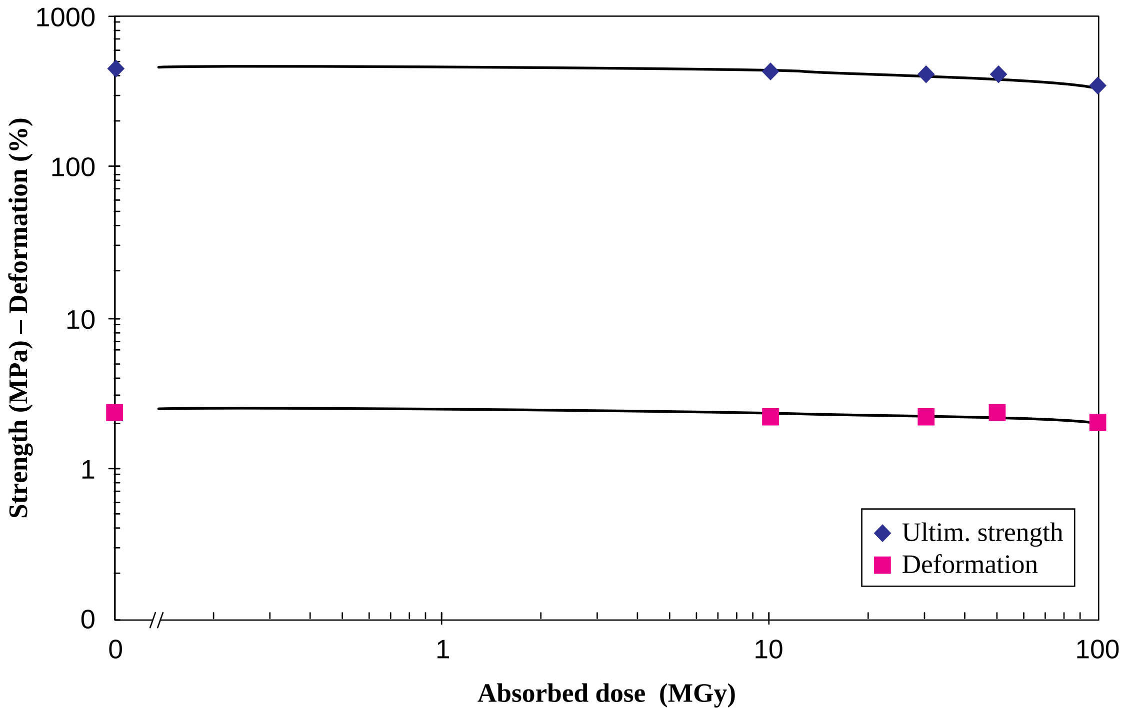
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **453**±15 | **2.3**±0.1 | **22.1**±0.42 |
| **220** | **10** | **445**±13 | **2.24**±0.06 | **22.2**±0.45 |
| **220** | **30** | **429**±16 | **2.27**±0.07 | **22.1**±0.42 |
| **220** | **50** | **419**±25 | **2.30**±0.11 | **21.7**±0.3 |
| **220** | **100** | **360**±26 | **2.05**±0.21 | **21.7**±0.59 |

Critical property = flexural strength

Radiation index (RI) = > 8 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 409**



| | | |
|---|---|---|
| Material: | **Epoxy laminate – prepreg** | TIS No. **R 414** |
| Type | **ISOPREG 0.28 VP 288** | |
| Supplier: | **Isovolta** | UL 94: n.m. |
| Remarks: | via Ansaldo | LOI: |

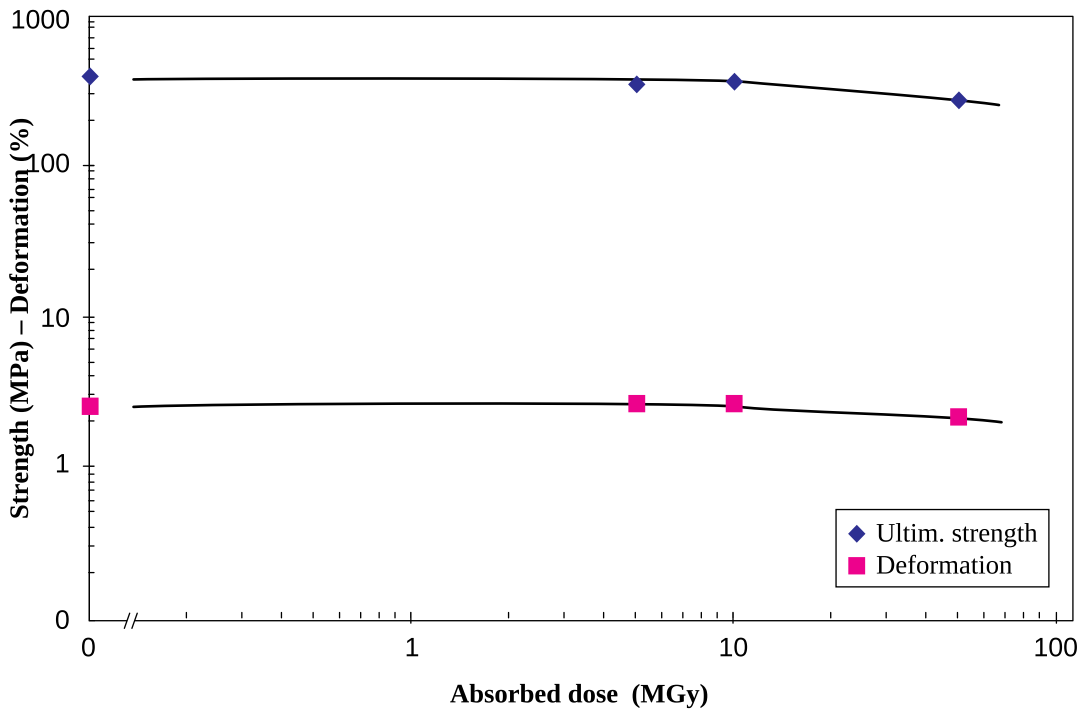
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **371**±13 | **2.6**±0.1 | **16.8**±0.7 |
| **220** | **5** | **350**±12 | **2.6**±0.2 | **19.6**±0.8 |
| **220** | **10** | **362**±16 | **2.7**±0.2 | **17.7**±1.0 |
| **220** | **50** | **272**±14 | **2.2**±0.4 | **16.5**±0.4 |

Critical property = flexural strength

Radiation index (RI) = > 7.7 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 414**



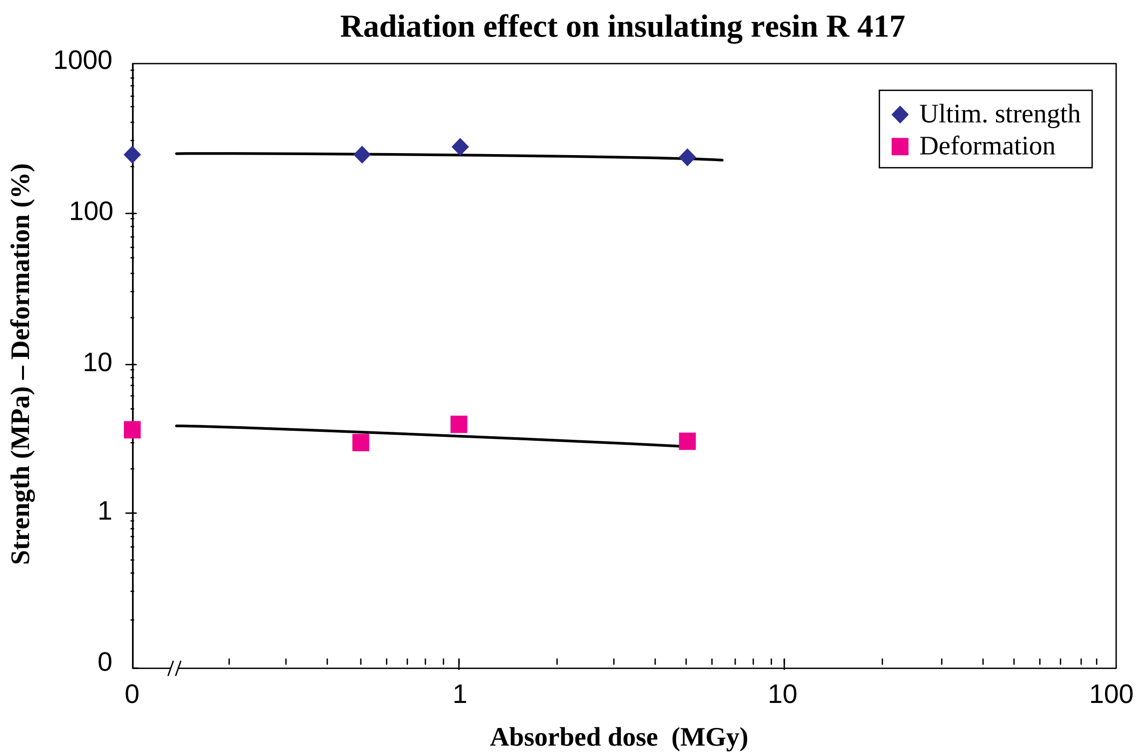
| | | |
|---|---|---|
| Material: | **Epikote + Aramid fibre** | TIS No. **R 417** |
| Type | **Arenka 900** | |
| Supplier: | **Enka (D)** | UL 94: n.m. |
| Remarks: | SC coils | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **248**±35 | **3.79**±0.8 | **14.4**±3.7 |
| **220** | **0.5** | **251**±84 | **2.93**±0.64 | **17.0**±4.6 |
| **220** | **1** | **279**±33 | **3.86**±0.71 | **14.4**±2.7 |
| **220** | **5** | **240**±34 | **3.04**±0.34 | **14.9**±1.7 |

Critical property = flexural strength

Radiation index (RI) > 6.7 at a mean dose rate of 220 kGy/h



| | | |
|---|---|---|
| Material: | **Epoxy resin** | TIS No. **R 422** |
| Type | **MY 745 (50) + EPN 1138 (50) + CY 221 (20) + HY 905 (120) + DY 073 (0.3)** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | used for the ISR dipoles | LOI: |

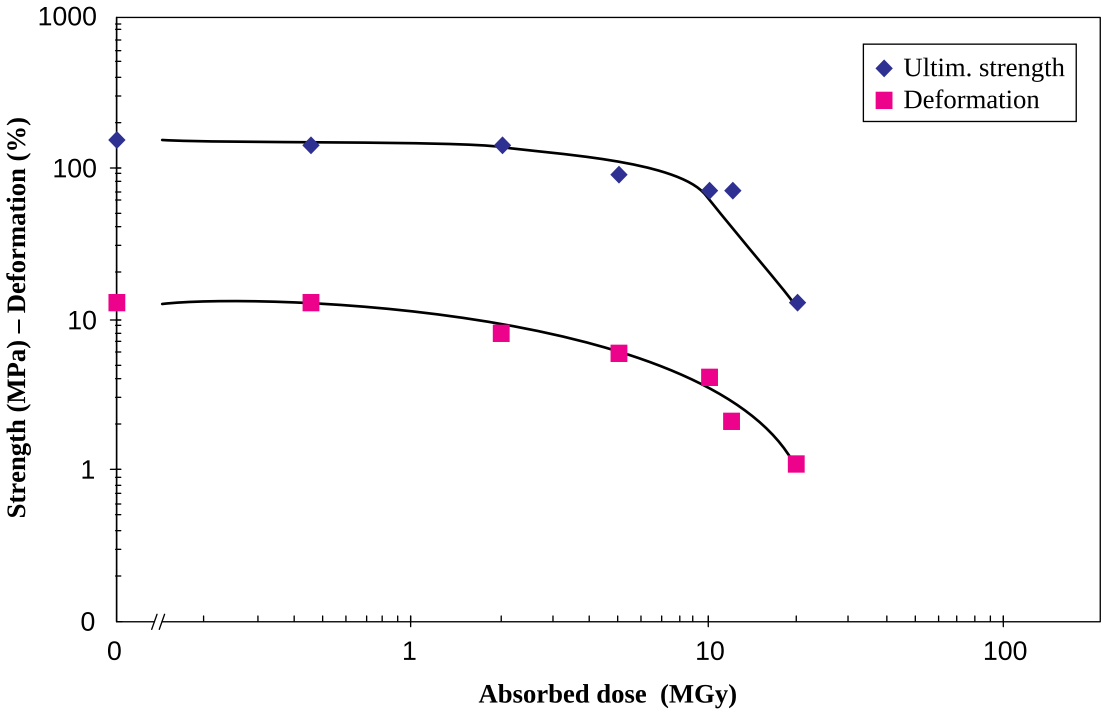
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **153**±3 | **13.1**±1.9 | **3.80**±0.03 |
| **0.2** | **0.5** | **142**±1 | **12.9**±0.3 | **3.50**±0.02 |
| **0.2** | **2.0** | **140**±1 | **7.9**±0.3 | **3.50**±0.02 |
| **180** | **5** | **93**±2 | **6.1**±0.3 | **4.00**±0.03 |
| **180** | **10** | **73**±3 | **4.2**±0.2 | **4.10**±0.04 |
| **0.5** | **12** | **71**±6 | **2.1**±0.2 | **3.7**±0.1 |
| **180** | **20** | **13**±1 | **1.1**±0.1 | **3.40**±0.04 |

Radiation index (RI) = 6.9 if strength is the critical property

Radiation index (RI) = 6.6 if deformation is the critical property

**Radiation effect on Epoxy resin R 422**



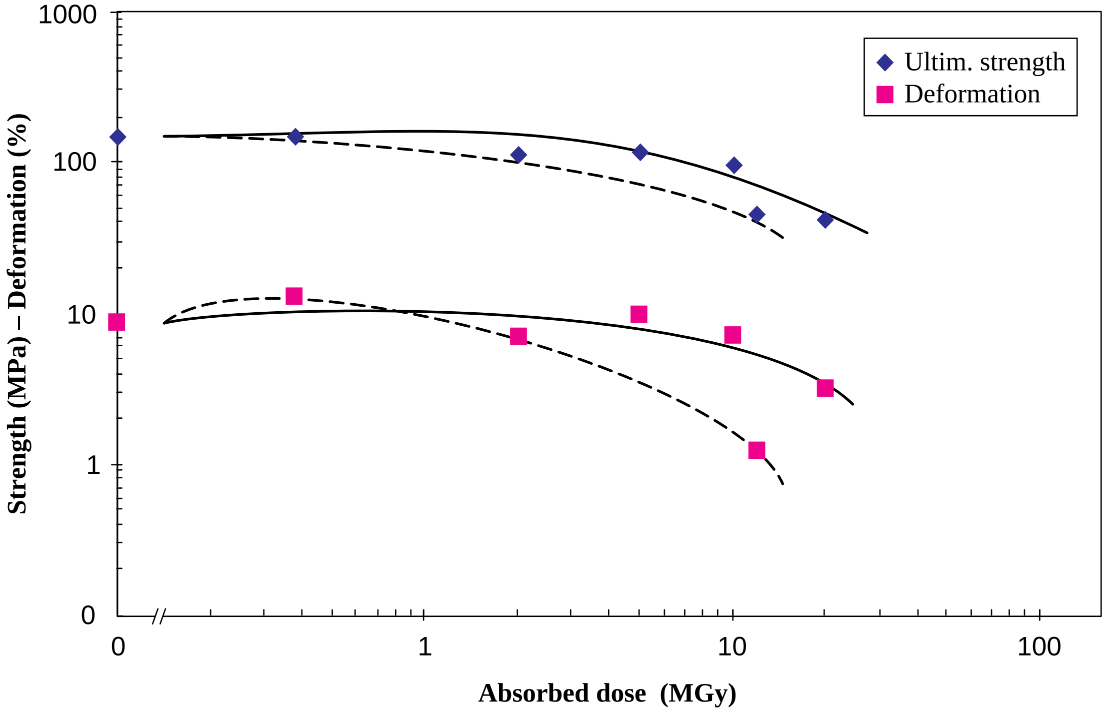
| | | |
|---|---|---|
| Material: | **Epoxy resin** | TIS No. **R 423** |
| Type | **MY 745 (100) + HY 906 (90) + DY 073 (1.5)** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | used for the SPS dipoles | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **148**±15 | **8.8**±1.3 | **3.8**±0.1 |
| **0.2** | **0.4** | **149**±1 | **12.9**±0.8 | **3.47**±0.01 |
| **0.2** | **2** | **118**±33 | **7.1**±3.7 | **3.47**±0.01 |
| **180** | **5** | **118**±10 | **10**±2 | **3.7**±0.3 |
| **180** | **10** | **98**±5 | **7.2**±1.4 | **4.1**±0.4 |
| **0.5** | **12** | **45**±6 | **1.3**±0.1 | **3.7**±0.3 |
| **180** | **20** | **43**±4 | **3.2**±0.6 | **4.2**±0.4 |

| | | |
|---|---|---|
| Radiation index (RI): | 6.6 | at 500 Gy/h |
| Radiation index (RI): | 7.1 | at 180 kGy/h |

**Radiation effect on Epoxy resin R 423**




Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Epoxy resin (based on Bisphenol A)** | TIS No. **R 424** |
| Type | **Durotenax** | |
| Supplier: | **Isola (CH)** | UL 94: n.m. |
| Remarks: | protection against X-rays | LOI: |

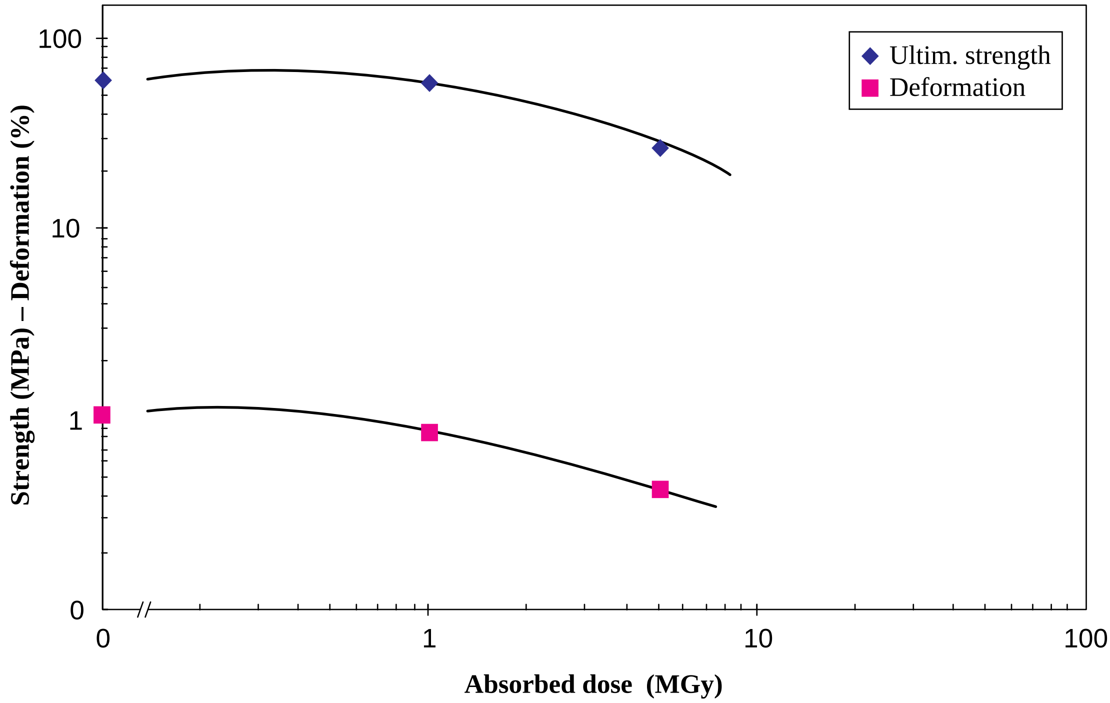
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **61.2**±5.2 | **1.05**±0.09 | **5.93**±0.10 |
| **220** | **1** | **58.6**±7.3 | **0.88**±0.11 | **6.33**±0.17 |
| **220** | **5** | **26.9**±3.2 | **0.43**±0.04 | **6.30**±0.25 |

Critical property = flexural strength

Radiation index (RI) = 6.6 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 424**



| | | |
|---|---|---|
| Material: | **Epoxy + glass fibres** | TIS No. **R 426** |
| Type | **Vetresit 1101** | |
| Supplier: | **Micafil** | UL 94: n.m. |
| Remarks: | | LOI: |

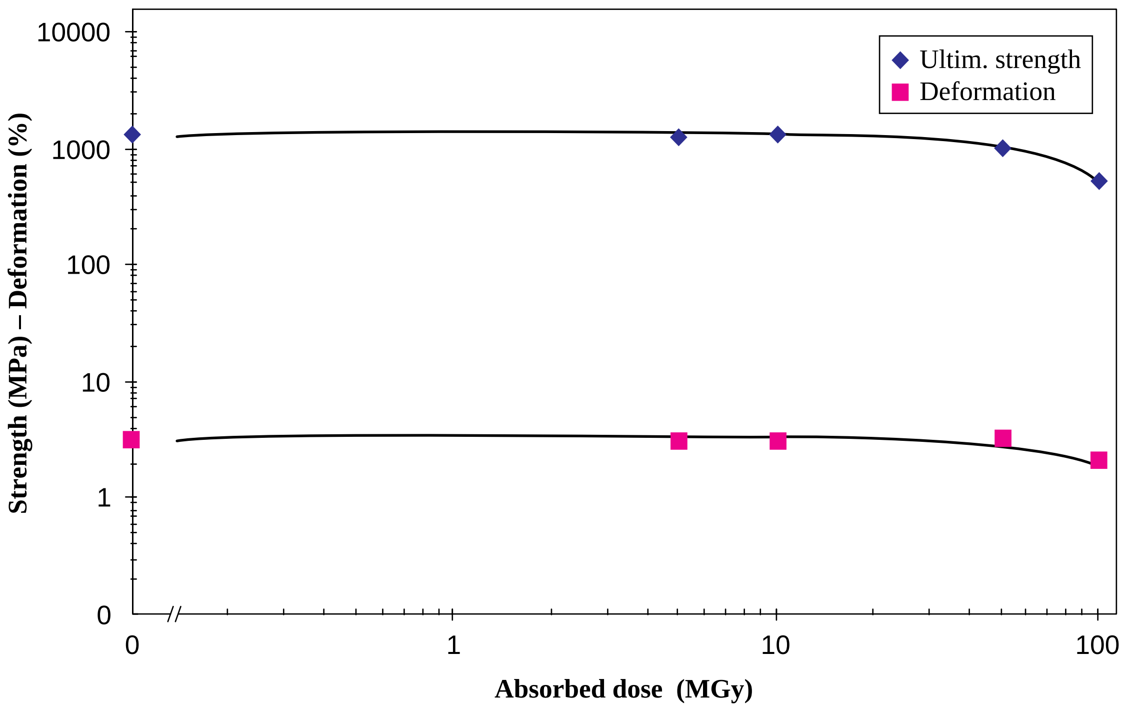
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **1342**±61 | **3.20**±0.14 | **42.8**±0.9 |
| **170** | **5** | **1282**±74 | **3.10**±0.18 | **43.2**±1.1 |
| **170** | **10** | **1351**±53 | **3.17**±0.26 | **43.5**±0.9 |
| **170** | **50** | **1017**±65 | **3.44**±0.29 | **42.7**±1.6 |
| **170** | **100** | **543**±132 | **2.18**±0.32 | **35.8**±3.8 |

Critical property = flexural strength

Radiation index (RI) = 7.9 at a mean dose rate of 170 kGy/h

**Radiation effect on insulating resin R 426**



| | | |
|---|---|---|
| Material: | **Epoxy (cycloaliphatic) + glass** | TIS No. **R 427** |
| Type | **Vetresit 312** | |
| Supplier: | **Micafil** | UL 94: n.m. |
| Remarks: | + roving glass | LOI: |

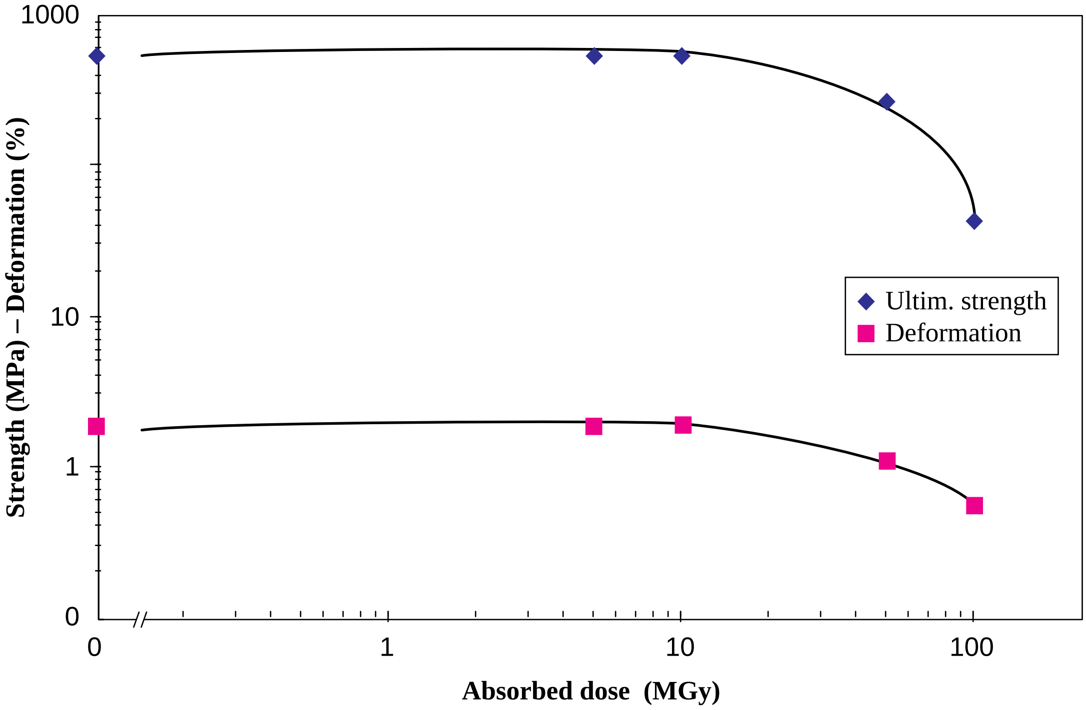
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **547**±26 | **1.88**±0.13 | **31.0**±1.7 |
| **170** | **5** | **533**±26 | **1.83**±0.16 | **31.9**±1.5 |
| **170** | **10** | **529**±33 | **1.94**±0.17 | **31.2**±0.8 |
| **170** | **50** | **266**±21 | **1.08**±0.08 | **27**±1.5 |
| **170** | **100** | **43**±7 | **0.56**±0.26 | **17.8**±1.8 |

Critical property = flexural strength

Radiation index (RI) = 7.7 at a mean dose rate of 170 kGy/h

**Radiation effect on insulating resin R 427**



| | | |
|---|---|---|
| Material: | **Epoxy (cycloaliphatic) + glass** | TIS No. **R 428** |
| Type | **Vetresit 300** | |
| Supplier: | **Micafil** | UL 94: n.m. |
| Remarks: | + glass mat | LOI: |

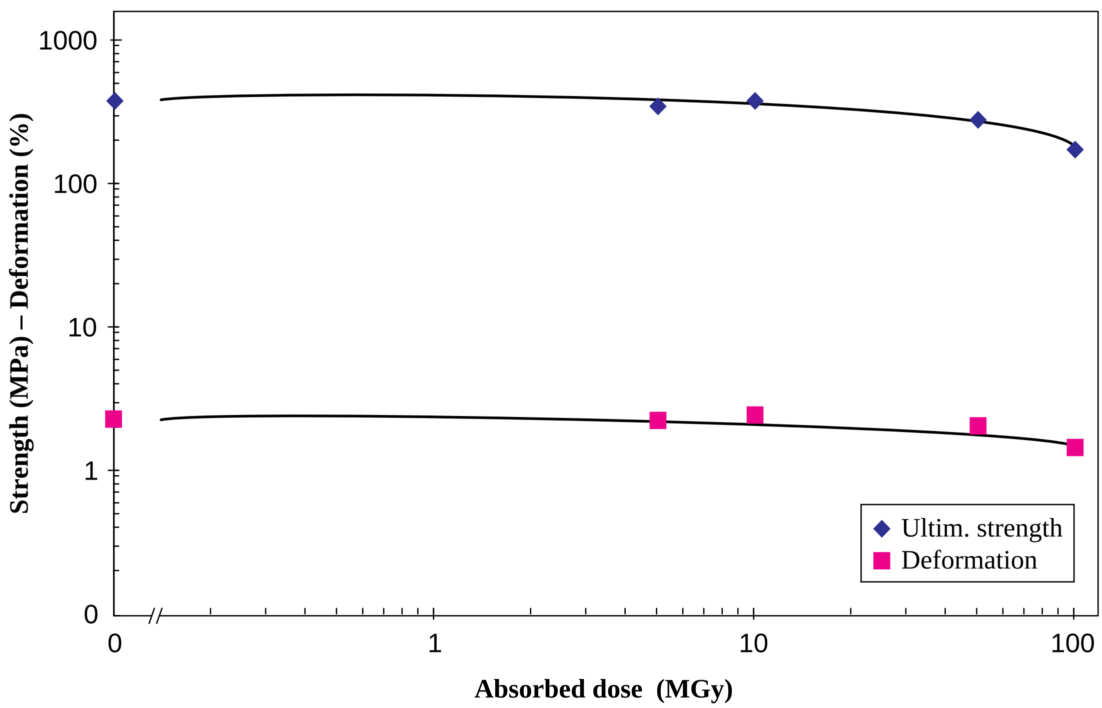
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **388**±11 | **2.33**±0.06 | **18.8**±0.4 |
| **170** | **5** | **359**±18 | **2.29**±0.14 | **18.1**±1 |
| **170** | **10** | **386**±21 | **2.47**±0.13 | **18.1**±1 |
| **170** | **50** | **284**±12 | **2.06**±0.05 | **17.8**±0.5 |
| **170** | **100** | **178**±7 | **1.48**±0.25 | **15.7**±1.1 |

Critical property = flexural strength

Radiation index (RI) = 7.9 at a mean dose rate of 170 kGy/h

**Radiation effect on insulating resin R 428**



| | | |
|---|---|---|
| Material: | **Epoxy resin (based on Bisphenol A)** | TIS No. **R 433** |
| Type | **Durotenax Art. 521-02** | |
| Supplier: | **Isola** | UL 94: n.m. |
| Remarks: | Bisphenol A + quartz-powder | LOI: |

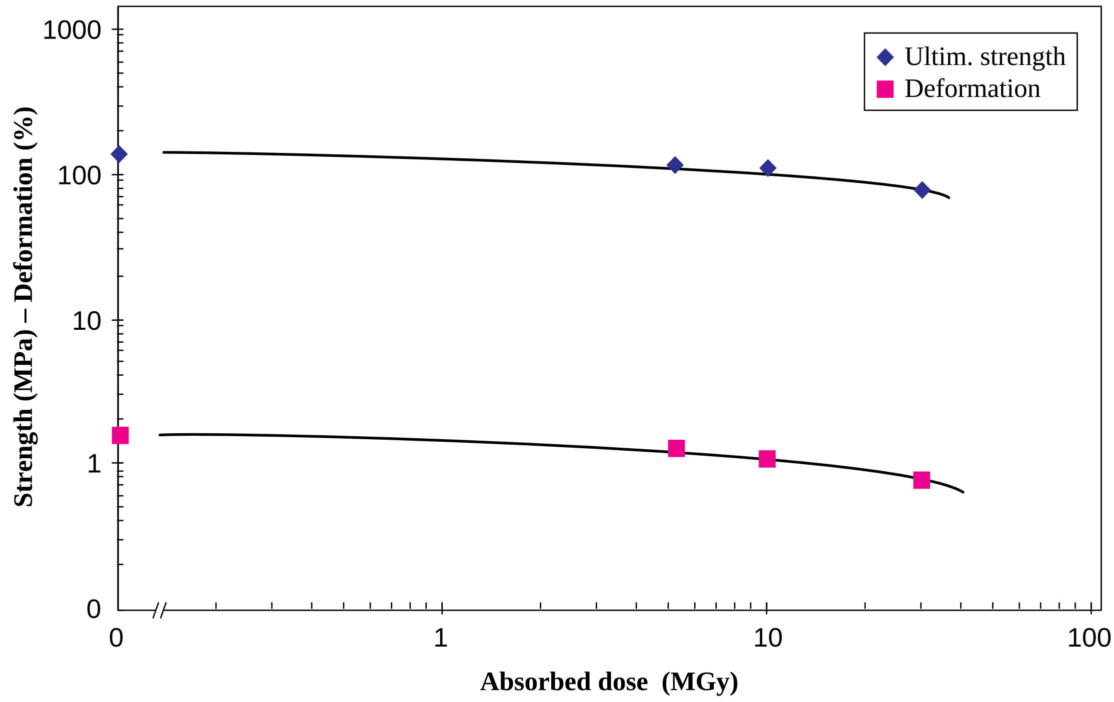
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **141**±8 | **1.58**±0.11 | **10.1**±0.6 |
| **220** | **5.2** | **119**±4 | **1.24**±0.05 | **10.4**±0.6 |
| **220** | **10** | **114**±3 | **1.1**±0.1 | **11.2**±0.5 |
| **220** | **30** | **78**±2 | **0.79**±0.02 | **10.4**±0.4 |

Critical property = deformation

Radiation index (RI) = 7.5 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 433**



| | | |
|---|---|---|
| Material: Type | **Epoxy resin (based on Bisphenol A) + Methyl Hexahydrophtal Anhydride** | TIS No. **R 434** |
| Supplier: | **Elin Union** | UL 94: n.m. |
| Remarks: | Dipole for SPS-LEP transfer lines | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

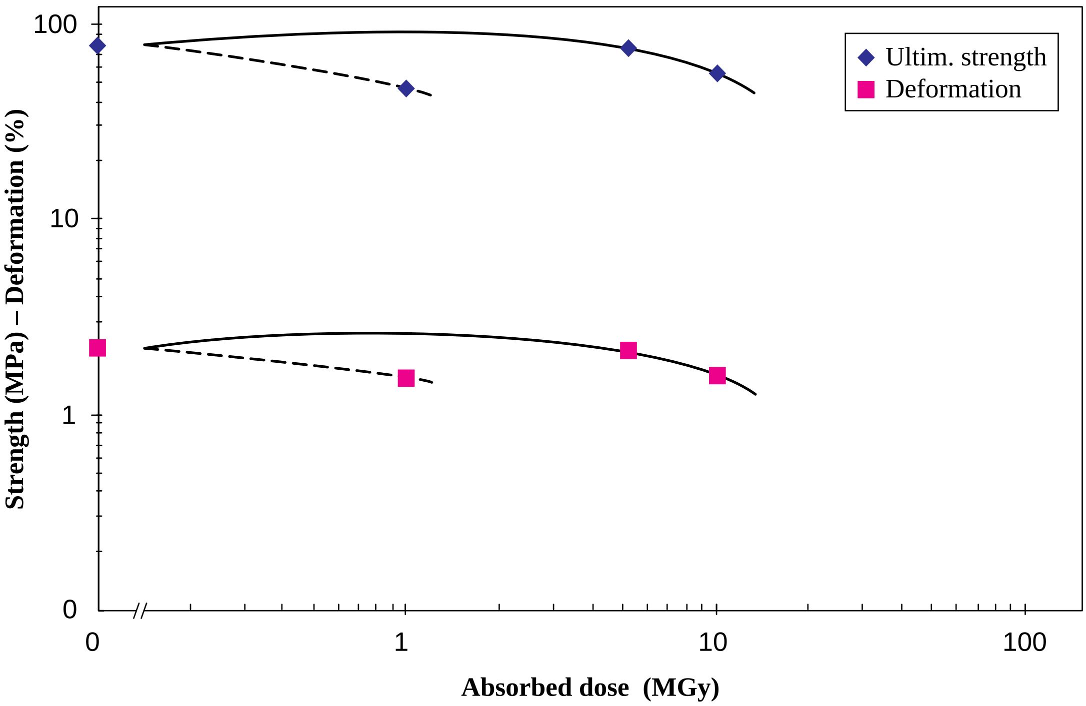
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **78**±22 | **2.2**±0.5 | **3.6**±0.5 |
| **0.1** | **1** | **47**±9 | **1.5**±0.2 | **3.0**±0.3 |
| **170** | **5.2** | **76**±15 | **2.2**±0.4 | **3.6**±0.2 |
| **170** | **10** | **57**±4 | **1.6**±0.1 | **3.5**±0.1 |

Critical property = flexural strength

Radiation index (RI) = > 7 at a mean dose rate of 170 kGy/h

Radiation index (RI) = > 6 at a mean dose rate of 100 Gy/h

**Radiation effect on Epoxy R 434**




Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Epoxy moulding compound** | TIS No. **R 437** |
| Type | **Neonit EG 61** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | not cured | LOI: |

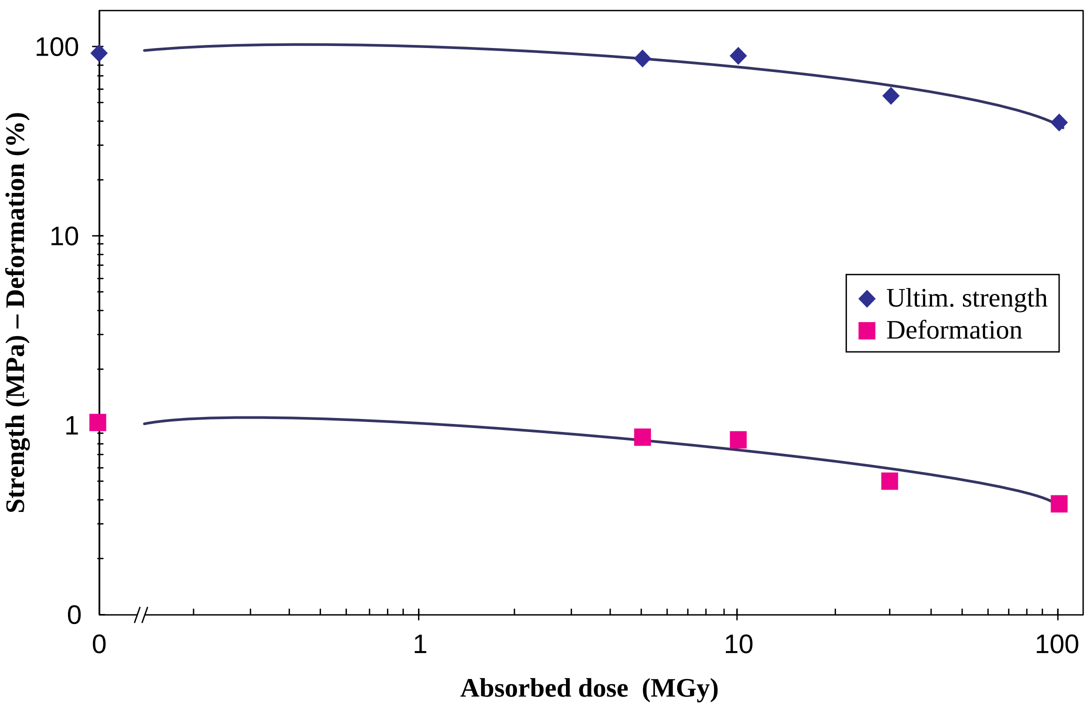
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **92.9**±2.7 | **1.03**±0.11 | **10.8**±1 |
| **220** | **5** | **86.8**±14.4 | **0.88**±0.17 | **11.4**±0.4 |
| **220** | **10** | **89.6**±11.4 | **0.85**±0.11 | **12.2**±0.6 |
| **220** | **30** | **55.8**±8.7 | **0.51**±0.08 | **12.7**±0.3 |
| **220** | **100** | **39.9**±6.9 | **0.39**±0.07 | **11.4**±0.2 |

Critical property = deformation

Radiation index (RI) = 7.5 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 437**



| | | |
|---|---|---|
| Material: | **Epoxy resin SIB 3309 + tape** | TIS No. **R 460** |
| Type | **tape: Samicapor 326.95-47X** | |
| Supplier: | **Isola** | UL 94: n.m. |
| Remarks: | LEP-QP insulations based on EPN 1138 from Ciba-Geigy | LOI: |

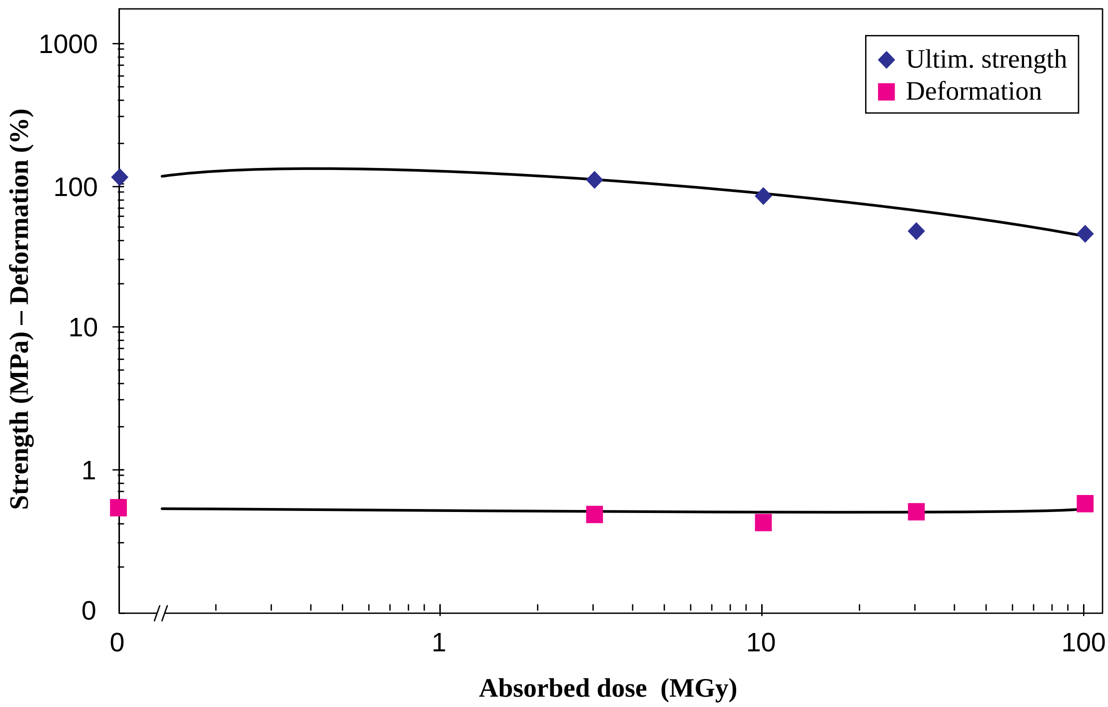
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **117**±8 | **0.54**±0.08 | **31.7**±1.6 |
| **220** | **3** | **110**±6 | **0.49**±0.07 | **31.9**±2.1 |
| **220** | **10** | **87**±21 | **0.42**±0.06 | **27.4**±6.1 |
| **220** | **30** | **48**±12 | **0.5**±0.1 | **15.0**±2.5 |
| **220** | **100** | **46**±6 | **0.57**±0.06 | **11.2**±1.9 |

Critical property = flexural strength

Radiation index (RI) = 7.3 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 460**



| | | |
|---|---|---|
| Material: | **Epoxy resin SIB 3309 + tape** | TIS No. **R 461** |
| Type | **tape: Samicapor 326.96-86X** | |
| Supplier: | **Isola** | UL 94: n.m. |
| Remarks: | | LOI: |

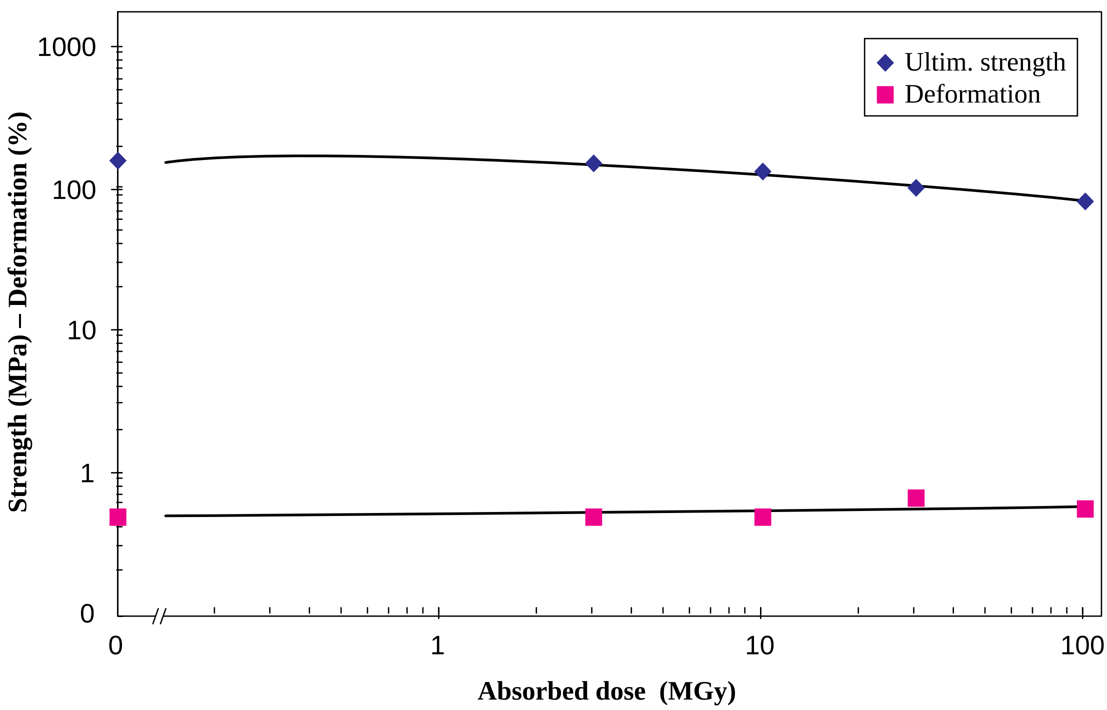
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **163**±11.2 | **0.52**±0.08 | **41.4**±1.7 |
| **220** | **3** | **159**±13.5 | **0.51**±0.05 | **40.2**±2.2 |
| **220** | **10** | **135**±13.0 | **0.52**±0.07 | **36.2**±1.8 |
| **220** | **30** | **104**±10.0 | **0.69**±0.05 | **19.4**±5.8 |
| **220** | **100** | **85**±3.0 | **0.58**±0.15 | **16.9**±2.5 |

Critical property = flexural strength

Radiation index (RI) = > 8 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 461**



| | | |
|---|---|---|
| Material: | **Epoxy resin + glass fabric** | TIS No. **R 465** |
| Type | **G-Etronax EP 11** | |
| Supplier: | **Elektro-Isola** | UL 94: n.m. |
| Remarks: | insulations for the dipoles in LEP | LOI: |

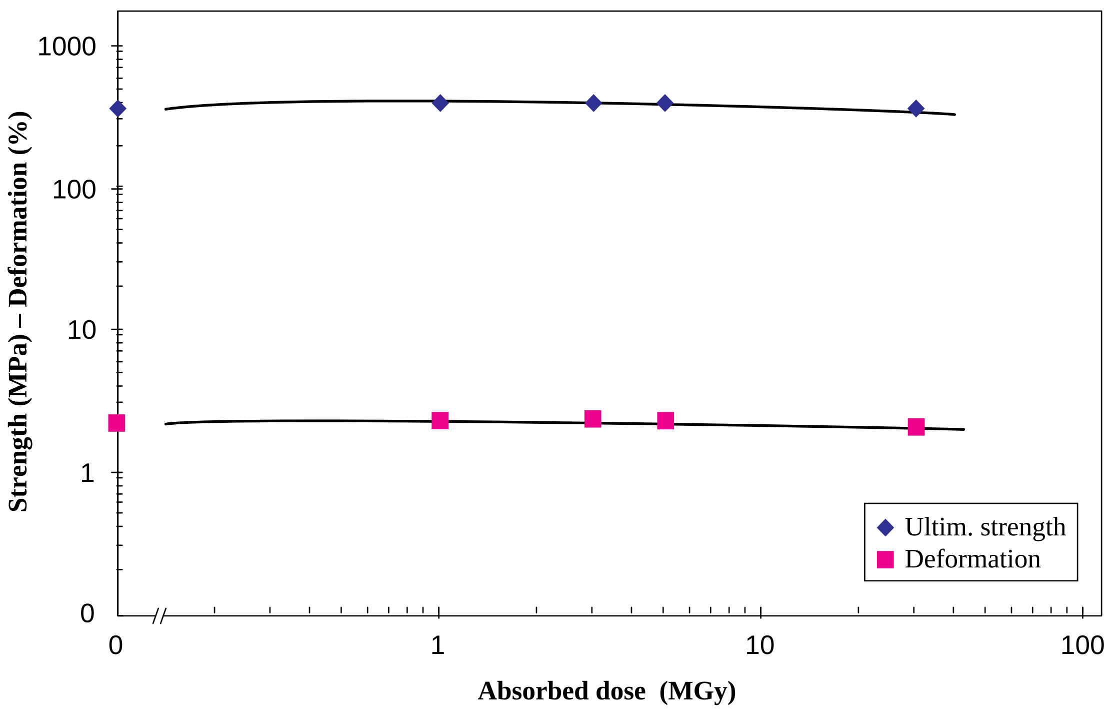
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **388**±23 | **2.28**±0.11 | **18.7**±0.5 |
| **220** | **1** | **413**±31 | **2.34**±0.16 | **20.0**±1.0 |
| **220** | **3** | **418**±21 | **2.35**±0.12 | **20.9**±1.8 |
| **220** | **5** | **418**±30 | **2.34**±0.08 | **20.0**±1.0 |
| **220** | **30** | **383**±11 | **2.2**±0.1 | **21.9**±0.9 |

Critical property = none

Radiation index (RI) = > 7.5 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 465**



| | | |
|---|---|---|
| Material: | **Epoxy moulding compound** | TIS No. **R 466** |
| Type | **MY 790 + HY 1102BD** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | via Elin Union | LOI: |

### Radiation test results according to IEC Standard 544 (and ISO 178)

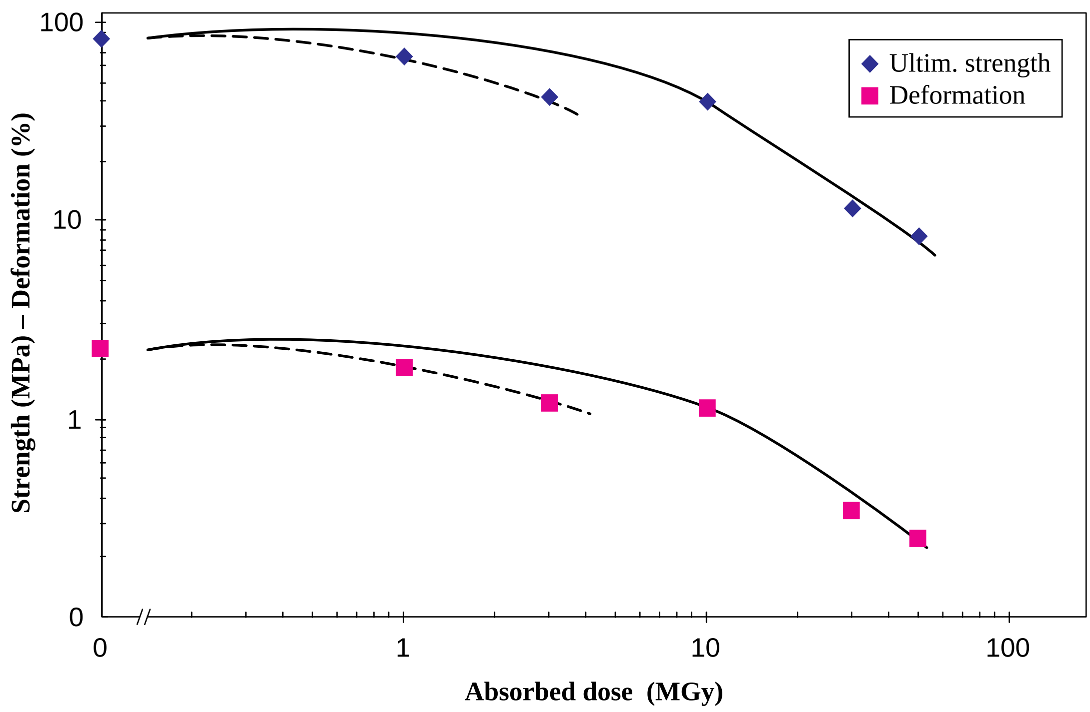
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **84**±19 | **2.24**±0.56 | **3.91**±0.25 |
| **0.1** | **1** | **69**±15 | **1.82**±0.35 | **3.87**±0.04 |
| **1** | **3** | **43**±8 | **1.21**±0.23 | **3.74**±0.11 |
| **220** | **10** | **41**±9 | **1.16**±0.24 | **3.64**±0.08 |
| **220** | **30** | **12**±2 | **0.34**±0.05 | **3.78**±0.23 |
| **220** | **50** | **9**±3 | **0.25**±0.08 | **3.6**±0.4 |

Critical property = flexural strength

Radiation index (RI) = 6.9 at a mean dose rate of 220 kGy/h

Radiation index (RI) = 6.5 at a mean dose rate of 1000 Gy/h

### Radiation effect on Epoxy R 466




Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Epoxy MY 790 + HY 1102 BD** | TIS No. **R 467** |
| Type | **= R 466 + Mica + glass fibres** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | via Elin Union | LOI: |
| | This resin is used for the AA magnets | |

### Radiation test results according to IEC Standard 544 (and ISO 178)

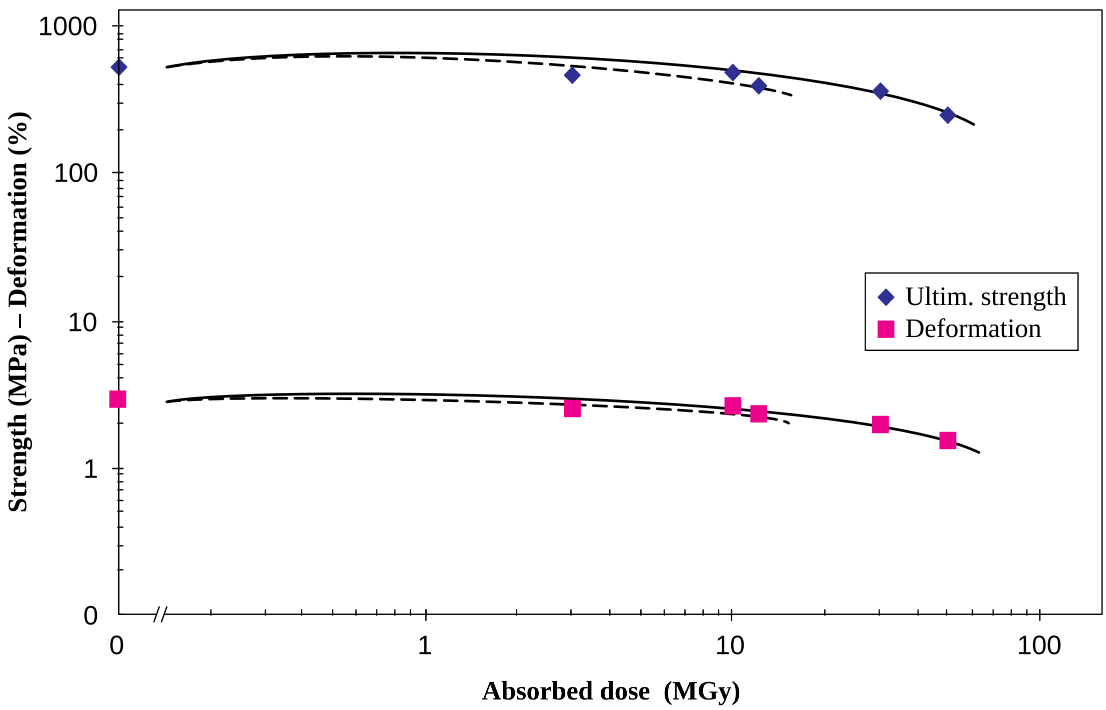
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **545**±9 | **2.87**±0.08 | **23.0**±0.1 |
| **1** | **3** | **463**±28 | **2.54**±0.08 | **21.8**±1.5 |
| **220** | **10** | **490**±35 | **2.7**±0.1 | **22.0**±1.5 |
| **1** | **12** | **398**±31 | **2.42**±0.04 | **20.9**±1.2 |
| **220** | **30** | **371**±19 | **2.0**±0.1 | **22.7**±1.1 |
| **220** | **50** | **250**±12 | **1.56**±0.35 | **21.6**±1.1 |

Critical property = flexural strength

Radiation index (RI) = 7.6 at a mean dose rate of 220 kGy/h

Radiation index (RI) = 7.4 at a mean dose rate of 1000 Gy/h

### Radiation effect on Epoxy composite R 467




Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Epoxy laminate – prepreg** | TIS No. **R 468** |
| Type | **Isopreg EP spess 0.33** | |
| Supplier: | **Isovolta** | UL 94: n.m. |
| Remarks: | Used by Ansaldo for LEP dipoles | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

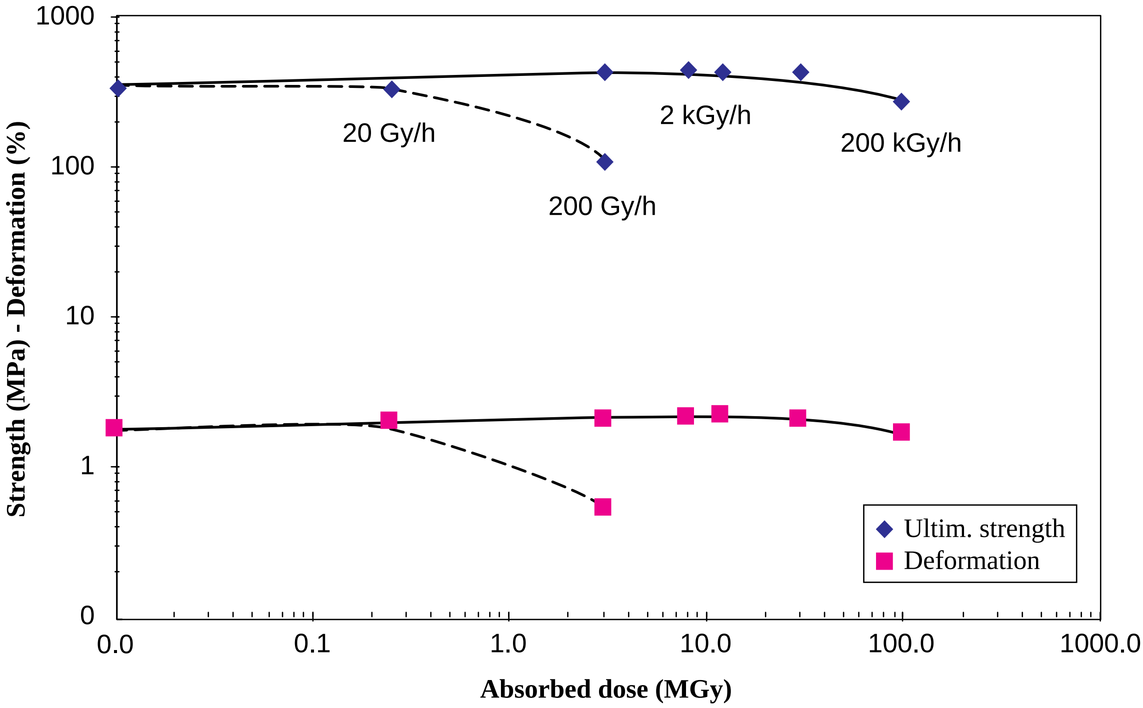
| Dose rate (kGy/h) | Dose (MGy) | Irradiation Conditions | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|---|
| **0** | **0** | | **355**±28 | **1.79**±0.05 | **22.6**±2.3 |
| **0.02** | **0.25** | LEP | **331**±16 | **1.99**±0.03 | **22.6**±1.1 |
| **0.20** | **3** | LEP | **115**±28 | **0.54**±0.15 | **18.4**±1.0 |
| **2** | **3** | Co-60 | **432**±21 | **2.09**±0.05 | **22.9**±0.4 |
| **220** | **8** | reactor | **446**±25 | **2.11**±0.02 | **23.6**±1.4 |
| **2** | **12** | Co-60 | **426**±34 | **2.18**±0.05 | **20.8**±2.2 |
| **200** | **30** | reactor | **420**±25 | **2.03**±0.04 | **23.3**±1.6 |
| **200** | **100** | reactor | **281**±9 | **1.72**±0.08 | **18.4**±0.7 |

Critical property = flexural strength

Radiation index (RI) = > 8 at a mean dose rate of 200 kGy/h

Radiation index (RI) = 6.2 at a mean dose rate of 200 Gy/h

**Radiation effect on Isopreg R 468**




Comment: Low-dose rate irradiations — dotted lines — correspond to life irradiation in LEP.

| | | |
|---|---|---|
| Material: | **Epoxy moulding compound** | TIS No. **R 502** |
| Type | **R112 + H 232** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | via L.E. Pink | LOI: |

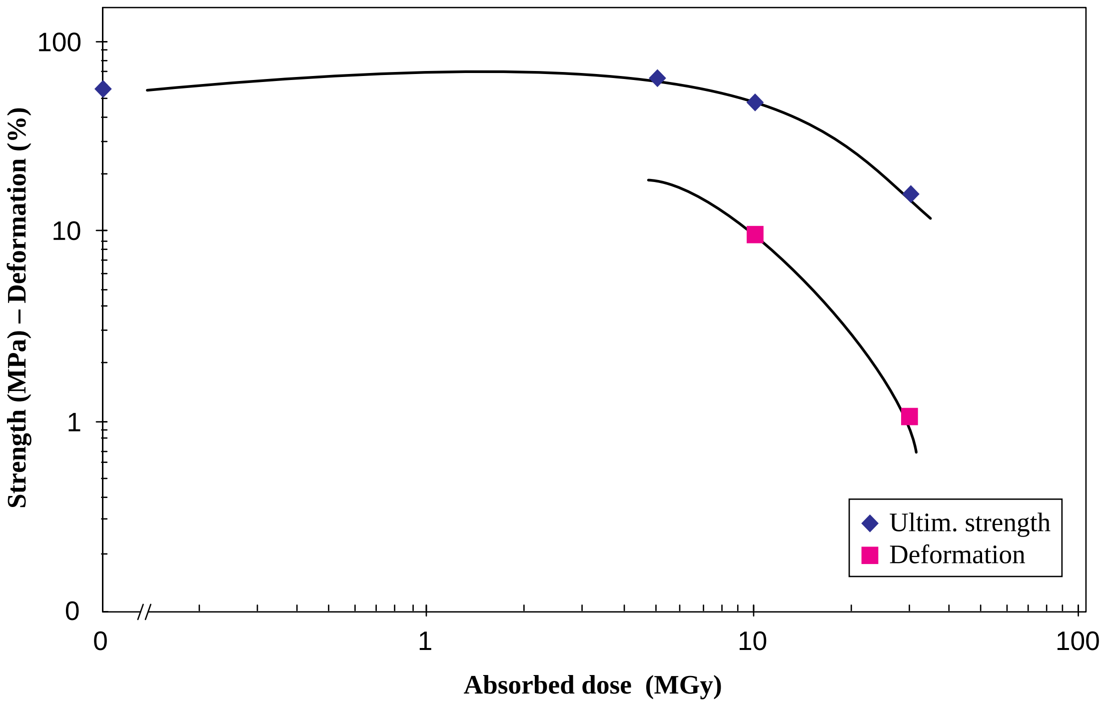
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **57.6**±1.8 | > **12** | **1.57**±0.05 |
| **4** | **5** | **64.7**±3 | > **12** | **1.8**±0.1 |
| **220** | **10** | **49.4**±9.4 | **9.87**±4.36 | **1.49**±0.37 |
| **220** | **30** | **16.2**±4.7 | **1.07**±0.36 | **1.58**±0.15 |

Critical property = deformation

Radiation index (RI) = ~ 7.1 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 502**



| | | |
|---|---|---|
| Material: | **Epoxy laminate + glass** | TIS No. **R 506** |
| Type | **ACO 1 + GLASS A** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | via Ansaldo<br>VPI product | LOI: |

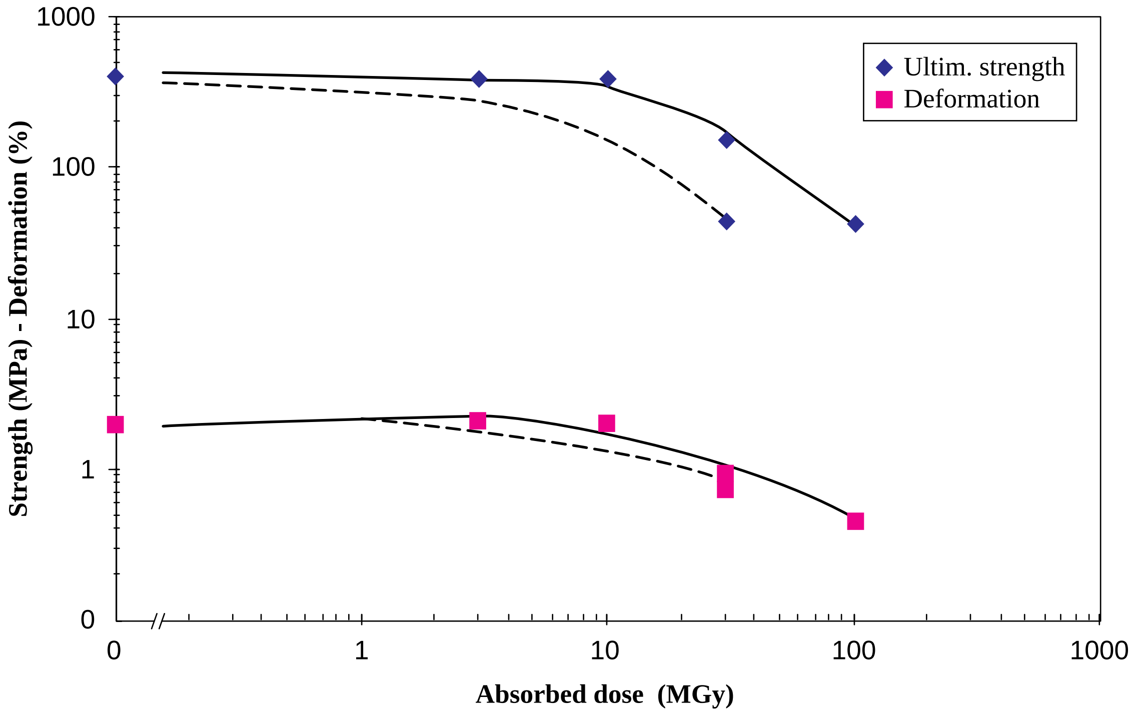
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **408**±15 | **1.96**±0.04 | **23**±1.1 |
| **220** | **3** | **388**±11 | **2.06**±0.24 | **23**±0.9 |
| **220** | **10** | **393**±13 | **2.02**±0.07 | **24**±0.9 |
| **250** | **30** | **154**±8 | **0.92**±0.03 | **21.2**±2.1 |
| **10** | **30.4** | **44**±4 | **0.73**±0.04 | **6.8**±0.4 |
| **220** | **100** | **43**±11 | **0.45**±0.07 | **12.6**±3.4 |

Critical property = flexural strength

Radiation index (RI) = 7.3 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 506**




Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Epoxy laminate + glass** | TIS No. **R 507** |
| Type | **ACO 2 + GLASS A** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | via Ansaldo | LOI: |
| | VPI product | |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

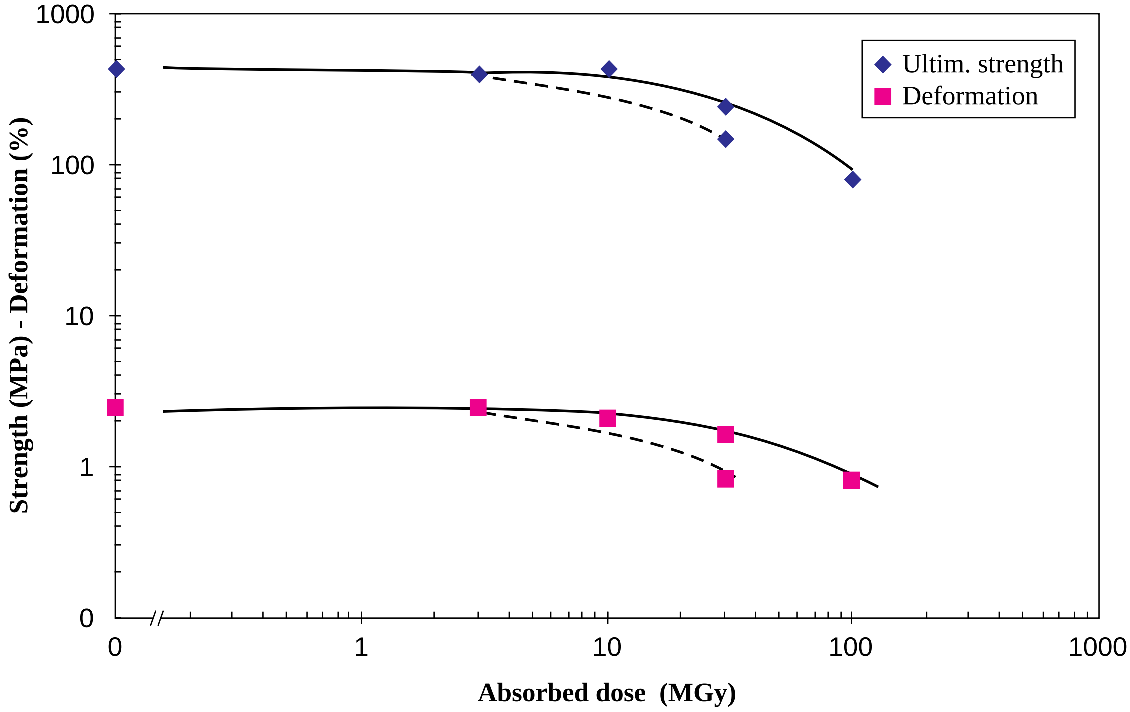
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **431**±25 | **2.47**±0.12 | **22.1**±1.78 |
| **220** | **3** | **409**±18 | **2.50**±0.24 | **21.2**±1.78 |
| **220** | **10** | **431**±10 | **2.11**±0.13 | **23.4**±1.16 |
| **220** | **30** | **243**±23 | **1.66**±0.13 | **19.5**±2.07 |
| **10** | **30.4** | **150**±14 | **0.87**±0.17 | **18.9**±1.92 |
| **220** | **100** | **80**±16 | **0.81**±0.10 | **15**±3.03 |

Critical property = flexural strength

Radiation index (RI) = 7.4 at a mean dose rate of 220 kGy/h

Radiation index (RI) = 7.0 at a mean dose rate of 10 kGy/h

**Radiation effect on insulating resin R 507**




Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Epoxy laminate + glass** | TIS No. **R 508** |
| Type | **ACO 1+ GLASS B** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | via Ansaldo<br>VPI product | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

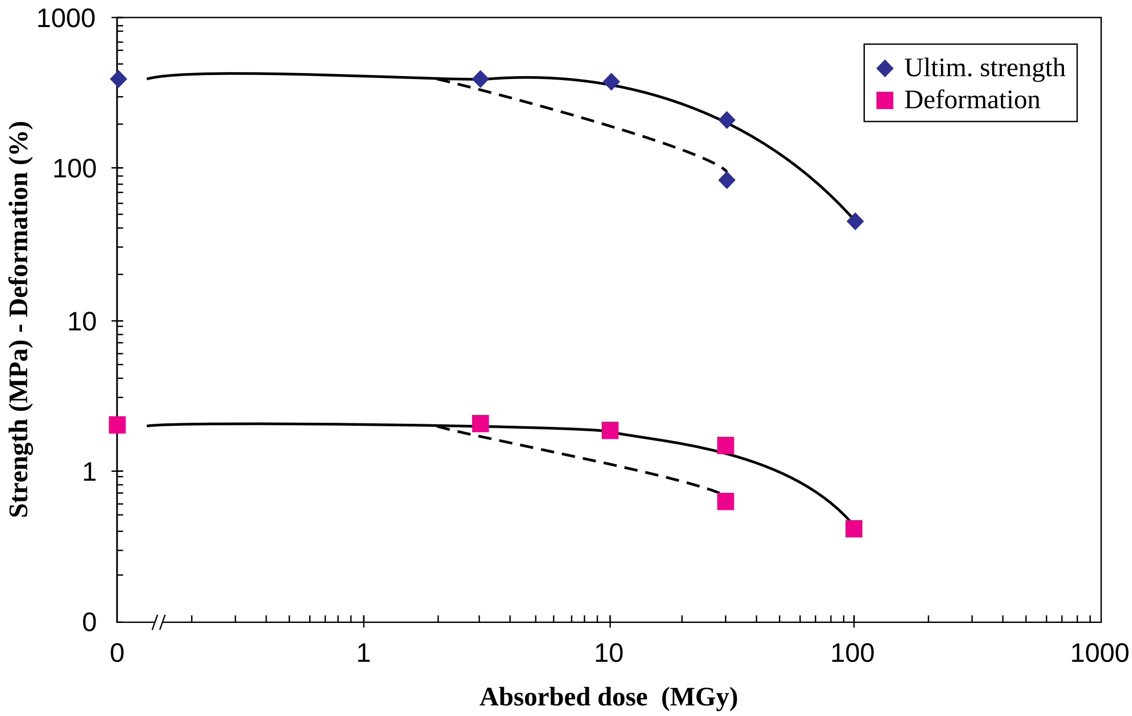
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **405**±13.8 | **2.05**±0.10 | **23.1**±0.7 |
| **220** | **3** | **406**±19.9 | **2.06**±0.22 | **23.0**±0.9 |
| **220** | **10** | **383**±20.2 | **1.83**±0.12 | **23.3**±0.9 |
| **220** | **30** | **213**±11.8 | **1.52**±0.15 | **19.8**±0.7 |
| **10** | **30** | **87**±3.1 | **0.61**±0.08 | **15.6**±0.6 |
| **220** | **100** | **46**±9.0 | **0.41**±0.06 | **13.6**±1.9 |

Critical property = flexural strength

Radiation index (RI) = 7.5 at a mean dose rate of 220 kGy/h

Radiation index (RI) = 6.2 at a mean dose rate of 10 kGy/h

**Radiation effect on insulating resin R 508**




Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Epoxy laminate + glass** | TIS No. **R 509** |
| Type | **ACO 2+ GLASS B** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | via Ansaldo<br>VPI product | LOI: |

## Radiation test results according to IEC Standard 544 (and ISO 178)

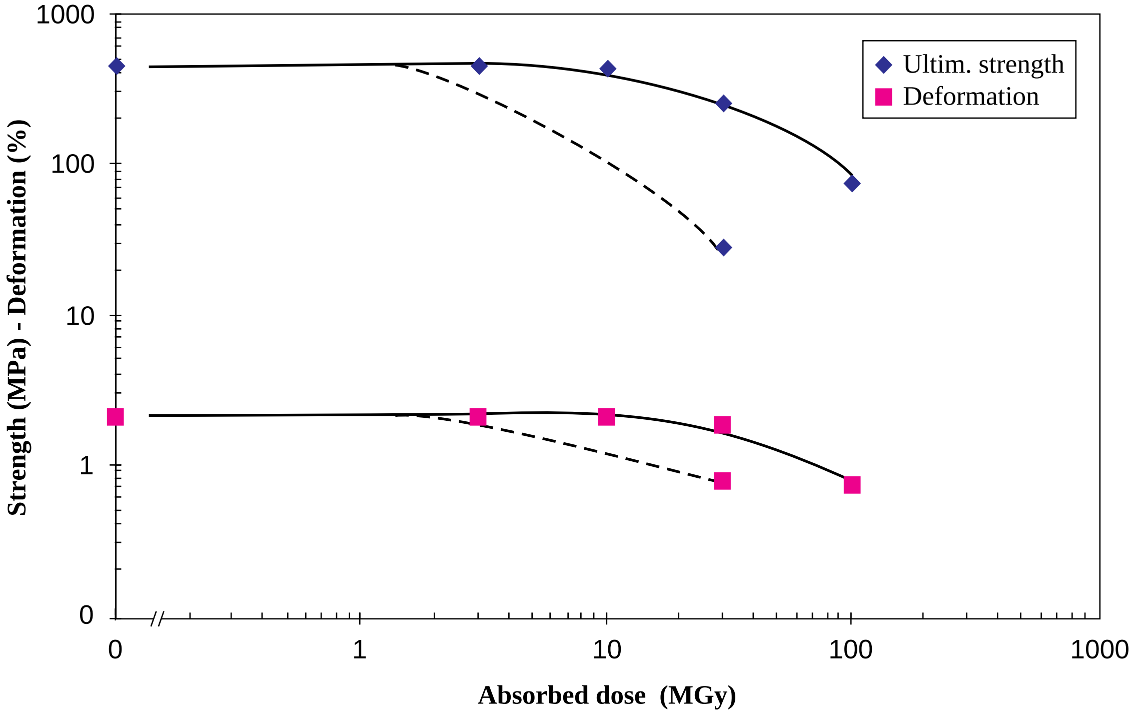
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **459**±28 | **2.06**±0.13 | **24.1**±1.6 |
| **220** | **3** | **465**±19 | **2.09**±0.15 | **24.4**±0.5 |
| **220** | **10** | **439**±29 | **2.09**±0.06 | **25.8**±0.9 |
| **220** | **30** | **258**±7 | **1.84**±0.06 | **18.8**±0.7 |
| **10** | **30.4** | **28.2**±0.4 | **0.77**±0.08 | **19.1**±0.3 |
| **220** | **100** | **74.4**±5 | **0.75**±0.10 | **14.3**±1.3 |

Critical property = flexural strength

Radiation index (RI) = 7.6 at a mean dose rate of 220 kGy/h

Radiation index (RI) = 6 at a mean dose rate of 10 kGy/h

**Radiation effect on insulating resin R 509**




Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Epoxy** | TIS No. **R 511** |
| Type | **Scotchcast 9** | |
| Supplier: | **3M** | UL 94: n.m. |
| Remarks: | mid-flexibility (cold) | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

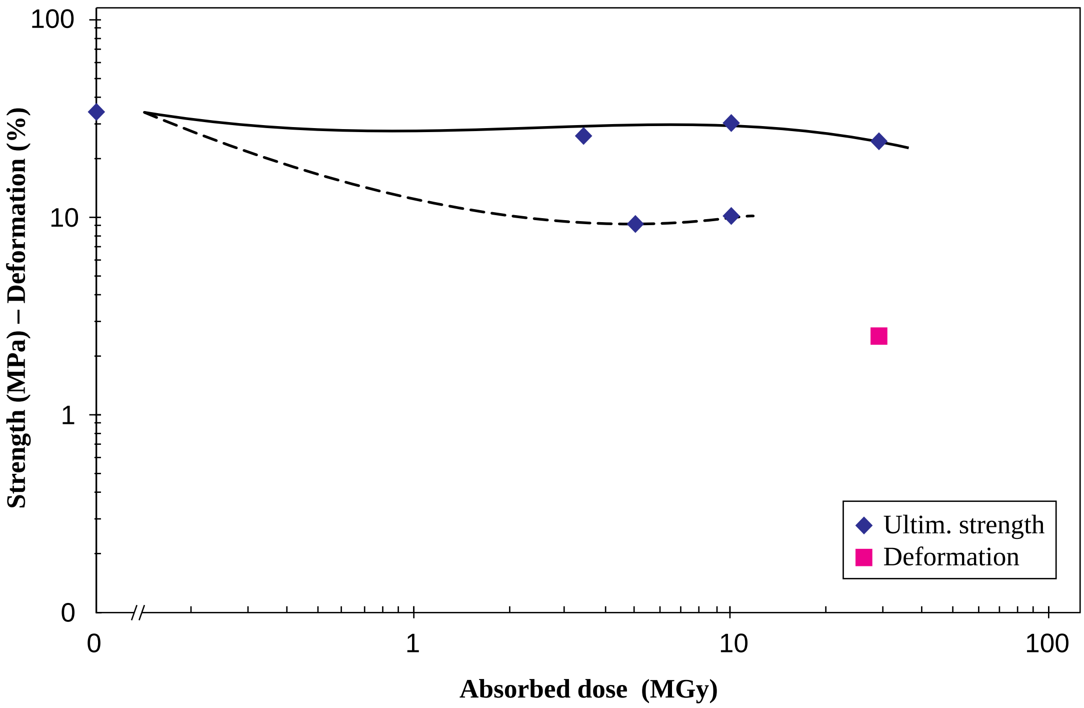
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **34.3**±3.7 | > **12** | **1.5**±0.2 |
| **200** | **3.4** | **26.4**±3.2 | > **12** | **1.5**±0.1 |
| **3** | **5** | **9.5**±2.1 | > **12** | **0.7**±0.1 |
| **3** | **10** | **10.4**±1.1 | > **12** | **1.0**±0.1 |
| **200** | **10** | **31.1**±4.7 | > **12** | **1.9**±0.1 |
| **200** | **29** | **24.6**±3.5 | **2.52**±1.84 | **2.1**±0.5 |

Critical property = deformation for short term and flexural strength for long term

Radiation index (RI) =7 at a mean dose rate of 200 kGy/h

Radiation index (RI) = 6 at a mean dose rate of 3000 Gy/h

**Radiation effect on Epoxy R 511**




Comment: Dotted line corresponds to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Epoxy** | TIS No. **R 512** |
| Type | **Scotchcast 281** | |
| Supplier: | **3M** | UL 94: n.m. |
| Remarks: | mid-flexibility (cold) | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

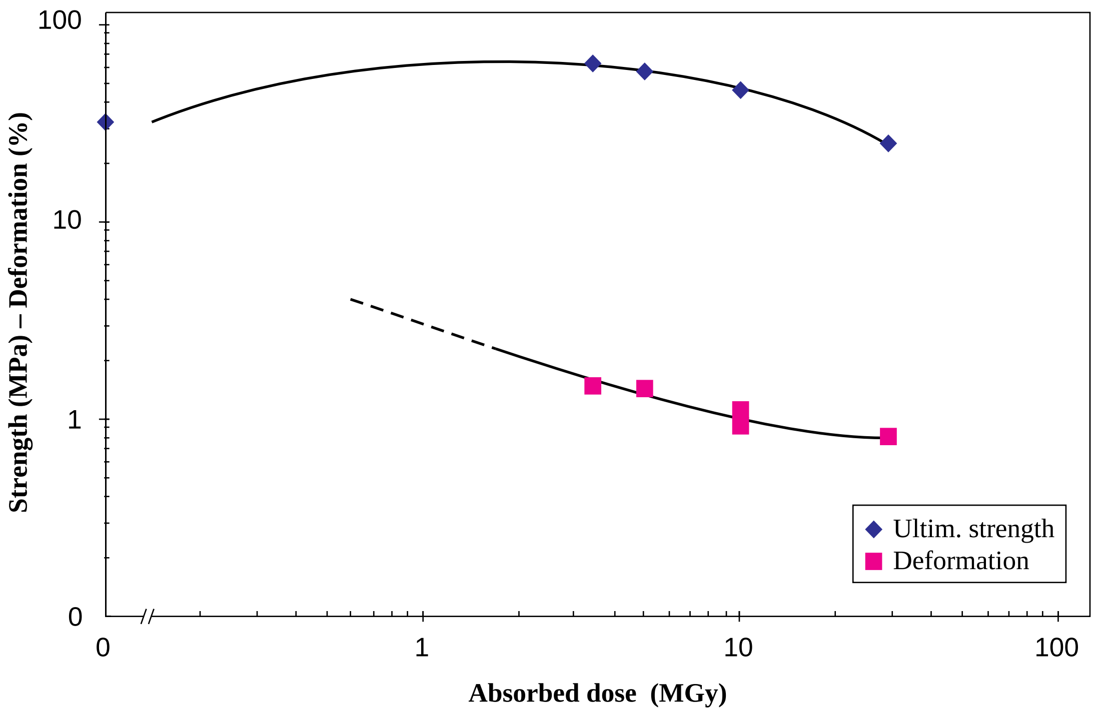
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **32.9**±0.6 | **>12** | **2.3**±0.1 |
| **200** | **3.4** | **65.2**±3.4 | **1.5**±0.1 | **5.2**±0.2 |
| **3** | **5** | **58.0**±4.4 | **1.5**±0.2 | **4.7**±0.3 |
| **3** | **10** | **47.4**±7.9 | **1.2**±0.3 | **4.8**±0.1 |
| **200** | **10** | **47.6**±2.6 | **1.0**±0.1 | **5.5**±0.1 |
| **200** | **29** | **25.3**±5.8 | **0.8**±0.2 | **4.0**±0.2 |

Critical property = deformation

Radiation index (RI) = < 6.5 at a mean dose rate of 200 kGy/h

Radiation index (RI) = < 6.5 at a mean dose rate of 3000 Gy/h

**Radiation effect on Epoxy R 512**



| | | |
|---|---|---|
| Material: | **Epoxy** | TIS No. **R 514** |
| Type | **Scotchcast 804** | |
| Supplier: | **3M** | UL 94: n.m. |
| Remarks: | rigid (cold)<br>contains chlorine | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

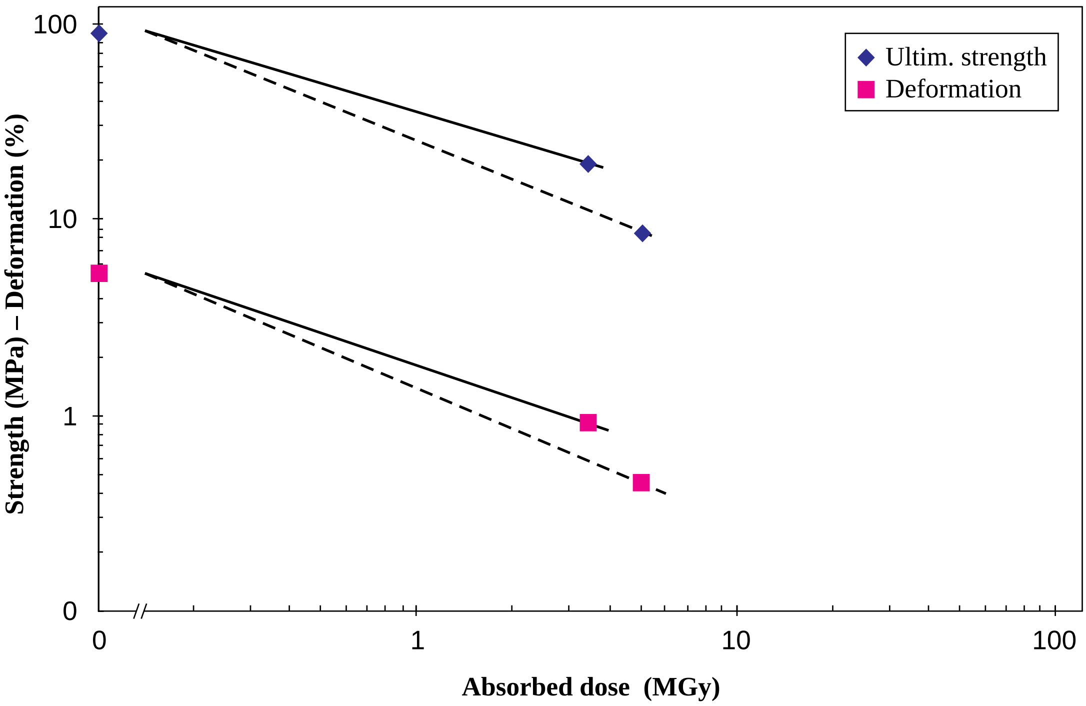
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **90.5**±9.6 | **5.4**±1.5 | **2.4**±0.1 |
| **200** | **3.4** | **19.6**±0.3 | **0.9**±0.3 | **2.3**±0.8 |
| **3** | **5** | **8.5**±0.1 | **0.5**±0.1 | **1.9**±0.1 |

Critical property = flexural strength

Radiation index (RI) < 6.5 at a mean dose rate of 200 kGy/h

Radiation index (RI) < 6.7 at a mean dose rate of 3000 Gy/h

**Radiation effect on Epoxy R 514**




Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Epoxy** | TIS No. **R 515** |
| Type | **Scotchcast 824** | |
| Supplier: | **3M** | UL 94: n.m. |
| Remarks: | rigid (cold) | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

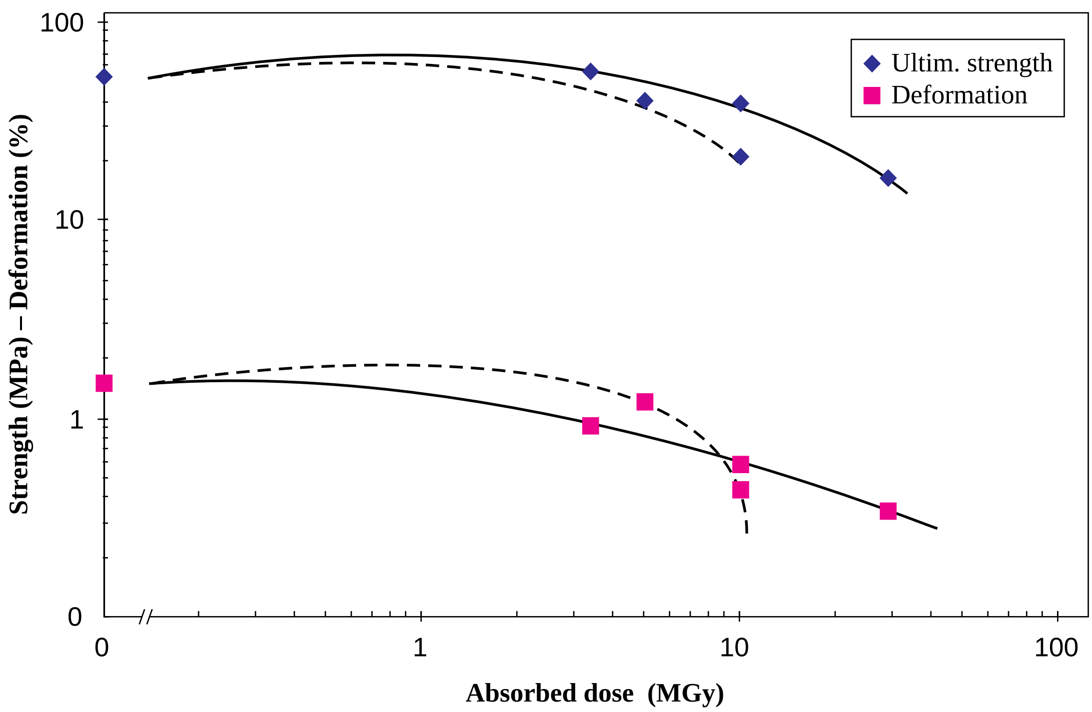
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **54.6**±3.1 | **1.53**±0.11 | **5.6**±0.6 |
| **200** | **3.4** | **57.5**±2.2 | **0.94**±0.03 | **7.5**±0.4 |
| **3** | **5** | **41.0**±3.4 | **1.2**±0.1 | **5.0**±0.3 |
| **3** | **10** | **21.5**±2.7 | **0.44**±0.03 | **6.0**±0.4 |
| **200** | **10** | **39.3**±10.6 | **0.6**±0.2 | **8.2**±0.6 |
| **200** | **29** | **16.6**±5.2 | **0.3**±0.1 | **6.7**±0.8 |

Critical property = deformation

Radiation index (RI) = 6.8 at a mean dose rate of 200 kGy/h

Radiation index (RI) = 6.8 at a mean dose rate of 3000 Gy/h

**Radiation effect on Epoxy R 515**




Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Epoxy A + glass + Kevlar** | TIS No. **R 525** |
| Type | **Novolac resin + fibres** | |
| Supplier: | **Isovolta** | UL 94: n.m. |
| Remarks: | prepreg for LHC magnets for coil insulation | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

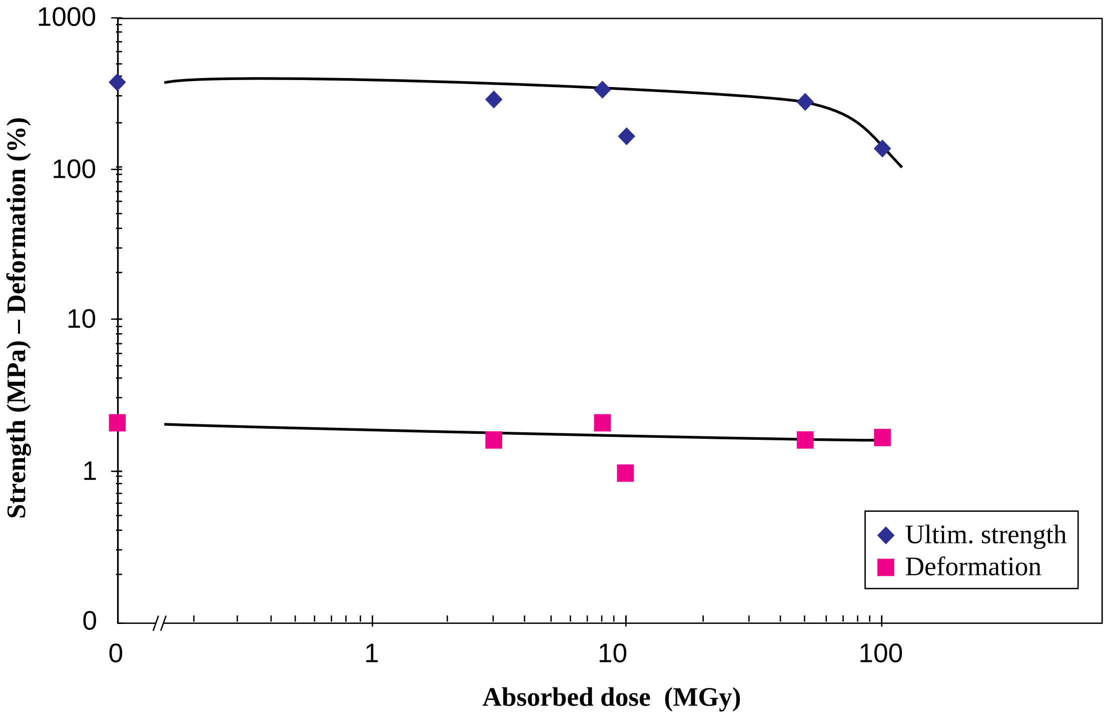
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **377**±9 | **2.05**±0.02 | **33.3**±1.4 |
| **240** | **3** | **289**±8 | **1.62**±0.07 | **30.3**±0.8 |
| **1** | **8** | **337**±19 | **2.05**±0.21 | **29.4**±0.9 |
| **210** | **10** | **169**±21 | **0.95**±0.11 | **27.1**±2.4 |
| **210** | **50** | **280**±5 | **1.58**±0.06 | **29.0**±1.0 |
| **220** | **100** | **139**±42 | **1.68**±1.92 | **26.3**±3.9 |

Critical property = flexural strength

Radiation index (RI) = 6.9 at a mean dose rate of 210 kGy/h

Radiation index (RI) > 6.9 at a mean dose rate of 1000 Gy/h

**Radiation effect on Epoxy R 525**



| | | |
|---|---|---|
| Material: | **Epoxy resin** | TIS No. **R 539** |
| Type | **Vetronite** | |
| Supplier: | **Von Roll Isola** | UL 94: n.m. |
| Remarks: | grade tube 64770 | LOI: |

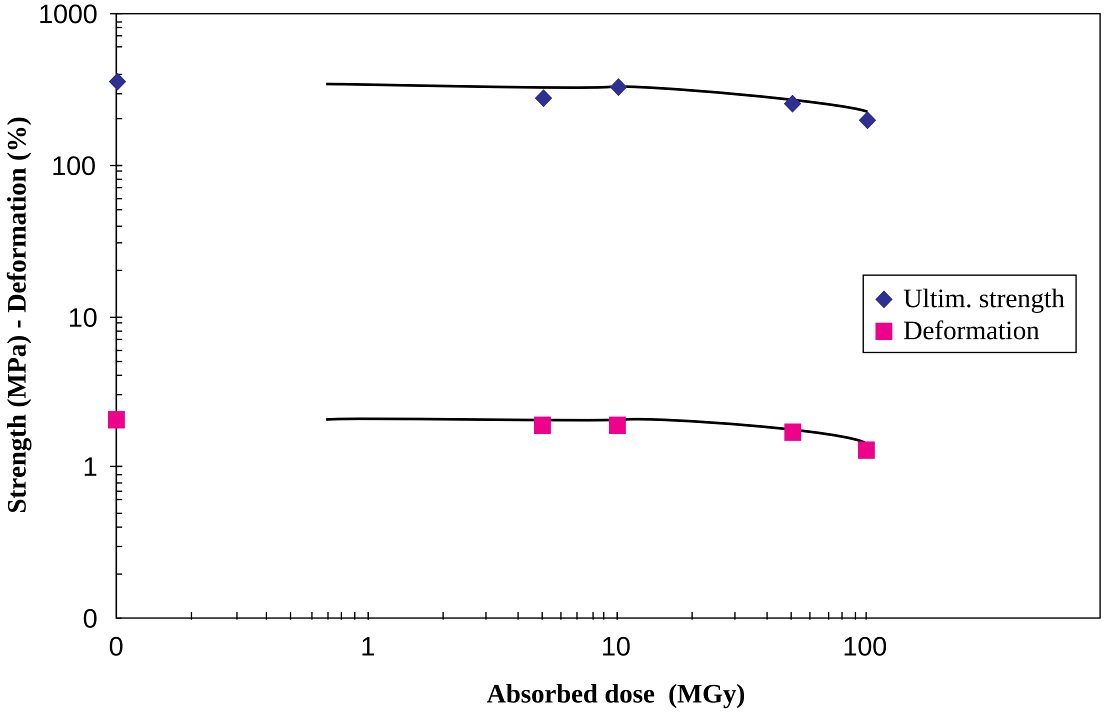
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **363**±33 | **2.10**±0.09 | **20.9**±1.3 |
| **220** | **5** | **280**±8 | **1.92**±0.06 | **18.7**±1.4 |
| **220** | **10** | **342**±20 | **1.90**±0.10 | **21.9**±0.3 |
| **230** | **50** | **264**±8 | **1.77**±0.08 | **20.1**±0.8 |
| **230** | **100** | **206**±20 | **1.31**±0.07 | **19.9**±1.3 |

Critical property = flexural strength

Radiation index (RI) > 7.7 at a mean dose rate of 220 kGy/h

**Radiation effect on Epoxy Vetronite  R 539**



| | | |
|---|---|---|
| Material: | **Epoxy resin + mineral filler + glass mica + Dacron** | TIS No. **R 540** |
| Type | **Samicatherm** | |
| Supplier: | **Ansaldo** | UL 94: n.m. |
| Remarks: | conductor insulation for the LHC dump | LOI: |

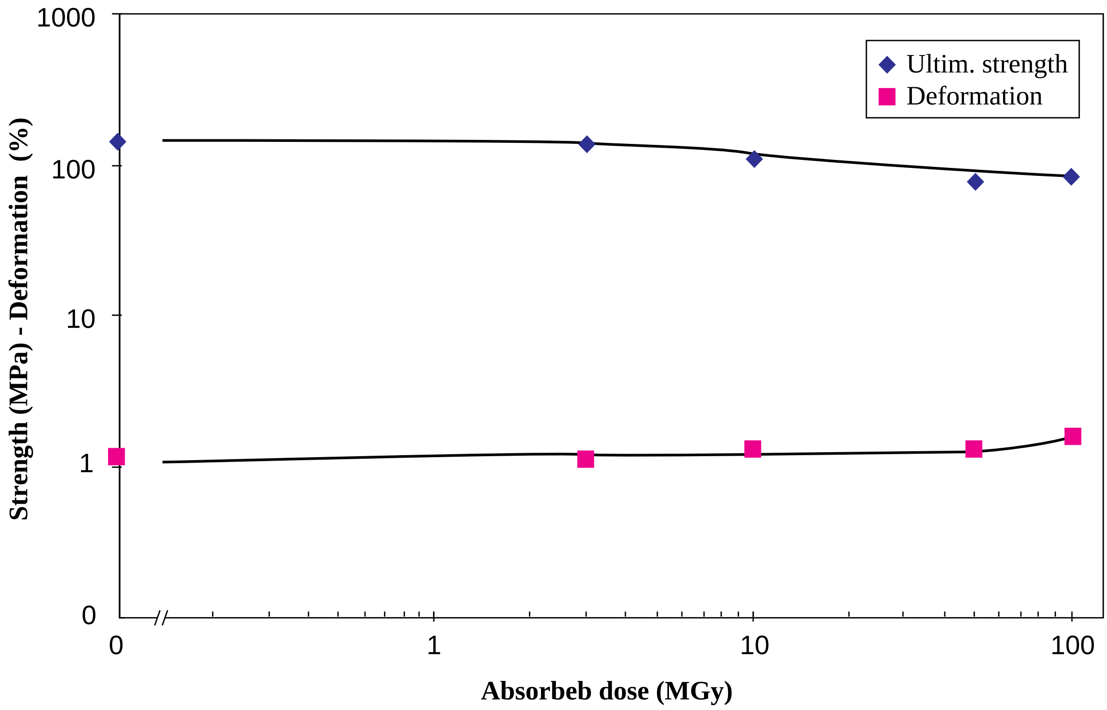
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **143**±14.5 | **1.14**±0.12 | **19.8**±3.1 |
| **220** | **3** | **141**±8.7 | **1.09**±0.09 | **20.2**±1.7 |
| **220** | **10** | **108**±15.9 | **1.28**±0.20 | **14.5**±3.3 |
| **220** | **50** | **76**±18.2 | **1.26**±0.13 | **8**±2 |
| **220** | **100** | **84**±7.5 | **1.55**±0.27 | **7**±2 |

Critical property = Modulus

Radiation index (RI) = 7.6 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 540**



| | | |
|---|---|---|
| Material: | **Epoxy resin** | TIS No. **R 541** |
| Type | **XNR 4153/XNH 4153** | |
| Supplier: | **Ciba-Geigy (Japan)** | UL 94: n.m. |
| Remarks: | via Ansaldo | LOI: |

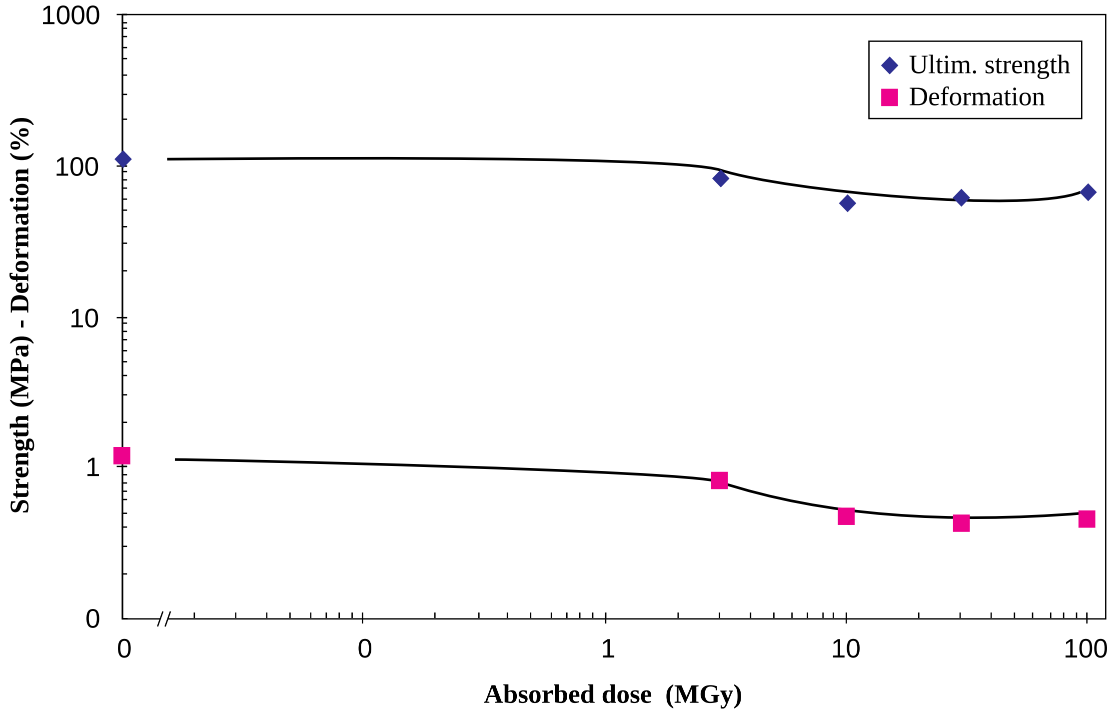
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **112**±3 | **1.18**±0.07 | **11.3**±0.3 |
| **220** | **3** | **84**±3 | **0.81**±0.04 | **11.6**±0.5 |
| **220** | **10** | **57**±3 | **0.48**±0.03 | **13.0**±0.6 |
| **230** | **30** | **61**±2 | **0.44**±0.01 | **15.9**±0.9 |
| **220** | **100** | **67**±2 | **0.46**±0.01 | **15.5**±0.8 |

Critical property = Deformation at break

Radiation index (RI) = 6.9 at a mean dose rate of 220 kGy/h

**Radiation effect on Epoxy 4153  R 541**



| | | |
|---|---|---|
| Material: | **Epoxy resin** | TIS No. **R 554** |
| Type | **AS/37-3** | |
| Supplier: | **Ciba-Geigy** | UL 94: n.m. |
| Remarks: | | DATE: Nov-97 |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

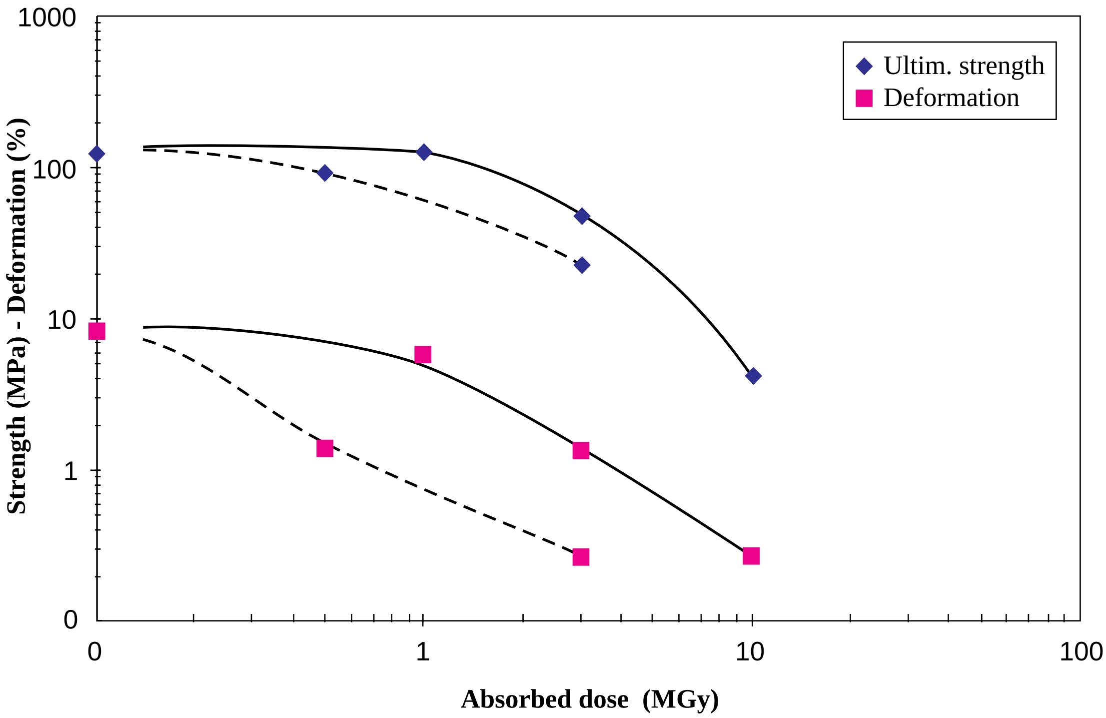
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **126**±2.2 | **8.35**±0.42 | **2.88**±0.09 |
| **4** | **0.5** | **93**±19.4 | **1.38**±0.44 | **7.79**±0.17 |
| **230** | **1** | **126**±4.1 | **5.82**±0.69 | **3.29**±0.05 |
| **230** | **3** | **48**±10.1 | **1.33**±0.28 | **3.82**±0.13 |
| **0.5** | **3** | **22**+6.3 | **0.26**+0.08 | **8.92**+0.63 |
| **230** | **10** | **4**± | **0.26**± | **4.30**± |

Critical property = deformation

Radiation index (RI) ~ 6.1 at a mean dose rate of 230 kGy/h

Radiation index (RI) < 5.7 at a mean dose rate of 4 kGy/h

**Radiation effect on Epoxy resin - R554**




Comments: At 10 MGy, one sample was tested, the four others were broken before test.
Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Epoxy moulding compound** | TIS No. **R 557** |
| Type | **Matramid 5292 A/B (M 5.500/1)** | |
| Supplier: | **Ciba-Geigy** | UL 94: |
| Remarks: | | LOI: |

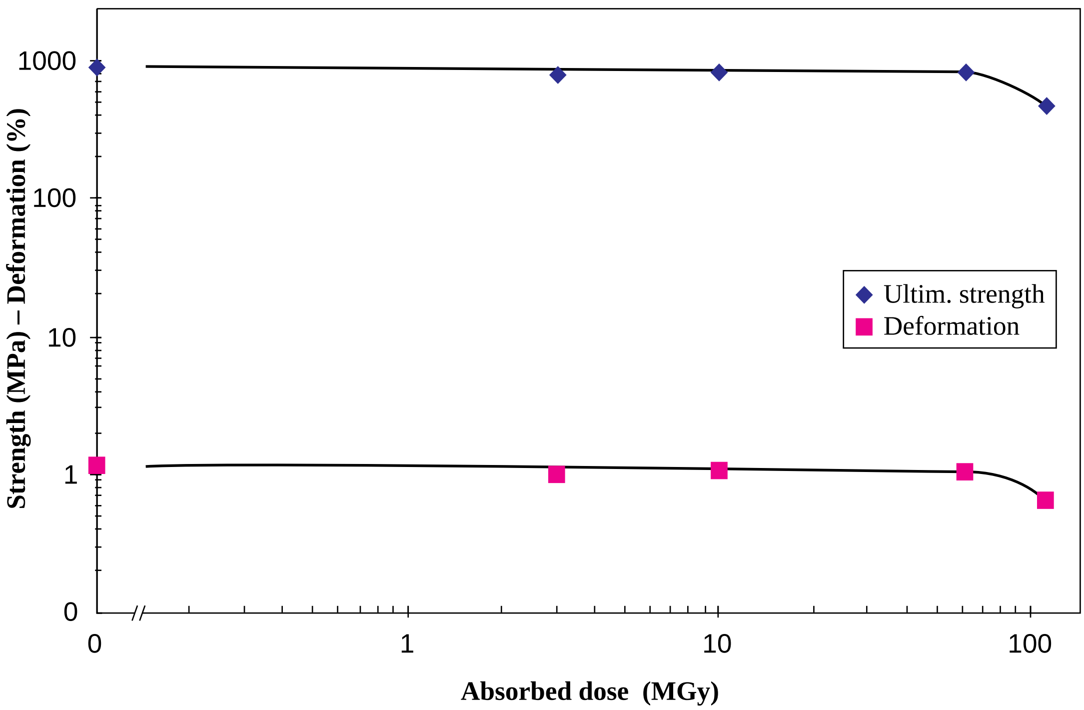
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **165**±3 | **6.27**±0.3 | **3.9**±0.06 |
| **6** | **1** | **152**±24 | **5.32**±1.4 | **3.9**±0.03 |
| **230** | **3** | **159**±8 | **5.83**±0.67 | **4.0**±0.04 |
| **230** | **10** | **152**±16 | **5.61**±0.97 | **4.0**±0.17 |
| **180** | **50** | **109**±21 | **2.80**±0.6 | **4.1**±0.19 |

Critical property = deformation

Radiation index (RI) = 7.6 at a mean dose rate of 180 kGy/h

**Radiation effect on Epoxy R 557**



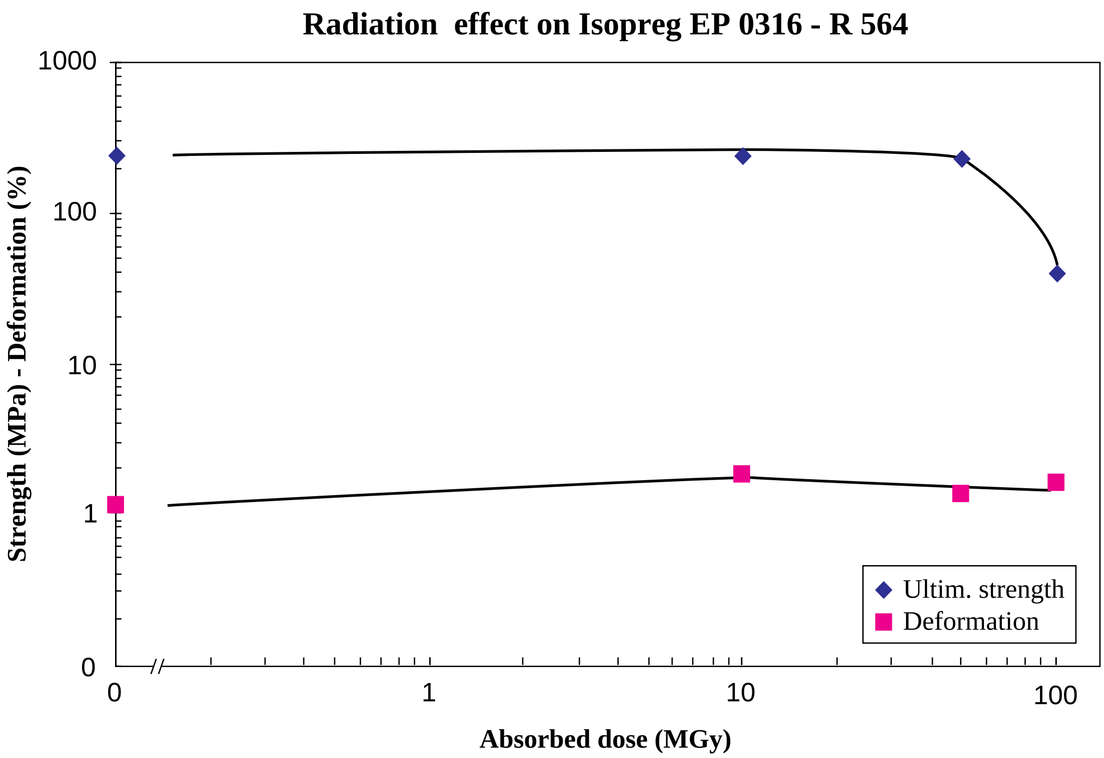
| | | |
|---|---|---|
| Material: | **Epoxy laminate** | TIS No. **R 564** |
| Type | **ISOPREG EP 0316** | |
| Supplier: | **ISOVOLTA AG** | UL 94: n.m. |
| Remarks: | | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **239**±61 | **1.14**±0.35 | ± |
| **220** | **10** | **243**±92 | **1.84**±0.91 | ± |
| **220** | **50** | **234**±69 | **1.39**±0.64 | ± |
| **220** | **100** | **40**±6 | **1.60**±1.15 | ± |

Critical property = flexural strength

Radiation index (RI) = 7.8 at a mean dose rate of 220 kGy/h




Comment: Tests carried out at the Österreichisches Forschungzentrum Seibersdorf.

| | | |
|---|---|---|
| Material: | **Epoxy laminate** | TIS No. **R 565** |
| Type | **ISOPREG EP 1037/IDT** | |
| Supplier: | **ISOVOLTA AG** | UL 94: n.m. |
| Remarks: | | LOI: |

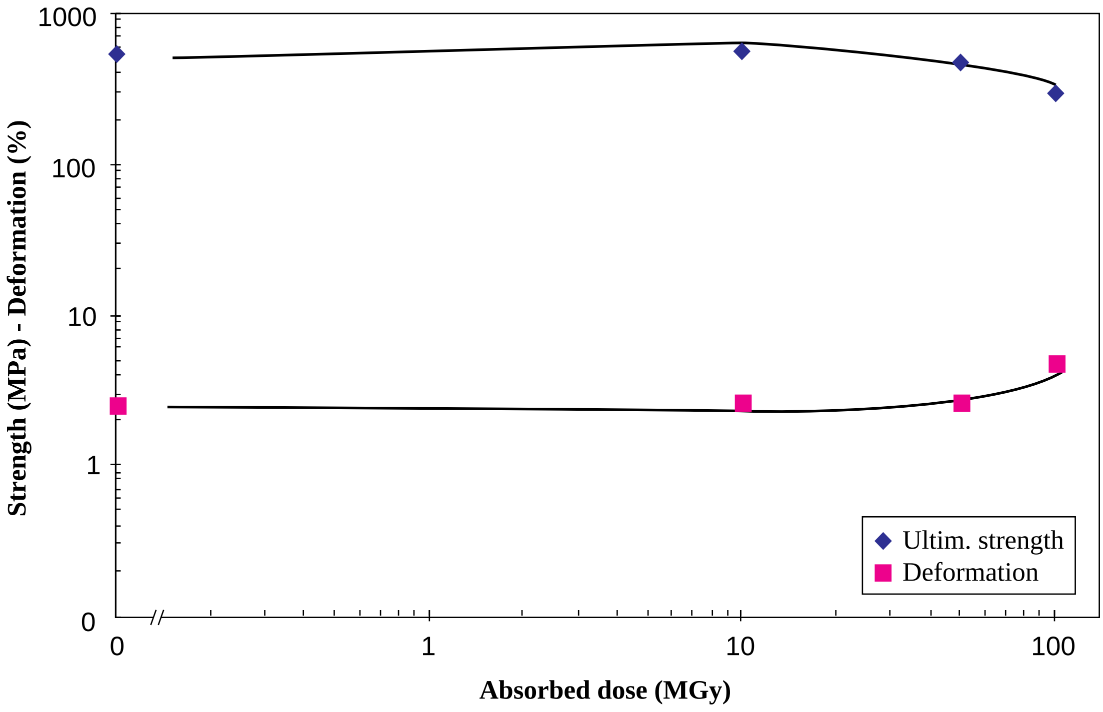
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **552**±6 | **2.46**±0.04 | **30.3**±0.7 |
| **220** | **10** | **561**±7 | **2.54**±0.11 | **30.5**±0.6 |
| **220** | **50** | **479**±9 | **2.61**±0.05 | **32.1**±0.2 |
| **220** | **100** | **306**±8 | **4.64**±0.39 | **29.8**±1.4 |

Critical property = flexural strength

Radiation index (RI) > 8 at a mean dose rate of 220 kGy/h

**Radiation effect on Isopreg EP 1037 - R 565**




Comment: Tests carried out at the Österreichisches Forschungzentrum Seibersdorf.

# F

| | |
|---|---|
| Fibredux | trade name of CIBA-GEIGY for carbon fibre reinforced epoxy laminate, see CFRP |

G-Etronax trade name of Elektro-Isola for glass-reinforced epoxy resins

GFRP glass fibre reinforced plastics; for behaviour under cryogenic irradiation, see Ref. [35]

Araldite + glass fibres, see Araldite
Epoxy + glass fibres, see Epoxy
Epoxy laminates, see Epoxy
Epoxy prepreg, see Epoxy
Polyamides + glass fibres, see PA
Polyesters + glass fibres, see Polyester
Polyetherimide + glass fibres, see PEI
Polyphenylsulfone + glass fibres, see PPS

# I

| | |
|---|---|
| Isaryl | trade name of Isonova for polyarylate (PAr), see polyarylate |
| Isopreg | trade name of Isovolta for epoxy pre-impregnated glass mat, see epoxy resin |
| Isoval | trade name of Isovolta for glass reinforced epoxy resin, see Ref. [25]; RI $\cong$ 7 |
| Ixef | trade name of Solvay for polyarylamide (PAA), see polyarylamide |

# K

| | |
|---|---|
| Kerimid | trade name of Rhône-Poulenc for polyimide (PI), see Ref. [25]; RI = 7.8 |
| Kevlar | trade name of Dupont for para-aramid fibres; RI ≃ 7 |
| Kinel | trade name of Rhône-Poulenc for polyimide (PI), see Ref. [25]; RI = 7.9 |

# L

| | |
|---|---|
| Laminates | see CFRP, GFRP, epoxy and other corresponding Polymers |
| Lexan | trade name of General Electric Plastics for polycarbonates (PC) |

Liquid Crystal Polymer (LCP)

## List of materials classified under letter L

| TIS number | Material name | Type | Mechanical properties | | | |
|---|---|---|---|---|---|---|
| | | | UTS (MPa) | Deform. (%) | Modulus (MPa) | RI |
| 560 | Liquid crystal polymer + 30% GF | Vectra C130 | 131 | 2 | 8.8 | > 7.7 |

| | | |
|---|---|---|
| Material: | **Liquid Crystal Polymer + 30% GF** | TIS No. **R 560** |
| Type | **Vectra C130** | |
| Supplier: | **Celanese (USA) via Hoechst** | UL 94: n.m. |
| Remarks: | anisotropic material | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

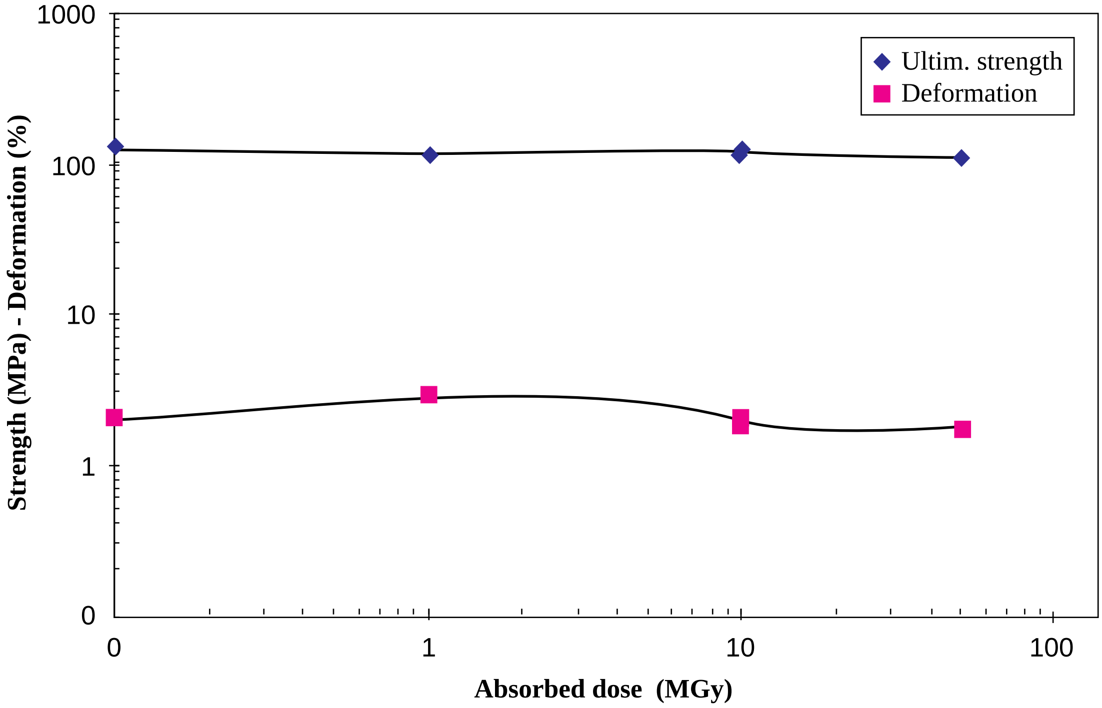
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **131**±13 | **2.0**±0.2 | **8.8**±1.8 |
| **185** | **1** | **118**±36 | **2.9**±1.8 | **7.0**±2.0 |
| **10** | **9.4** | **124**±16 | **2.0**±0.2 | **7.7**±0.9 |
| **190** | **10** | **128**±26 | **2.1**±0.1 | **7.7**±1.6 |
| **230** | **50** | **113**±11 | **1.7**±0.1 | **7.7**±0.7 |

Critical property =

Radiation index (RI) > 7.7 at a mean dose rate of 230 kGy/h

Radiation index (RI) > 7.0 at a mean dose rate of 10 kGy/h

**Radiation effect on Liquid Cristal Polymer R 560**



| | |
|---|---|
| Makrolon | trade name of BAYER for polycarbonates, see polycarbonate |
| Matramid | trade name of CIBA-GEIGY for epoxy moulding compound, see epoxy |
| Micares | trade name of Micafil for polyurethanes, see Ref. [25] and PUR |

# N

| | |
|---|---|
| Neonite | trade name of CIBA-GEIGY epoxy moulding compounds, see epoxy moulding compound |
| Nogentite | trade name of D.F.C. for polyester, see polyester |
| Nomex | trade name of Dupont for meta-aramid fibres, see Ref. [26]; RI ≈ 6.5 |
| Noryl | trade name of General Electric Plastics for PPO based compound, see PPO based compound |
| Novolac | trade name of ISOLA for epoxy resins, see Ref. [25] |
| Nylon | trade name of Dupont for polyamides |

# O

Orlitherm — trade name of BBC Baden for glass fibre reinforced epoxy resins based on DGEBA with MNA, see Ref. [25]; RI > 7.7

# P

Phenolic resin

Plexiglas trade name of Röhm for polyarylates and PMMA

Polyamide (PA)

Polyamide-imide (PAI)

Polyarylamide base thermoplastic (PAA)

Polyaryl ether ketone (PAEK)

Polyarylate (PAr)

Polycarbonate (PC)

Polyester

Polyether-ether-ketone (PEEK); for behaviour under cryogenic irradiation, see Ref. [35]

Polyetherimide (PEI); for behaviour under cryogenic irradiation, see Ref. [35]

Polyethersulfone (PES); for behaviour under cryogenic irradiation, see Ref. [35]

Polyethylene (PE)

Polyethylene therephtalate PETP (for Mylar film, see Ref. [26])

Polyimide (PI)

Polyimide + silicon copolymer (see silicon)

Polymethyl-metacrylate (PMMA)

Polyoximethylene (POM)

Polypenco trade name of Cellpack for cross-linked styrene copolymer, see styrene

Polyphenyl sulfone

Polysulfone (PSu)

Polyurethane (PUR) see also cyanate-ester

Polyphenyl oxide (PPO) based compound

Prepreg see epoxy

## List of materials classified under letter P

| TIS | Material | Type | Mechanical properties | | | |
|---|---|---|---|---|---|---|
| number | name | | UTS (MPa) | Deform. (%) | Modulus (MPa) | RI |
| 375 | Polyphenyl Oxide based plastic | Noryl ENV 125 | 77.6 | > 5 | 2.3 | < 6.5 |
| 416 | Polyurethane | Micares 700 | 95.4 | 3.30 | 5.09 | 7.7 |
| 419 | Polycarbonate | Makrolon 218 | 86.3 | > 10 | 2.30 | 5.7 |
| 435 | Polyester + glass mat | Nogentite NR2-71A | 141 | 2.39 | 6.8 | > 7 |
| 459 | Polyester + glass fibres | Nogentite NZ-3 71E | 96.1 | 1.25 | 11.2 | > 7.5 |
| 464 | Polyphenyl Oxide based plastic | Noryl ENV 509 | 82.8 | > 12 | 2.9 | < 5 |
| 473 | Polyester resin + glass fibres | KK/RI | 93.7 | 2.1 | 12.3 | 7.5 |
| 474 | Polyester resin + glass fibres | KK/530I | 106 | 2.1 | 11 | > 7 |
| 491 | Polyphenyl Oxide based plastic | Univolt HFT | 68.1 | > 6 | 2.59 | 6.7 |
| 499 | Polyester resin + glass mat | Polyester 1 | 215.9 | 3.6 | 5.89 | > 7 |
| 500 | Polyester resin + glass mat | Polyester 2 | 148.1 | 3.77 | 5.3 | > 7 |
| 501 | Polyester resin + glass mat | Polyester 3 | 129.6 | 3.6 | 3.5 | > 7 |
| 503 | Polyoximethylene | Delrin | 98.6 | > 13 | 3.4 | < 5 |
| 504 | Polyetherimide + glass fibres | Ultem 1000 | 288 | 2.83 | 10.5 | > 8 |
| 513 | Polyurethane, polyalcohol | Scotchcast 800 | 114.6 | 6.5 | 3.0 | 6.8 |
| 516 | Polyurethane, polyalcohol | Scotchcast 840 | 0.9 | > 12 | 0.0 | 6.5 |
| 520 | PEEK Natural polyether-ether-ketone | | 176.9 | > 15 | 4.30 | 6.8 |
| 521 | Polyimide | Sintimid | 223.2 | 6.60 | 3.91 | > 6.8 |
| 522 | Polyetherimide + Siloxane | Siltem STM1500 | 25.8 | > 10 | 0.71 | 6.8 |
| 523 | Polyarylamide base thermoplastic | IXEF1002 | 274.1 | 2.71 | 11.30 | 7.5 |
| 524 | Polyarylamide base thermoplastic | IXEF1501 | 271.1 | 2.62 | 11.81 | > 7.5 |
| 526 | Polyamide 4.6 | Ertalon | 125.3 | 5.20 | 5.80 | 6.5 |
| 528 | Polyamide 6 | Ertalon 6PLA | 97.6 | > 15 | 2.50 | 6 |
| 529 | Polyamide PA 6 | Ertalon LFX | 84.4 | > 15 | 2.07 | 6 |
| 530 | Polyamide 6 | Ertalon 6XAU+ | 76.1 | > 15 | 1.84 | 6.5 |
| 531 | PETP | Ertalyte | 134.8 | > 15 | 3.28 | 5.7 |
| 532 | PETP | Ertalyte TX | 119.9 | 6.37 | 3.05 | 8 |
| 533 | Polyetherimide | Erta PEI | 171.0 | > 15 | 3.15 | > 7.7 |
| 534 | Polyethersulfone | Erta PES | 140.7 | > 15 | 2.70 | 6.3 |
| 535 | Polysulfone | Erta PSU | 120.15 | > 15 | 2.59 | 6.5 |
| 536 | Polyamide 6 | Ertalon 6 SA | 63.4 | > 15 | 1.38 | ~ 7 |
| 537 | Polyamide 66 | Ertalon 66SA | 101.6 | > 15 | 2.4 | 6.5 |
| 542 | Polyarylate | Isaryl 15M | 110.4 | > 12 | 2.40 | 6.3 |
| 563 | Polyaryl ether ketone | Stilan/Ultrapek | 153.0 | > 6 | 5.46 | > 7.5 |
| 568 | Polyimide | Vespel SP-1 | 91.9 | 4.18 | 2.52 | > 7.5 |
| 569 | Polyphenyl sulfone + glass fibres | Ertaxel | 89.3 | 3.32 | 3.29 | > 7.5 |
| 570 | Polyamide + 30% glass fibres | Ertalon 66GF30 | 197 | 4.58 | 5.76 | 6.7 |
| 571 | Polyoximethylene | Ertacetal | 101.0 | > 15 | 3.09 | 4 |
| 572 | Polyethylene | Borolene 4505 | 23.8 | > 15 | 1.11 | ~ 5.7 |
| 573 | Polyethylene | Cestilene HD 1000 | 23.3 | > 15 | 0.81 | ~ 6 |
| 574 | Polyethylene | Cestilene HD 500 | 37.1 | > 15 | 1.69 | ~ 6.5 |
| 575 | Polyethylene | Cestidur | 22.7 | > 14.5 | 0.78 | > 6.5 |
| 576 | Polyethylene | Cestitech | 23.4 | > 14 | 0.83 | 6.4 |
| 577 | Polyamide-imide | Torlon 4203 | 188.2 | 14.96 | 4.06 | > 7.5 |
| 578 | Polyamide-imide | Torlon 4301 | 182.3 | 7.88 | 6.12 | > 7.5 |

| | | |
|---|---|---|
| Material: | **Polyphenyl oxide (PPO) based plastic** | TIS No. **R 375** |
| Type | **Noryl ENV 125** | |
| Supplier: | **Angst & Pfister** | UL 94: V-1 |
| Remarks: | no glass fibre<br>bus bar insulation for LEP | LOI: |

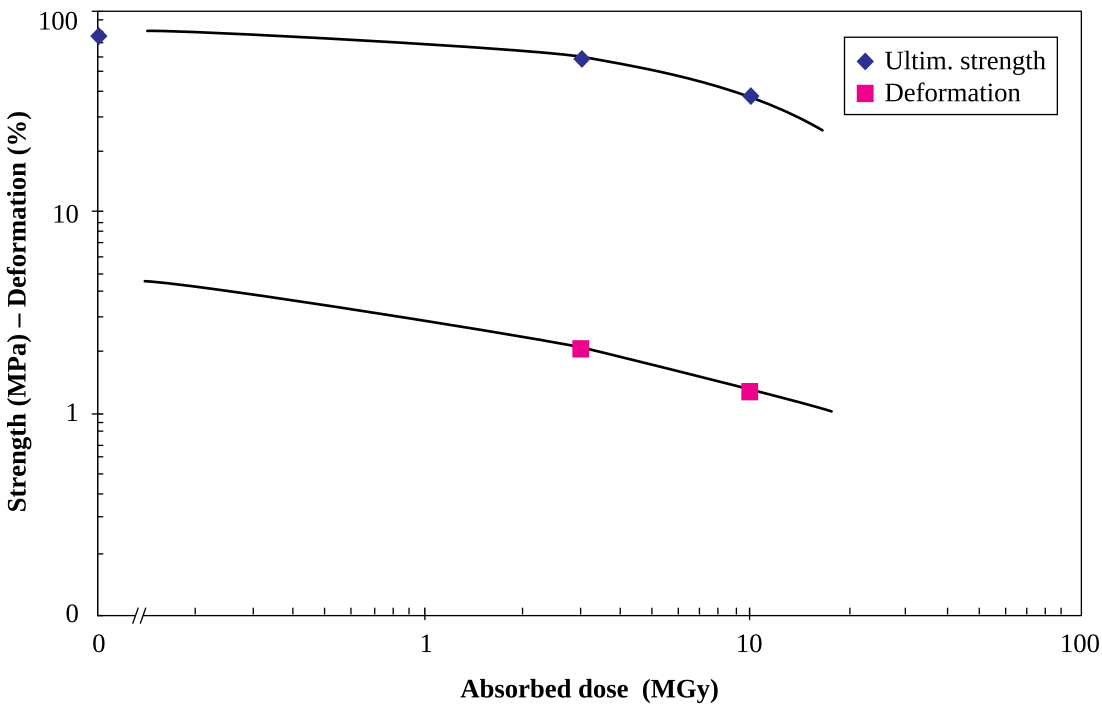
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **77.6**±8.1 | > **5** | **2.3**±0.3 |
| **220** | **3** | **58.4**±6.1 | **2.1**±0.1 | **5.6**±0.6 |
| **220** | **10** | **38.5**±4.7 | **1.3**±0.1 | **3.1**±0.2 |

Critical property = deformation

Radiation index (RI) = < 6.5 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 375**



| | | |
|---|---|---|
| Material: | **Polyurethane** | TIS No. **R 416** |
| Type | **Micares 700** | |
| Supplier: | **Micafil** | UL 94: n.m. |
| Remarks: | | LOI: |

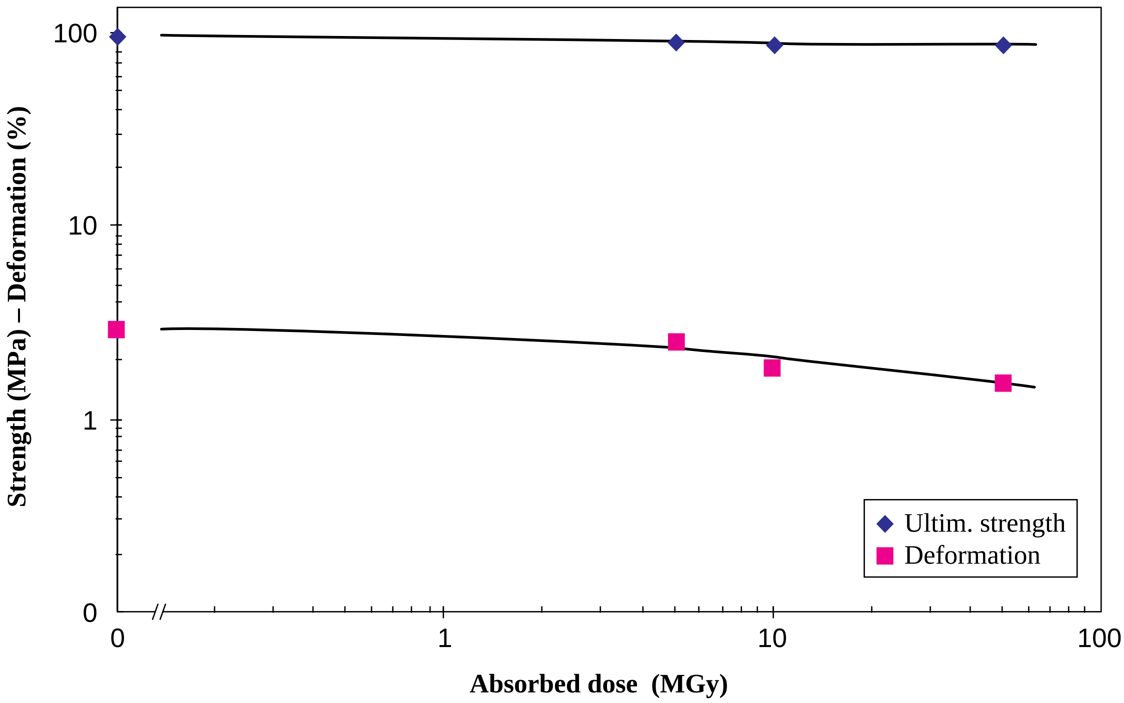
### Radiation test results according to IEC Standard 544 (and ISO 178)

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **95.4**±1.7 | **3.30**±0.42 | **5.09**±0.23 |
| **170** | **5** | **90.6**±2.8 | **2.75**±0.14 | **5.04**±0.16 |
| **170** | **10** | **88.1**±2.0 | **1.83**±0.08 | **5.60**±0.20 |
| **170** | **50** | **86.4**±9.7 | **1.60**±0.10 | **6.00**±0.60 |

Critical property = deformation

Radiation index (RI) = 7.7 at a mean dose rate of 170 kGy/h

### Radiation effect on insulating resin R 416



| | | |
|---|---|---|
| Material: | **Polycarbonate** | TIS No. **R 419** |
| Type | **Makrolon 218** | |
| Supplier: | **Bayer (CERN stores)** | UL 94: V-2 |
| Remarks: | translucent | LOI: 26% |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

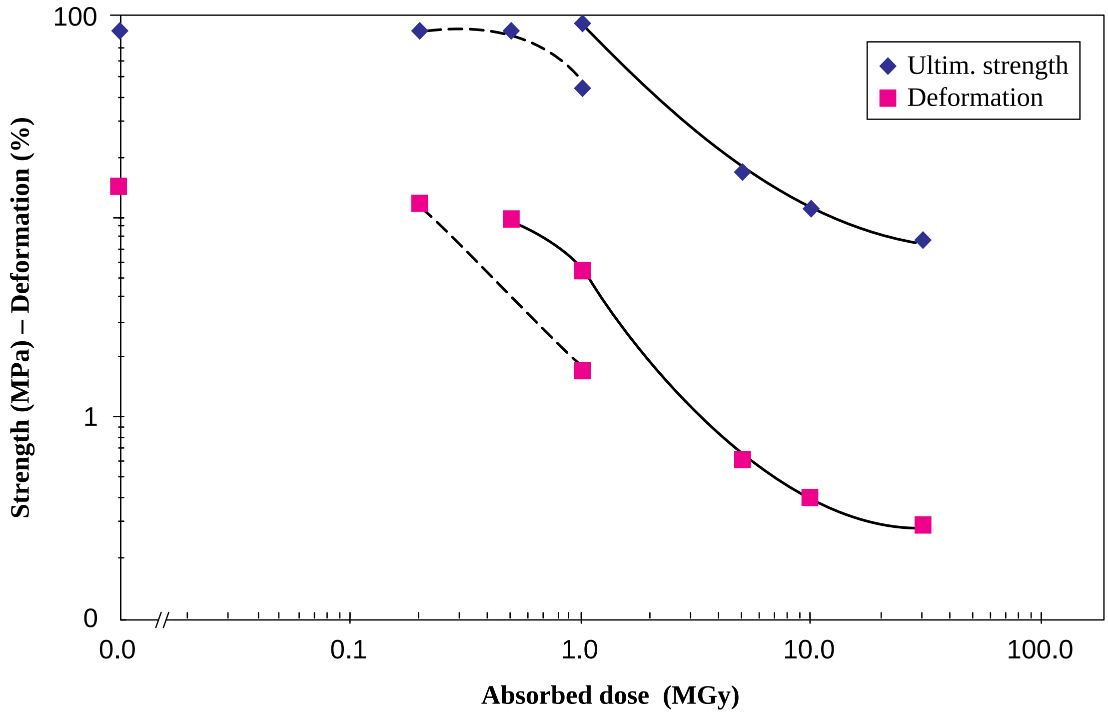
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0.0** | **86.3**±2.9 | > **10** | **2.3**±0.1 |
| **0.1** | **0.2** | **86.6**±2.5 | > **10** | **2.5**±0.1 |
| **0.1** | **0.5** | **85.0**±1.3 | > **10** | **2.6**±0.1 |
| **4.0** | **1.0** | **44.4**±13.5 | **1.71**±0.53 | **2.7**±0.1 |
| **190** | **1.0** | **91.6**±2.2 | **5.49**±0.13 | **2.7**±0.1 |
| **190** | **5.0** | **17.2**±2.9 | **0.62**±0.09 | **2.8**±0.1 |
| **190** | **10** | **11.3**±2.0 | **0.39**±0.07 | **2.9**±0.1 |
| **190** | **30** | **7.8**±2.5 | **0.29**±0.08 | **3.2**±0.2 |

Critical property = deformation

Radiation index (RI) = < 6 at a mean dose rate of 190 kGy/h

Radiation index (RI) = 5.7 at a mean dose rate of 100 Gy/h

**Radiation effect on translucent resin R 419**



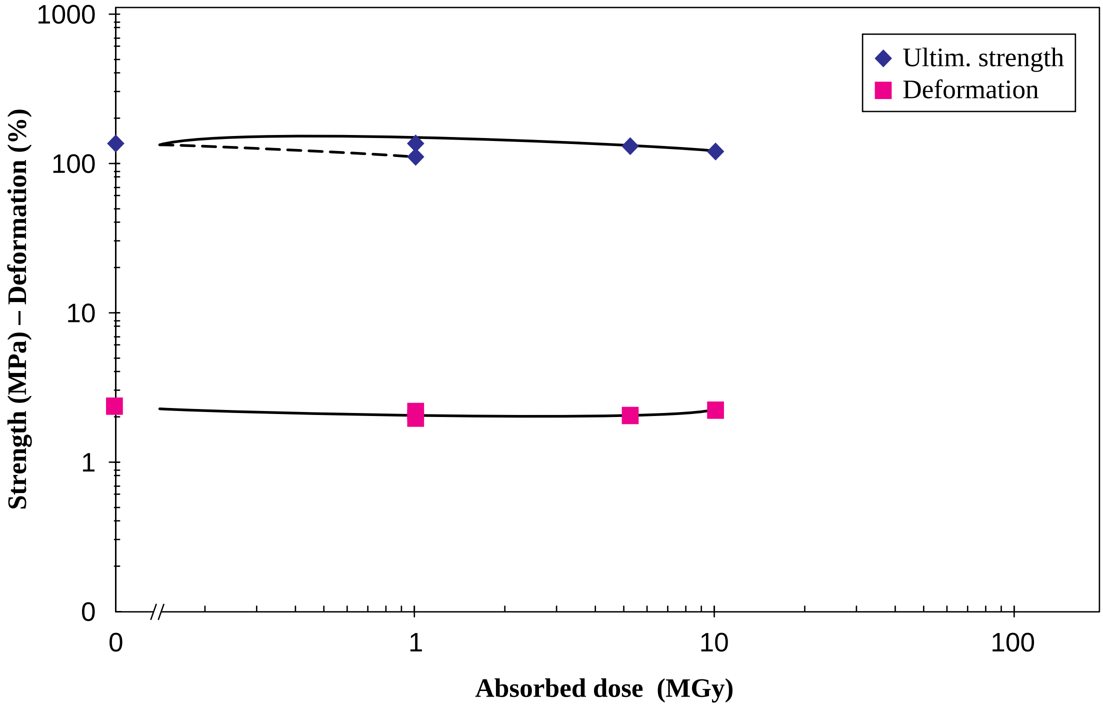

Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Polyester + glass mat** | TIS No. **R 435** |
| Type | **Nogentite NR2-71A** | |
| Supplier: | **D.F.C.** | UL 94: n.m. |
| Remarks: | high temperature applications | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **141**±20 | **2.39**±0.22 | **6.8**±0.8 |
| **0.1** | **1** | **114**±12 | **2.21**±0.17 | **7.5**±0.1 |
| **220** | **1** | **138**±12 | **2.05**±0.23 | **7.4**±0.0 |
| **220** | **5.2** | **131**±13 | **2.12**±0.23 | **6.8**±0.2 |
| **220** | **10** | **123**±19 | **2.28**±0.16 | **5.8**±0.4 |

**Radiation effect on Nogentite R 435**




Comment: Dotted line corresponds to low-dose-rate irradiation.

| | | |
|---|---|---|
| Material: | **Polyester + glass fibres** | TIS No. **R 459** |
| Type | **Nogentite NZ-3 71E** | |
| Supplier: | **D.F.C.** | UL 94: n.m. |
| Remarks: | high temperature applications | LOI: |

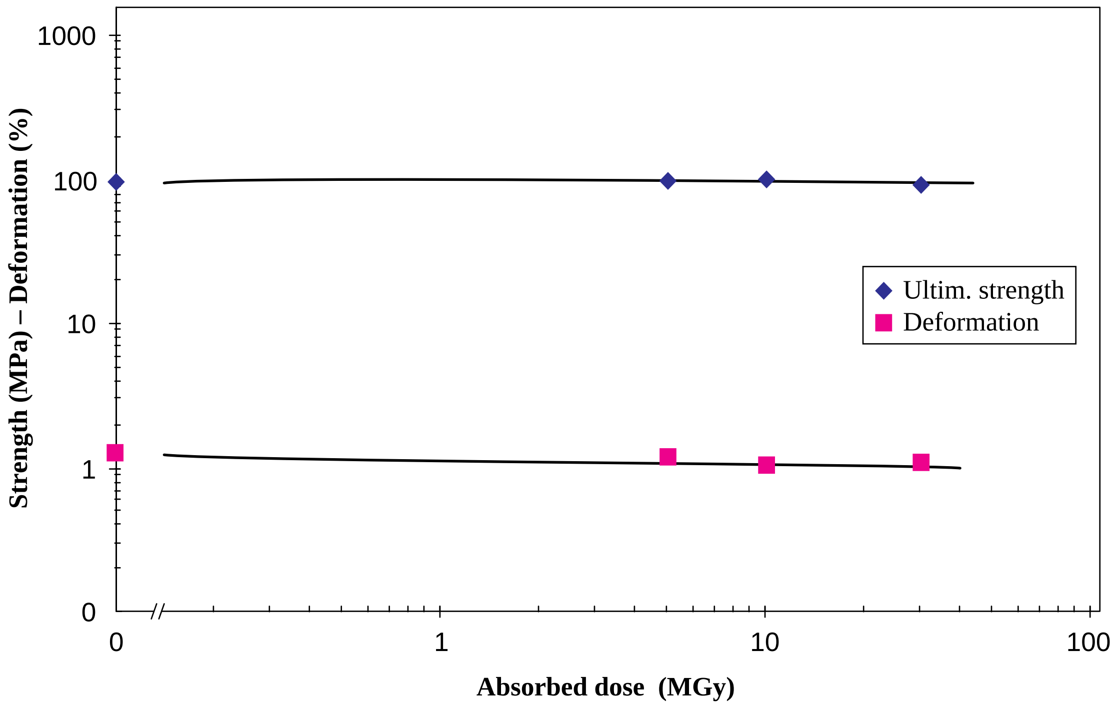
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **96**±24 | **1.25**±0.29 | **11.2**±0.8 |
| **220** | **5** | **111**±25 | **1.24**±0.14 | **12.2**±1.0 |
| **220** | **10** | **103**±23 | **1.06**±0.26 | **12.7**±1.5 |
| **220** | **30** | **93**±31 | **1.11**±0.35 | **11.9**±1.5 |

Critical property = flexural strength

Radiation index (RI) = > 7.5 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 459**



| | | |
|---|---|---|
| Material: | **Polyphenyl oxide (PPO)-based plastic** | TIS No. **R 464** |
| Type | **Noryl ENV 509** | |
| Supplier: | **General Electric Plastics** | UL 94: V-1 |
| Remarks: | insulation of LEP monorail | LOI: 31% |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

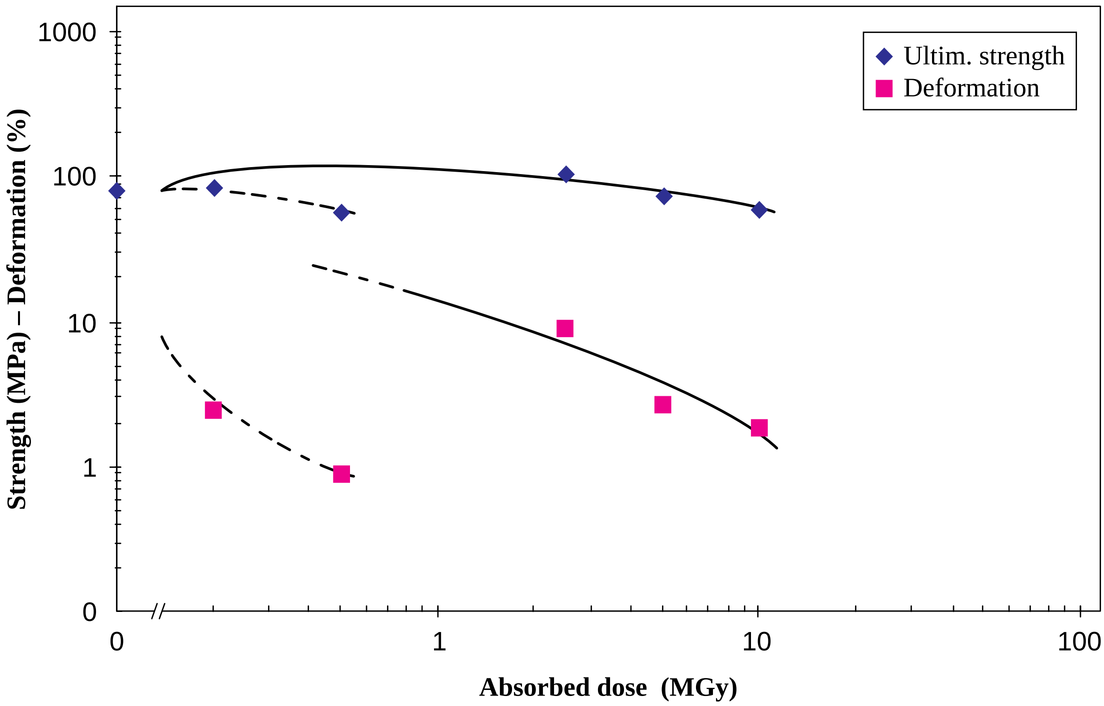
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **82.8**±2.9 | **> 12*** | **2.9**±0.1 |
| **0.1** | **0.2** | **84.7**±2.5 | **2.5**±0.1 | **6.7**±0.1 |
| **0.1** | **0.5** | **57.1**±1.3 | **0.9**±0.2 | **6.8**±0.1 |
| **220** | **3** | **104.0**±2.2 | **9.0**±1.4 | **3.0**±0.1 |
| **220** | **5** | **75.4**±20.4 | **2.7**±0.7 | **3.2**±0.1 |
| **220** | **10** | **59.9**±0.7 | **1.9**±0.1 | **3.3**±0.1 |

Critical property = deformation

Radiation index (RI) < 5 at a mean dose rate of 220 kGy/h

Radiation index (RI) ~ 6 at a mean dose rate of 100 Gy/h

**Radiation effect on Noryl ENV 509 R 464**




Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Polyester resin + glass fibres** | TIS No. **R 473** |
| Type | **KK/RI** | |
| Supplier: | **EBO AG** | UL 94: n.m. |
| Remarks: | | LOI: |

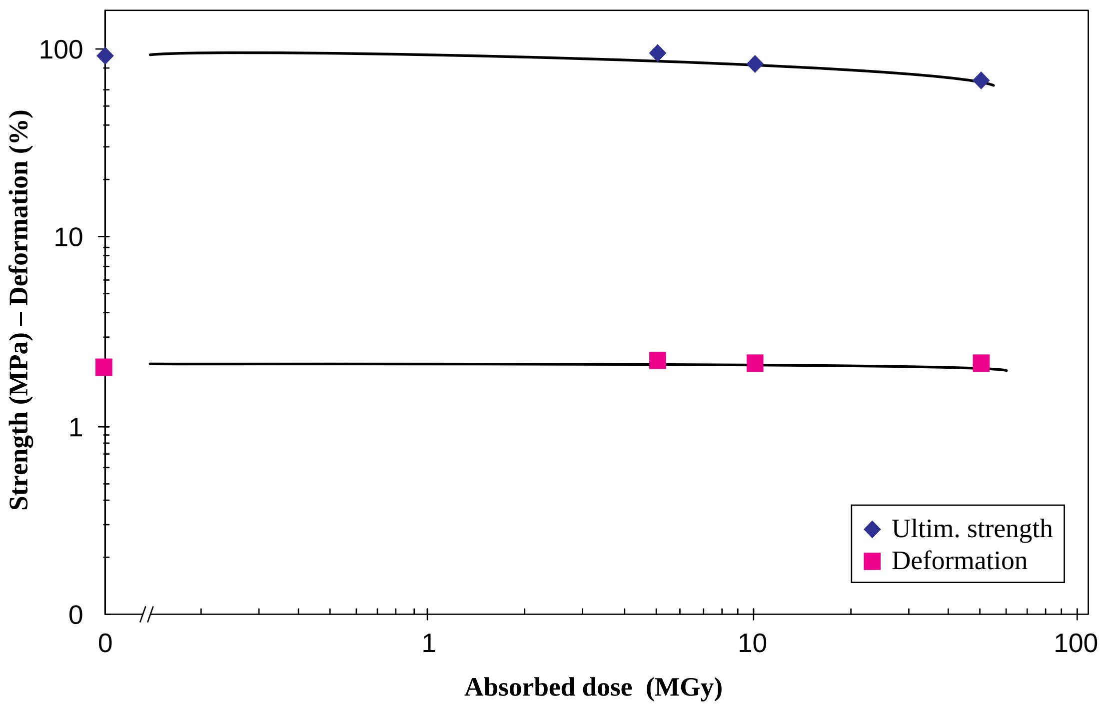
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **93.7**±11.4 | **2.1**±0.2 | **12.3**±0.7 |
| **220** | **5** | **95.7**±11.8 | **2.3**±0.2 | **7.3**±0.9 |
| **220** | **10** | **83.4**±4.8 | **2.2**±0.2 | **7.1**±0.4 |
| **220** | **50** | **68.4**±5.4 | **2.2**±0.1 | **4.9**±0.3 |

Critical property = Modulus

Radiation index (RI) = 7.5 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 473**



| | | |
|---|---|---|
| Material: | **Polyester resin + glass fibres** | TIS No. **R 474** |
| Type | **KK/530I** | |
| Supplier: | **EBO AG** | UL 94: n.m. |
| Remarks: | | LOI: |

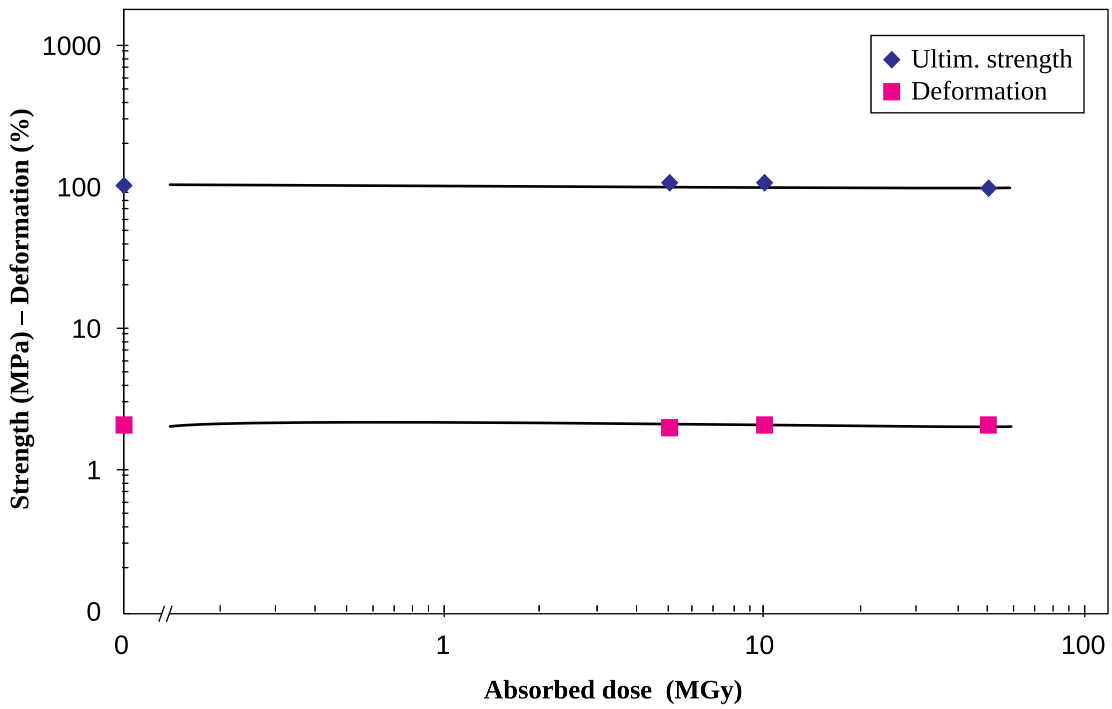
### Radiation test results according to IEC Standard 544 (and ISO 178)

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **106**±12 | **2.1**±0.2 | **11.0**±0.7 |
| **220** | **5** | **111**±11 | **2.0**±0.2 | **11.4**±0.6 |
| **220** | **10** | **110**±10 | **2.1**±0.1 | **11.3**±1.1 |
| **220** | **50** | **99**±17 | **2.1**±0.1 | **8.1**±0.5 |

Critical property = none

Radiation index (RI) = > 7 at a mean dose rate of 220 kGy/h

### Radiation effect on insulating resin R 474



| | | |
|---|---|---|
| Material: | **Polyphenyl oxide (PPO) based plastic** | TIS No. **R 491** |
| Type | **Univolt HFT** | |
| Supplier: | **AGRO, via Dietzel Electro GMBH** | UL 94: n.m. |
| Remarks: | | LOI: |

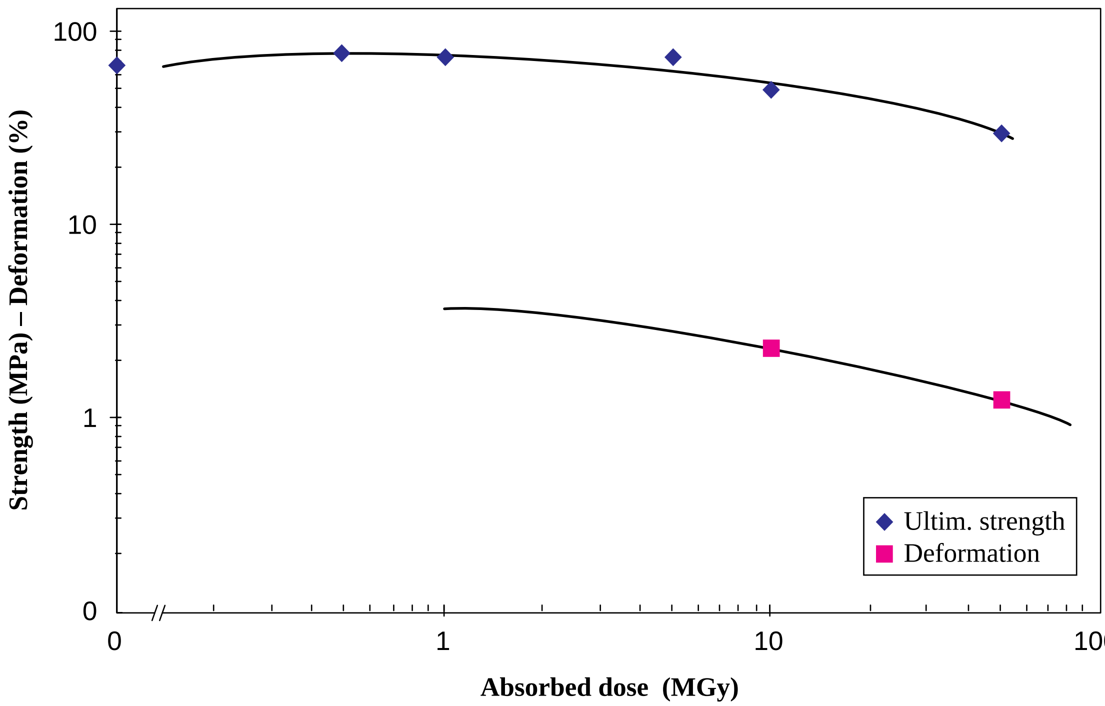
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **68.1**±1.5 | > **6** | **2.59**±0.06 |
| **0.1** | **0.5** | **73.7**±0.8 | > **6** | **2.53**±0.04 |
| **0.1** | **1** | **74.2**±2.2 | > **6** | **2.54**±0.05 |
| **220** | **5** | **75.4**±2.2 | > **6** | **2.66**±0.02 |
| **220** | **10** | **51.0**±7.9 | **2.29**±0.46 | **2.66**±0.07 |
| **220** | **50** | **30.5**±3.9 | **1.3**±0.2 | **2.41**±0.19 |

Critical property = deformation

Radiation index (RI) = 6.7 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating plastic R 491**



| | | |
|---|---|---|
| Material: | **Polyester resin + glass mat** | TIS No. **R 499** |
| Type | **Polyester 1** | |
| Supplier: | **FA-BA** | UL 94: n.m. |
| Remarks: | proposed for LEP magnet covers (hand-made) | LOI: |

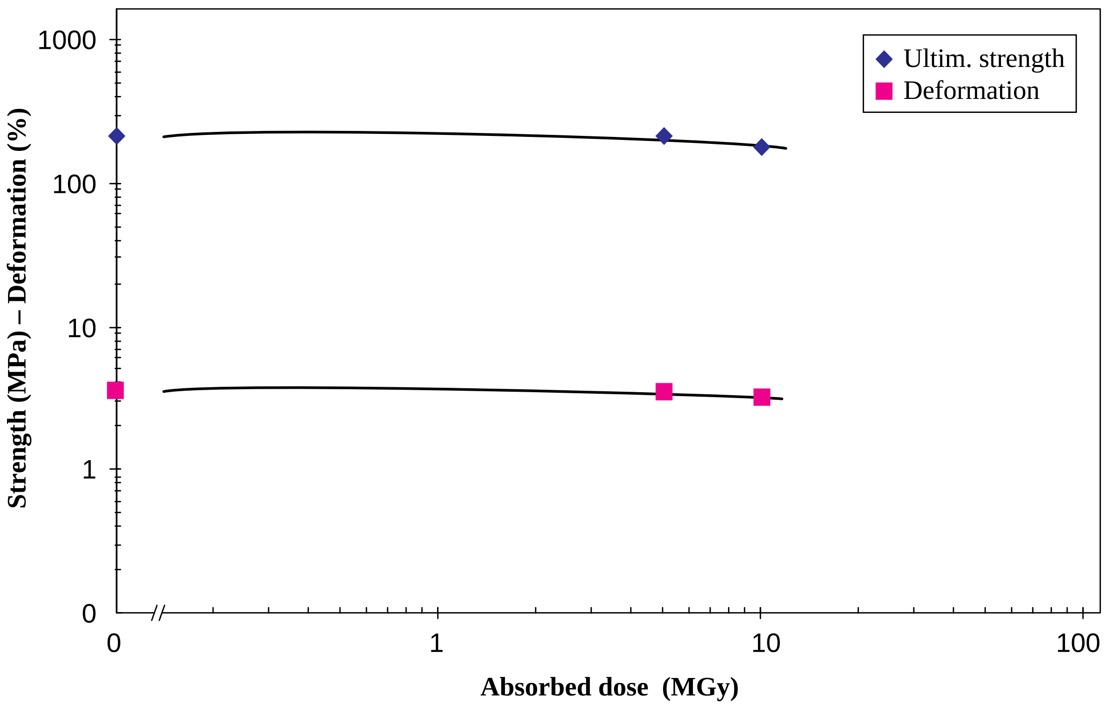
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **216**±27 | **3.60**±0.28 | **5.89**±3.04 |
| **220** | **5** | **214**±11 | **3.51**±0.26 | **7.57**±0.71 |
| **220** | **10** | **180**±20 | **3.29**±0.43 | **6.91**±0.57 |

Critical property = flexural strength

Radiation index (RI) = > 7 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 499**



| | | |
|---|---|---|
| Material: | **Polyester resin + glass mat** | TIS No. **R 500** |
| Type | **Polyester 2** | |
| Supplier: | **FA-BA** | UL 94: n.m. |
| Remarks: | proposed for LEP magnet covers (hand-made) | LOI: |

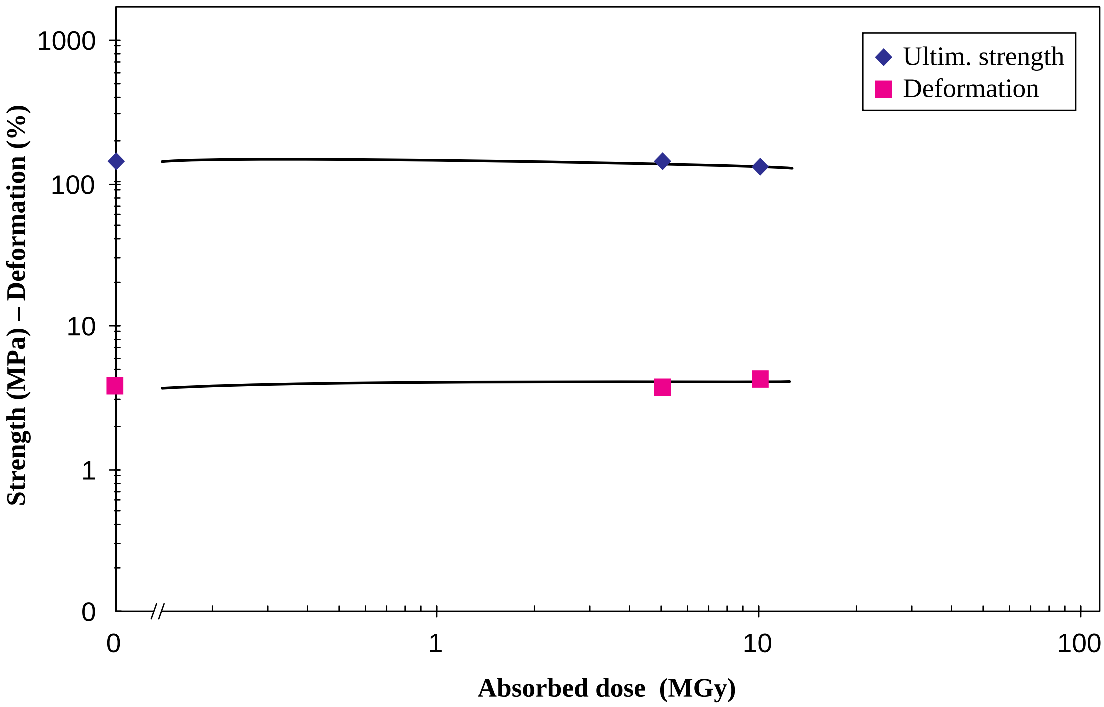
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **148**±5 | **3.77**±0.59 | **5.30**±2.53 |
| **220** | **5** | **143**±29 | **3.73**±0.32 | **7.07**±1.23 |
| **220** | **10** | **132**±27 | **4.27**±0.33 | **5.56**±0.75 |

Critical property = flexural strength

Radiation index (RI) = > 7 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 500**



| | | |
|---|---|---|
| Material: | **Polyester resin + glass mat** | TIS No. **R 501** |
| Type | **Polyester 3** | |
| Supplier: | **FA-BA** | UL 94: n.m. |
| Remarks: | proposed for LEP magnet covers (hand-made) | LOI: |

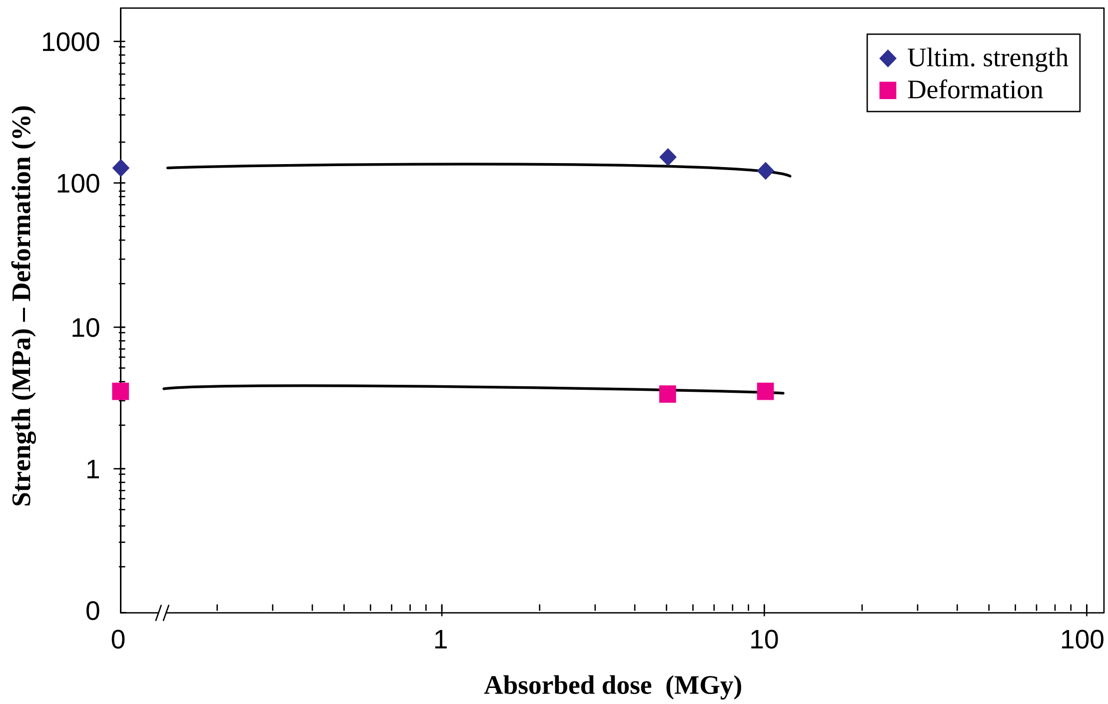
### Radiation test results according to IEC Standard 544 (and ISO 178)

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **130**±25 | **3.6**±0.9 | **3.5**±2.8 |
| **220** | **5** | **160**±9 | **3.4**±0.2 | **8.5**±0.6 |
| **220** | **10** | **123**±15 | **3.5**±0.1 | **5.9**±1.4 |

Critical property = flexural strength

Radiation index (RI) = > 7 at a mean dose rate of 220 kGy/h

### Radiation effect on insulating resin R 501



| | | |
|---|---|---|
| Material: | **Polyoximethylene (POM)** | TIS No. **R 503** |
| Type | **Delrin** | |
| Supplier: | **DuPont de Nemours** | UL 94: n.m. |
| Remarks: | also called acetal resin<br>CERN stores Scem 44 88 20 104.1 | LOI: n.m. |

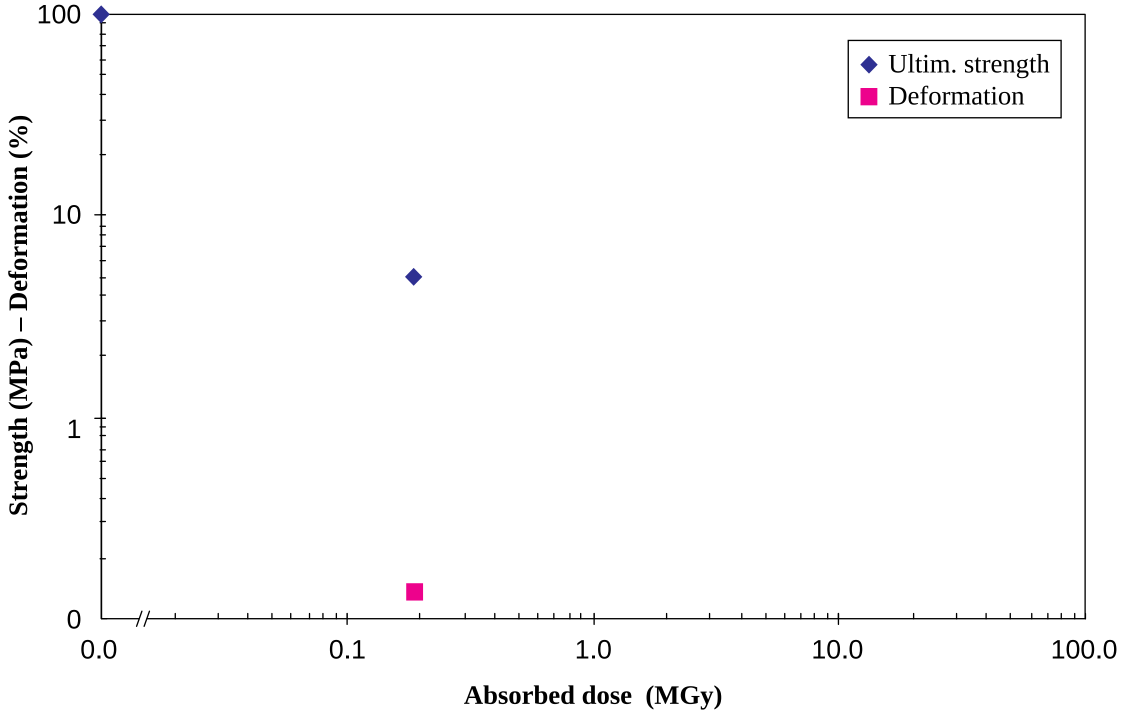
### Radiation test results according to IEC Standard 544 (and ISO 178)

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **98.6**±9.4 | > **13** | **3.4**±0.6 |
| **250** | **0.2** | **4.9**±0.9 | **0.1**±0.3 | **3.5**±0.3 |

Critical property = flexural strength and deformation

Radiation index (RI) < 5 at a mean dose rate of 250 kGy/h

### Radiation effect on insulating resin R 503




**Comment: This material should never be used in a radiation environment.**

| | | |
|---|---|---|
| Material: | **Polyetherimide + glass fibres** | TIS No. **R 504** |
| Type | **Ultem 1000** | |
| Supplier: | **General Electric Plastics** | UL 94: n.m. |
| Remarks: | | LOI: |

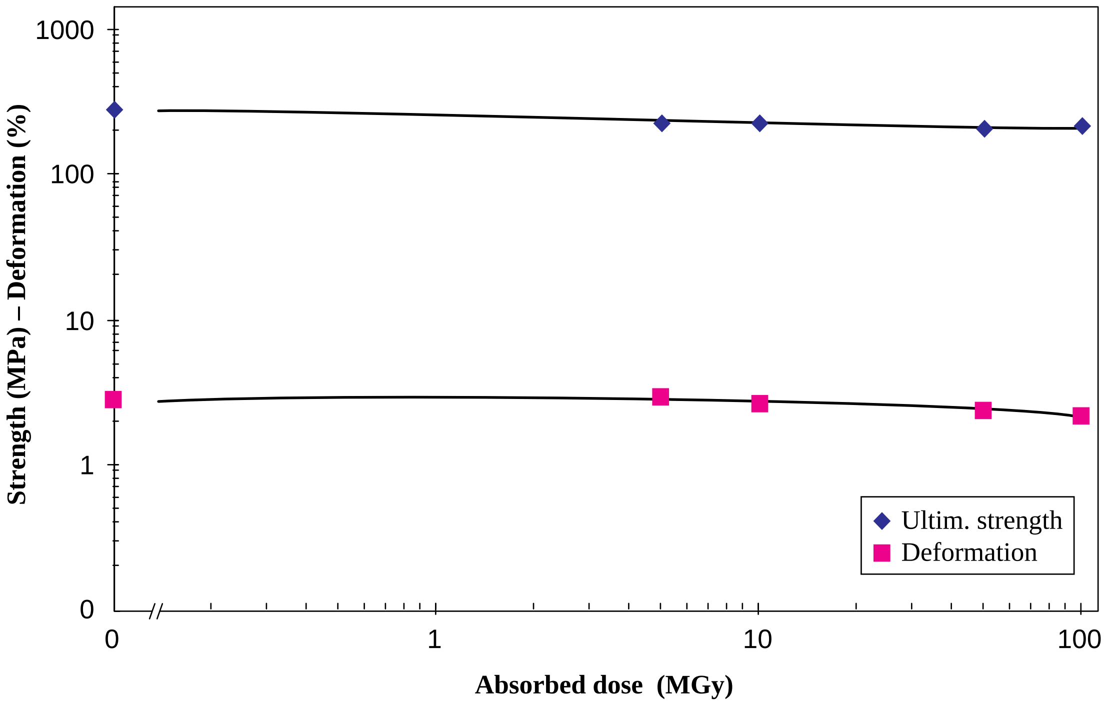
### Radiation test results according to IEC Standard 544 (and ISO 178)

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **288**±54 | **2.83**±0.08 | **10.5**±1.3 |
| **170** | **5** | **234**±29 | **2.86**±0.14 | **9.1**±1.4 |
| **70** | **10** | **235**±9 | **2.65**±0.09 | **9.5**±0.4 |
| **70** | **50** | **214**±6 | **2.39**±0.10 | **10.0**±0.5 |
| **220** | **100** | **216**±3 | **2.15**±0.04 | **10.8**±0.1 |

Critical property = flexural strength

Radiation index (RI) = > 8 at a mean dose rate of 220 kGy/h

### Radiation effect on insulating resin R 504



| | | |
|---|---|---|
| Material: | **PUR, Polyalcohol** | TIS No. **R 513** |
| Type | **Scotchcast 800** | |
| Supplier: | **3M** | UL 94: n.m. |
| Remarks: | rigid (cold)<br>contains chlorine | LOI: |

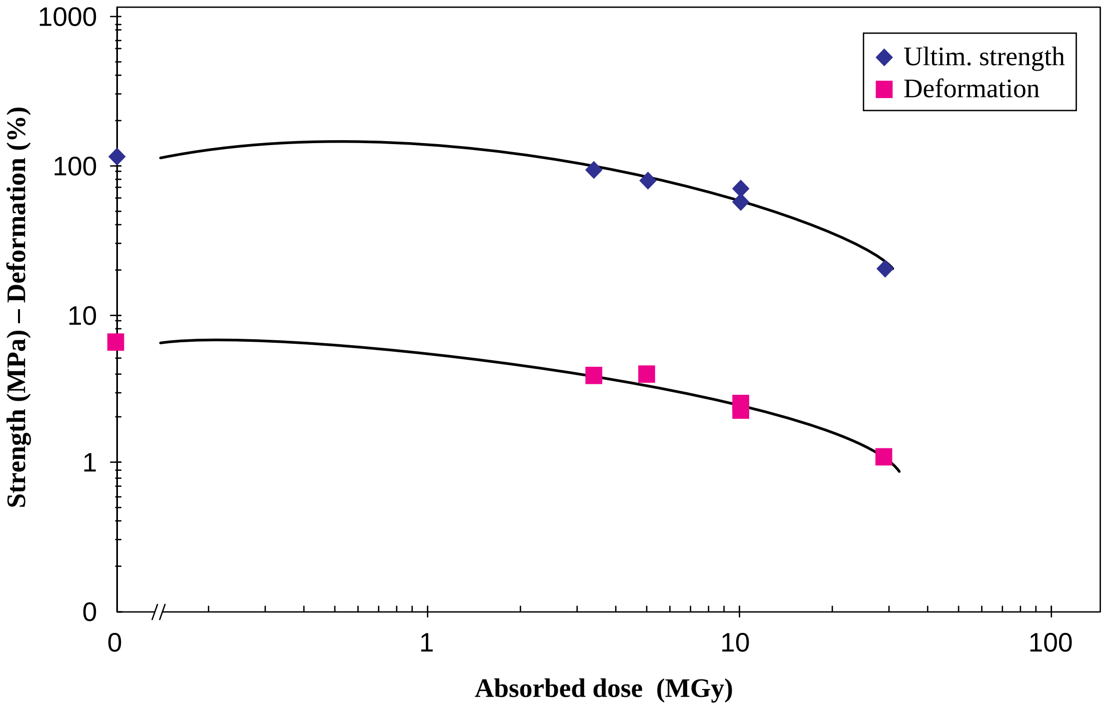
### Radiation test results according to IEC Standard 544 (and ISO 178)

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **115**±2 | **6.46**±0.69 | **3.0**±0.0 |
| **200** | **3.4** | **93.1**±9.2 | **3.98**±0.6 | **2.8**±0.1 |
| **3** | **5** | **81.7**±9.2 | **3.9**±0.6 | **2.5**±0.1 |
| **3** | **10** | **58.7**±8.3 | **2.5**±0.3 | **2.5**±0.2 |
| **200** | **10** | **70.4**±9.2 | **2.3**±0.4 | **3.3**±0.1 |
| **200** | **29** | **20.7**±2.8 | **1.1**±0.2 | **2.0**±0.1 |

Critical property = deformation

Radiation index (RI) = 6.8

### Radiation effect on Polyalcohol R 513



| | | |
|---|---|---|
| Material: | **PUR, Polyalcohol** | TIS No. **R 516** |
| Type | **Scotchcast 840** | |
| Supplier: | **3M** | UL 94: n.m. |
| Remarks: | flexible (cold)<br>contains chlorine | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

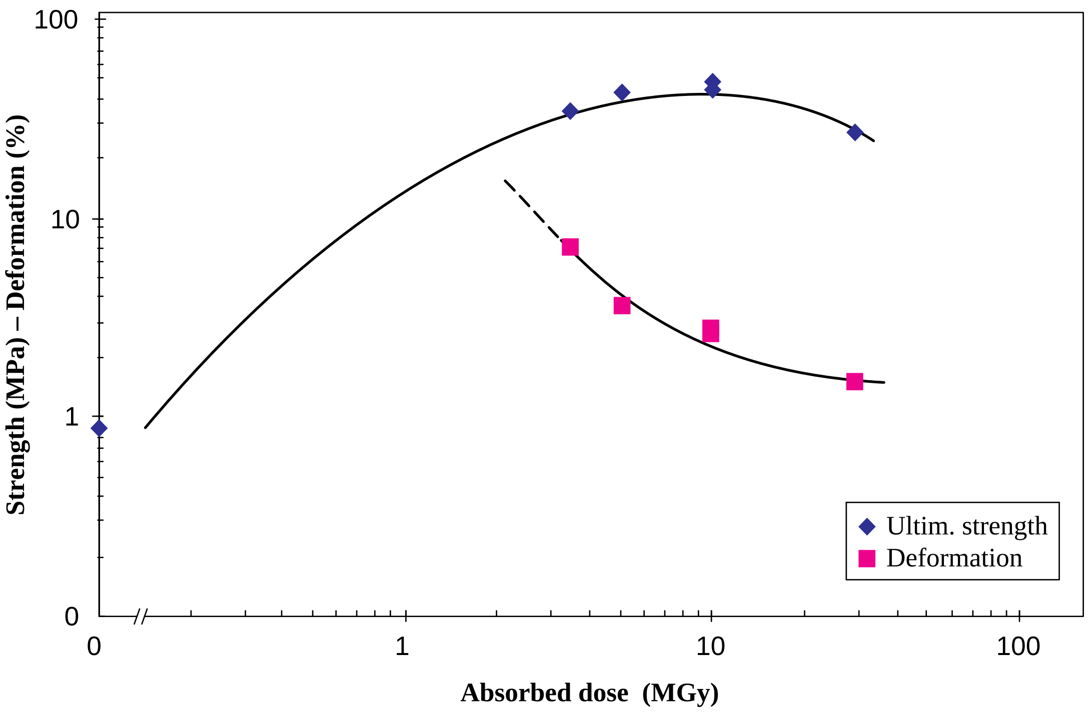
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **0.9**±0.1 | > **12** | **0.0**±0.0 |
| **200** | **3.4** | **35.5**±1.9 | **7.2**±1.6 | **0.9**±0.1 |
| **3** | **5** | **43.5**±2.2 | **3.6**±0.2 | **1.6**±0.1 |
| **3** | **10** | **48.6**±3.3 | **2.8**±0.2 | **4.1**±0.2 |
| **200** | **10** | **44.2**±3.7 | **2.7**±0.2 | **1.9**±0.1 |
| **200** | **29** | **27.2**±3.0 | **1.6**±0.1 | **1.9**±0.2 |

Critical property = deformation

Radiation index (RI) = 6.5 at a mean dose rate of 200 kGy/h

Radiation index (RI) = < 6.7 at a mean dose rate of 3000 Gy/h

**Radiation effect on Polyalcohol R 516**



| | | |
|---|---|---|
| Material: | **PEEK** | TIS No. **R 520** |
| Type | **Natural polyether-ether-ketone** | |
| Supplier: | **Erta-Epec** | UL 94: V-0 |
| Remarks: | via Angst and Pfister | LOI: 35% |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

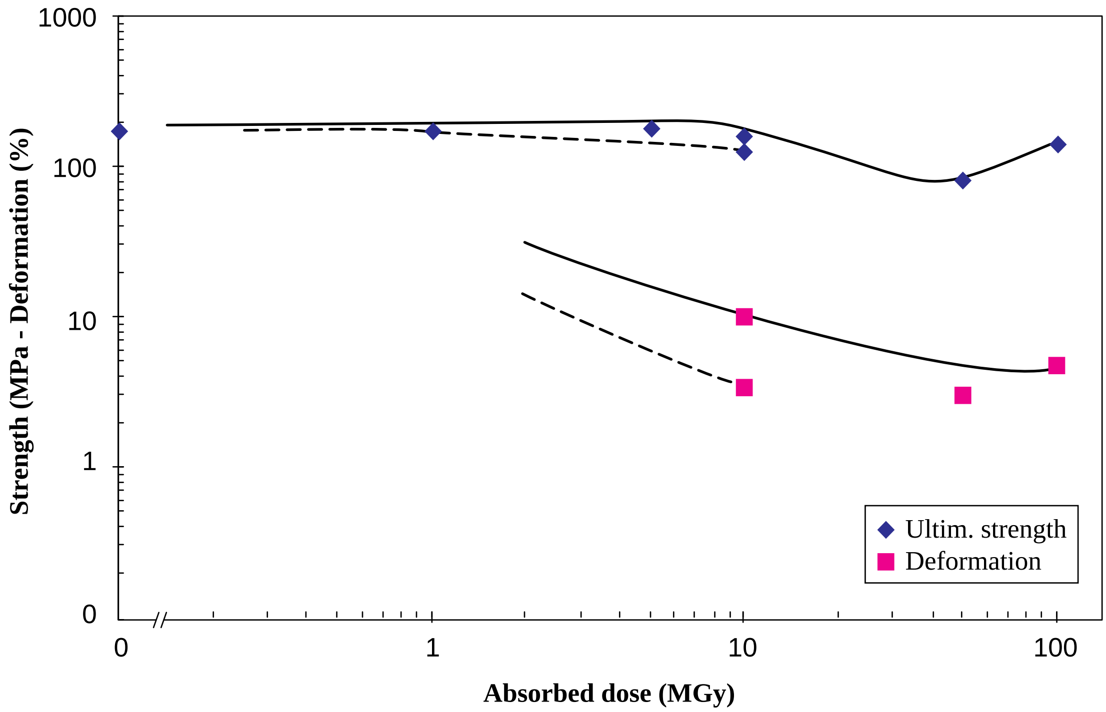
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **177**±3 | > **15** | **4.3**±0.1 |
| **1** | **1** | **177**±5 | > **15** | **4.3**±0.1 |
| **180** | **5** | **179**±0.3 | > **15** | **4.1**±0.1 |
| **180** | **10** | **161**±35 | **9.2**±4.5 | **4.2**±0.1 |
| **1** | **10** | **126**±7 | **3.4**±0.3 | **4.3**±0.3 |
| **210** | **50** | **81**±41 | **3.0**±1.1 | **4.3**±0.1 |
| **220** | **100** | **143**±22 | **4.7**±1.2 | **4.2**±0.1 |

Critical property = deformation

Radiation index (RI) = 7.1 at a mean dose rate of 220 kGy/h

Radiation index (RI) = 6.8 at a mean dose rate of 1 kGy/h

**Radiation effect on PEEK R 520**




Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Polyimide** | TIS No. **R 521** |
| Type | **Sintimid** | |
| Supplier: | **Lenzing & Plansee** | UL 94: n.m. |
| Remarks: | free of charge | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

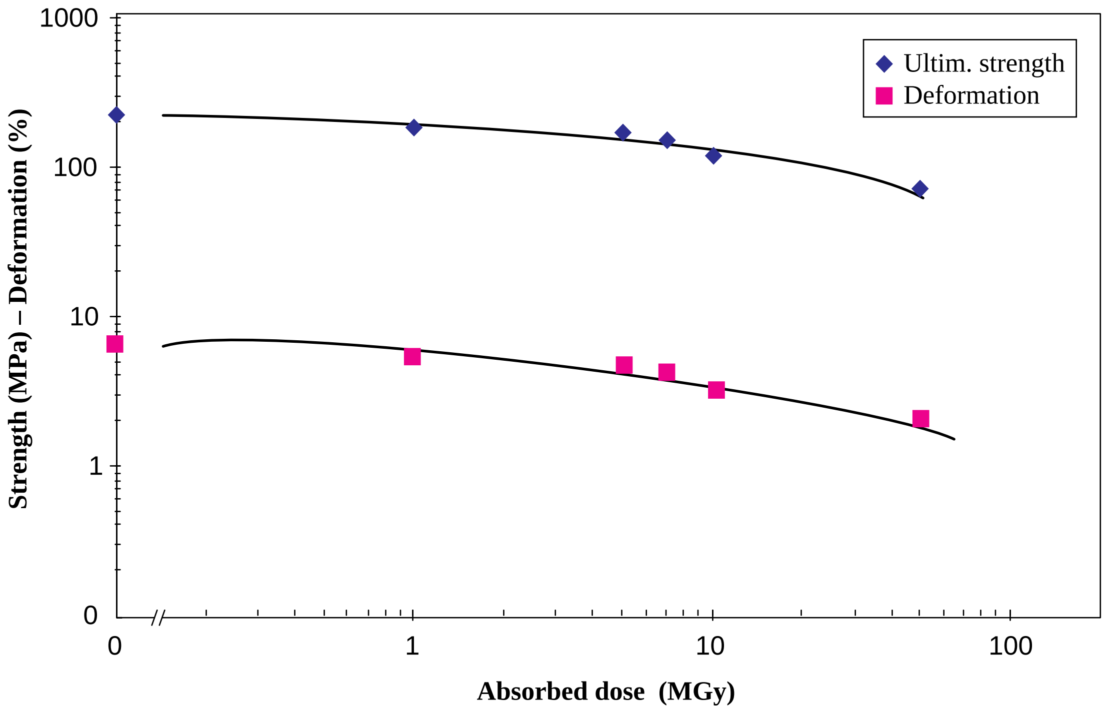
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **223**±16 | **6.60**±0.62 | **3.91**±0.05 |
| **1** | **1** | **189**±32 | **5.38**±0.84 | **3.91**±0.18 |
| **185** | **5** | **176**±20 | **4.71**±0.62 | **3.94**±0.08 |
| **1** | **7** | **152**±16 | **4.21**±0.40 | **3.85**±0.10 |
| **185** | **10** | **120**±5 | **3.24**±0.07 | **3.72**±0.09 |
| **210** | **50** | **73**±10 | **2.12**±0.29 | **3.52**±0.34 |

Critical property = deformation

Radiation index (RI) = 7 at a mean dose rate of 185 kGy/h

Radiation index (RI) > 6.8 at a mean dose rate of 1000 Gy/h

**Radiation effect on Sintimid R 521**



| | | |
|---|---|---|
| Material: | **Polyetherimide + Siloxane** | TIS No. **R 522** |
| Type | **Siltem STM 1500** | |
| Supplier: | **General electric Plastics** | UL 94: V-O |
| Remarks: | copolymer, free of charge<br>for wire insulation | LOI: 46% |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

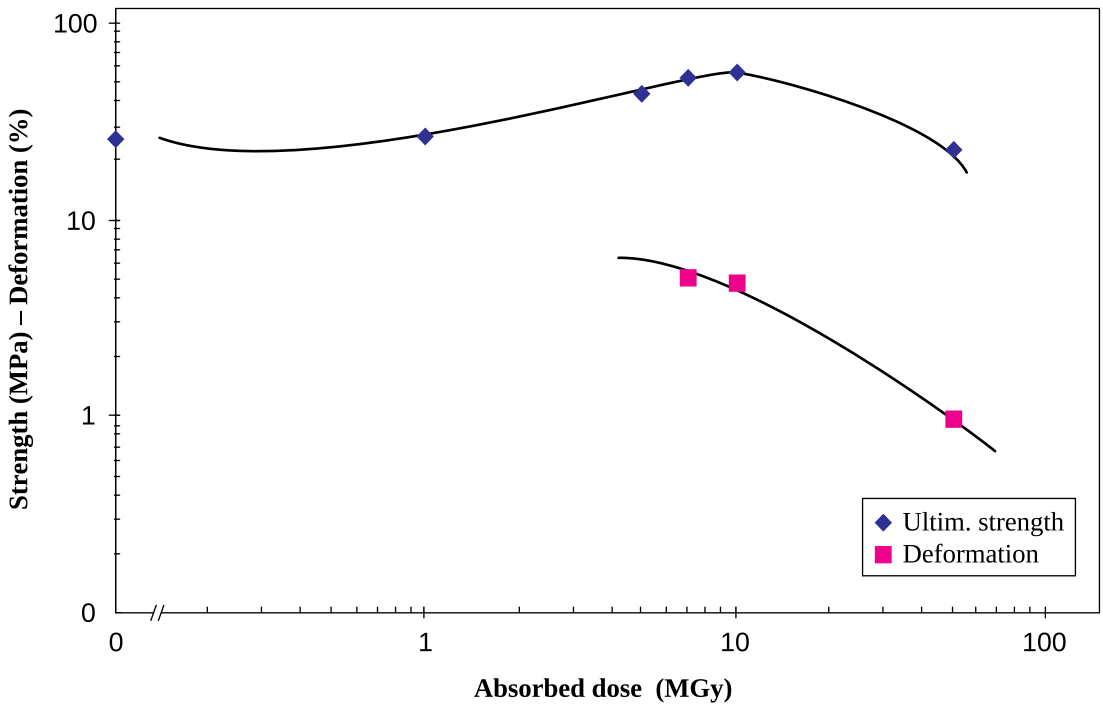
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **25.8**±1 | > **10** | **0.71**±0.03 |
| **1** | **1** | **27.3**±0.7 | > **10** | **0.72**±0.02 |
| **185** | **5** | **45.0**±0.1 | > **10** | **1.10**±0.03 |
| **1** | **7** | **53.2**±2.1 | **5.14**±0.58 | **1.40**±0.03 |
| **185** | **10** | **56.5**±3.2 | **4.8**±0.3 | **1.55**±0.03 |
| **220** | **50** | **23.2**±2.4 | **1.0**±0.1 | **2.68**±0.06 |

Critical property = deformation

Radiation index (RI) = 6.8 at a mean dose rate of 185 kGy/h

Radiation index (RI) = 6.8 at a mean dose rate of 1000 Gy/h

**Radiation effect on Siltem R 522**



| | | |
|---|---|---|
| Material: | **Polyarylamide base thermoplastic** | TIS No. **R 523** |
| Type | **IXEF 1002** | |
| Supplier: | **Solvay** | UL 94: HB |
| Remarks: | compound, + 30% glass fibre | LOI: |

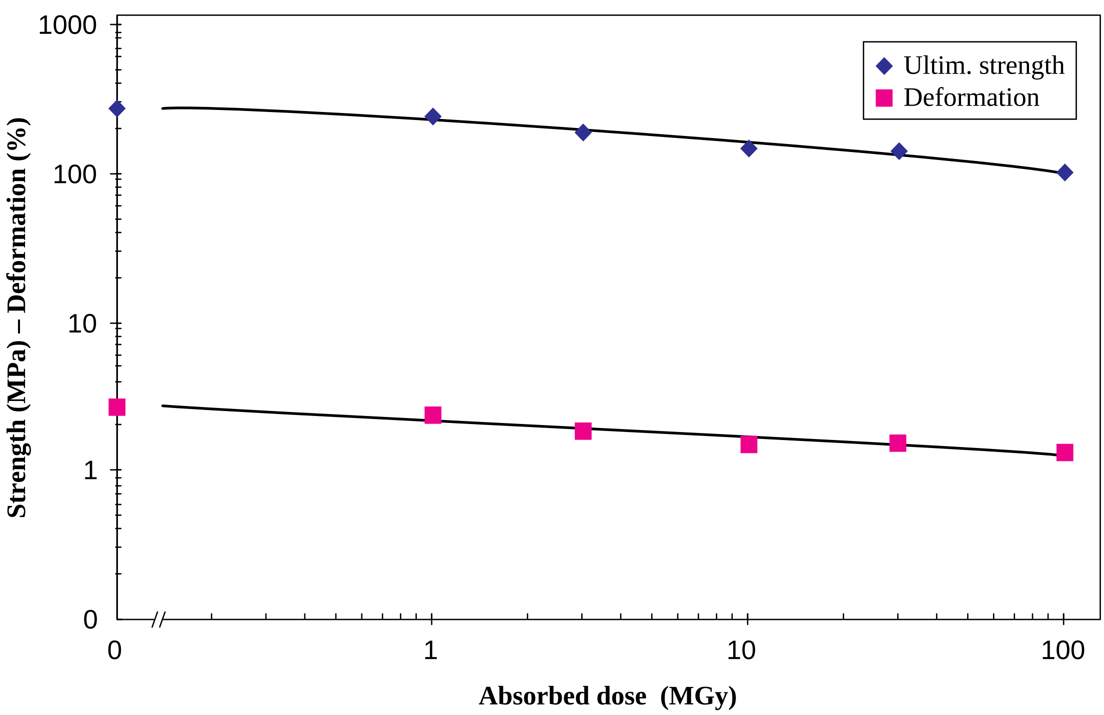
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **274**±3 | **2.71**±0.03 | **11.3**±0.1 |
| **6** | **1** | **247**±9 | **2.40**±0.10 | **11.4**±0.1 |
| **200** | **3** | **189**±7 | **1.88**±0.07 | **10.9**±0.1 |
| **200** | **10** | **151**±2 | **1.55**±0.02 | **10.8**±0.1 |
| **200** | **30** | **144**±3 | **1.55**±0.02 | **10.9**±0.1 |
| **200** | **100** | **105**±10 | **1.35**±0.07 | **7.65**±1.0 |

Critical property = flexural strength

Radiation index (RI) = 7.5 at a mean dose rate of 200 kGy/h

**Radiation effect on insulating resin R 523**



| | | |
|---|---|---|
| Material: | **Polyarylamide base thermoplastic** | TIS No. **R 524** |
| Type | **IXEF 1501** | |
| Supplier: | **Solvay** | UL 94: HB |
| Remarks: | compound, + 30% glass fibre<br>contains bromine as flame retardant | LOI: |

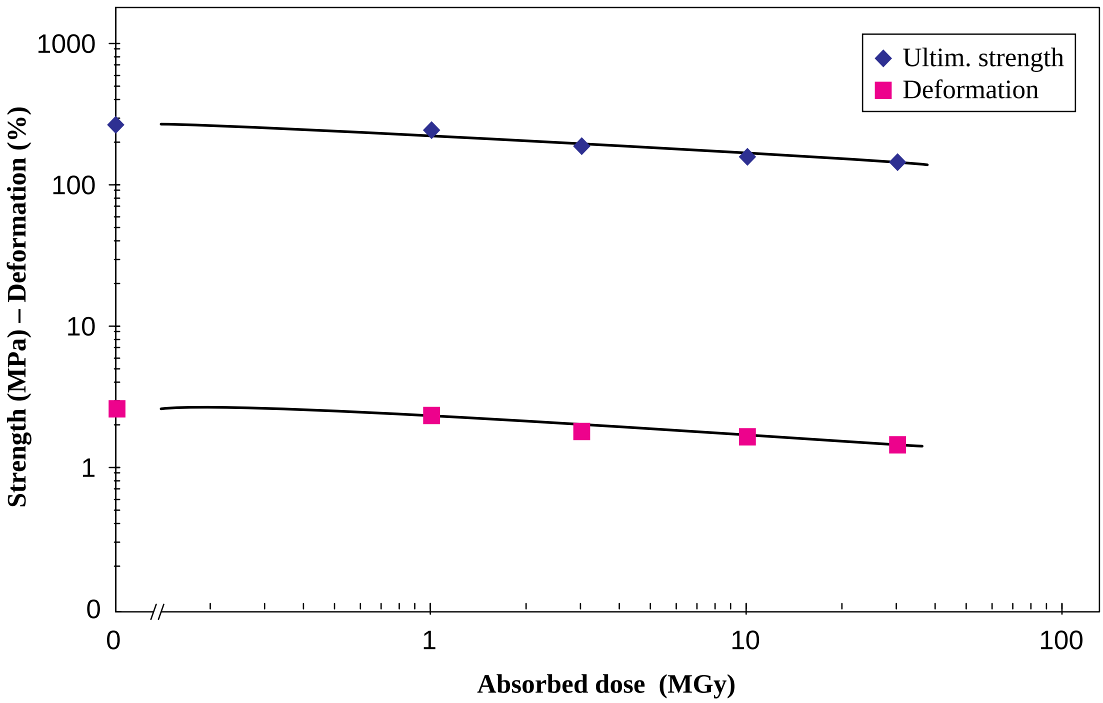
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **271**±7 | **2.62**±0.07 | **11.8**±0.2 |
| **6** | **1** | **254**±5 | **2.37**±0.07 | **11.8**±0.1 |
| **200** | **3** | **194**±7 | **1.84**±0.06 | **11.4**±0.1 |
| **200** | **10** | **158**±4 | **1.69**±0.21 | **11.4**±0.1 |
| **200** | **30** | **147**±9 | **1.50**±0.10 | **11.3**±0.2 |

Critical property = flexural strength

Radiation index (RI) = > 7.5 at a mean dose rate of 200 kGy/h

**Radiation effect on insulating resin R 524**



| | | |
|---|---|---|
| Material: | **Polyamide (PA) 4.6** | TIS No. **R 526** |
| Type | **Ertalon** | |
| Supplier: | **Erta-Epec** | UL 94: V-2 |
| Remarks: | via Angst and Pfister | LOI: 24% |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

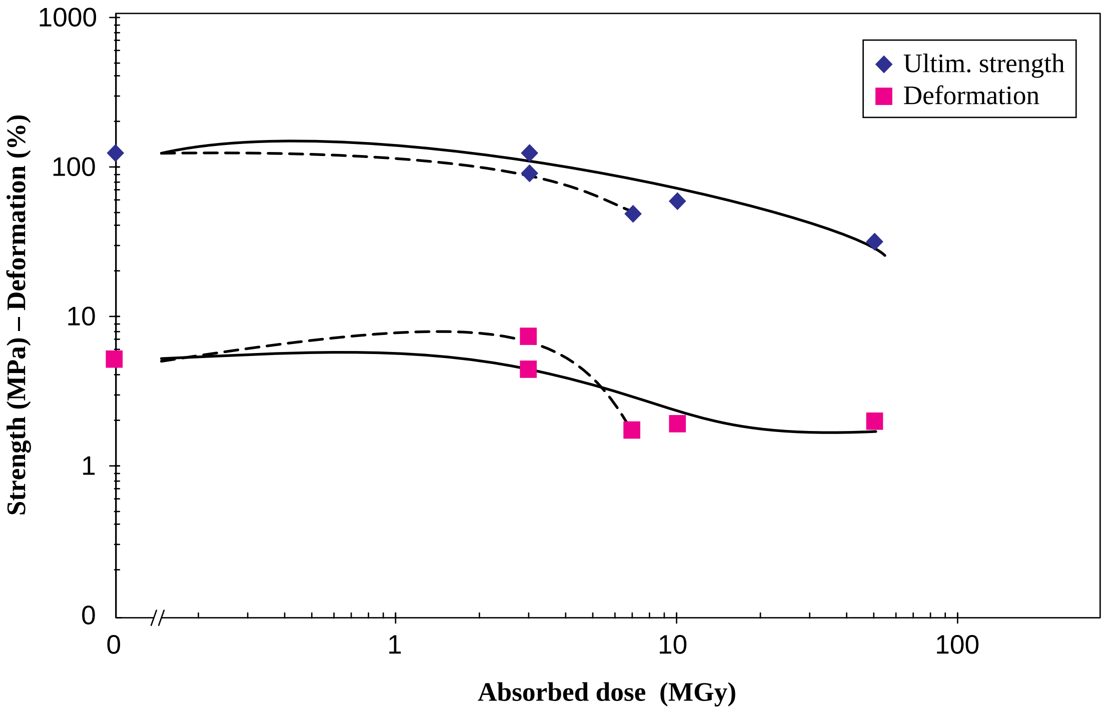
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **125**±2 | **5.2**±0.3 | **5.8**±0.3 |
| **240** | **3** | **128**±9 | **4.5**±0.4 | **5.6**±0.6 |
| **0.5** | **3** | **92**±7 | **7.4**±1.3 | **2.0**±0.2 |
| **1.0** | **7** | **50**±6 | **1.7**±0.2 | **3.0**±0.1 |
| **210** | **10** | **61**±7 | **2.0**±0.1 | **3.6**±0.4 |
| **220** | **50** | **32**±9 | **2.0**±0.7 | **2.0**±0.2 |

Critical property = deformation

Radiation index (RI) = 6.7 at a mean dose rate of 220 kGy/h

Radiation index (RI) = < 6.5 at a mean dose rate of 500 Gy/h

**Radiation effect on insulating resin R 526**




Comment: Dotted lines correspond to long-term irradiation.

| | | |
|---|---|---|
| Material: | **Polyamide (PA) 6** | TIS No. **R 528** |
| Type | **Ertalon 6 PLA** | |
| Supplier: | **Erta-Epec** | UL 94: V-2 |
| Remarks: | moulded | LOI: |

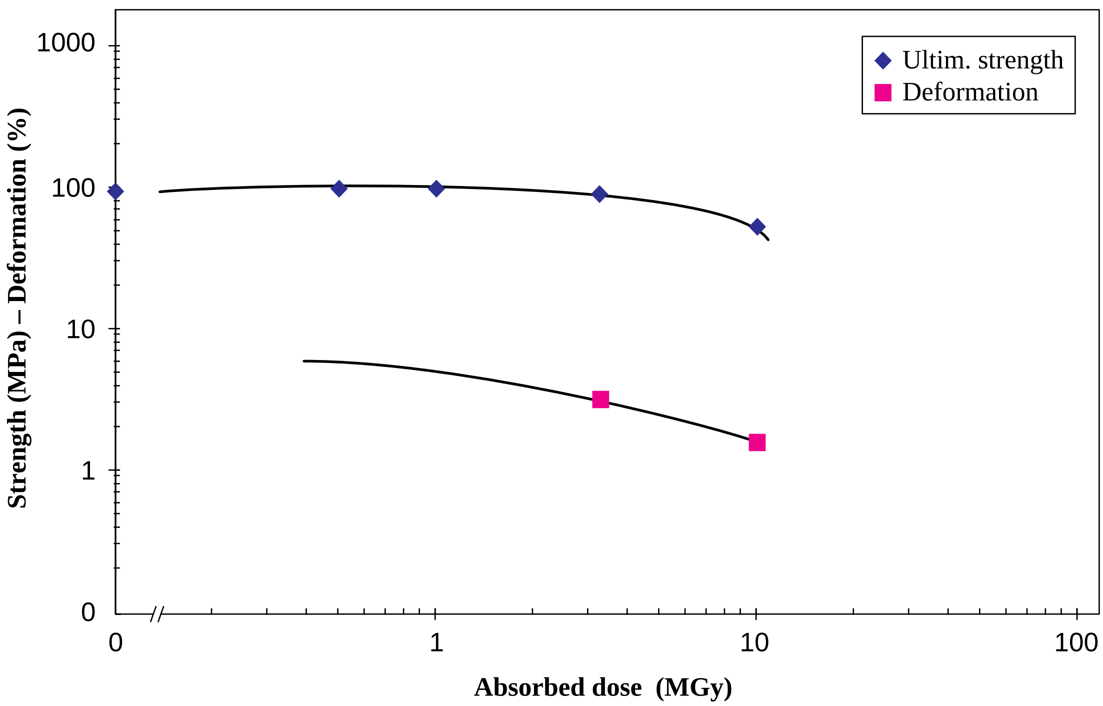
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **98**±2 | > **15** | **2.5**±0.1 |
| **4** | **0.5** | **101**±1 | > **15** | **2.6**±0.1 |
| **4** | **1** | **101**±3 | > **15** | **2.6**±0.2 |
| **220** | **3.2** | **91**±8 | **3.48**±0.03 | **3.11**±0.03 |
| **220** | **10** | **53**±6 | **1.76**±0.24 | **3.2**±0.1 |

Critical property = deformation

Radiation index (RI) = 6 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 528**



| | | |
|---|---|---|
| Material: | **Polyamide PA 6** | TIS No. **R 529** |
| Type | **Ertalon LFX** | |
| Supplier: | **Erta-Epec** | UL 94: V-2 |
| Remarks: | = 6 PLA + lubricant | LOI: |

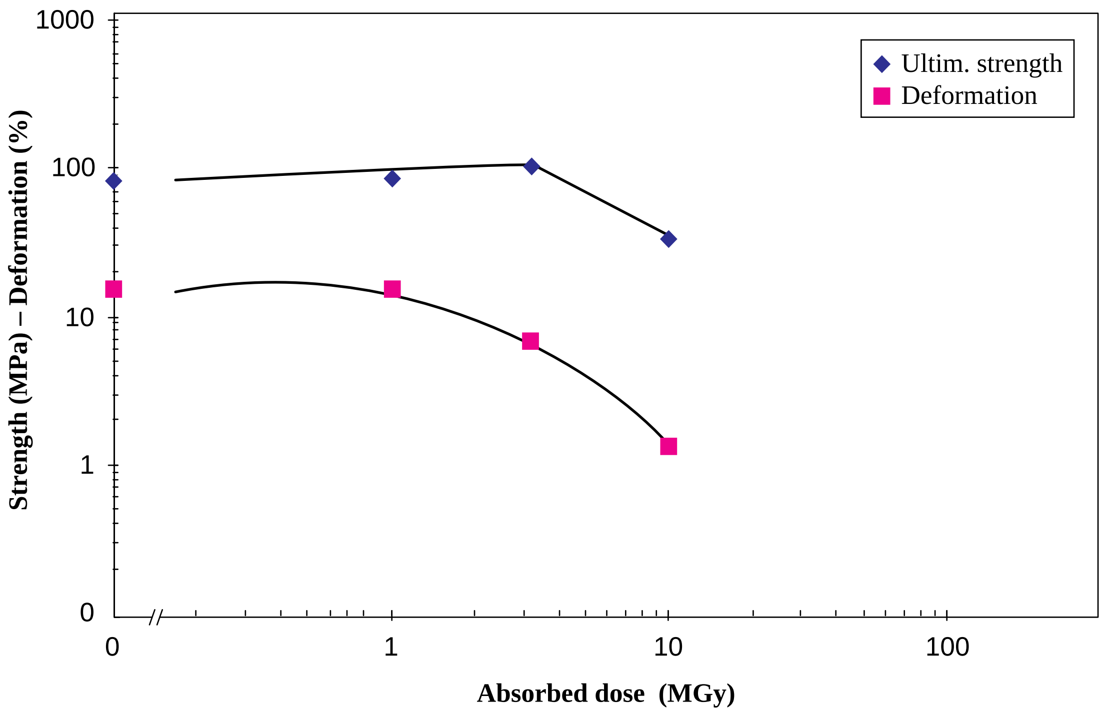
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **84.4**±1.3 | > **15** | **2.07**±0.05 |
| **4.0** | **1** | **85.4**±3.6 | > **15** | **2.18**±0.22 |
| **220** | **3.20** | **105.3**±3.2 | **6.82**±0.64 | **2.80**±0.02 |
| **220** | **10** | **34.5**±4.9 | **1.32**±0.18 | **2.80**±0.09 |

Critical property = deformation

Radiation index (RI) = 6 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 529**



| | | |
|---|---|---|
| Material: | **Polyamide PA 6** | TIS No. **R 530** |
| Type | **Ertalon 6 XAU+** | |
| Supplier: | **Erta-Epec** | UL 94: V-2 |
| Remarks: | = 6 PLA + heat stabilizer | LOI: |

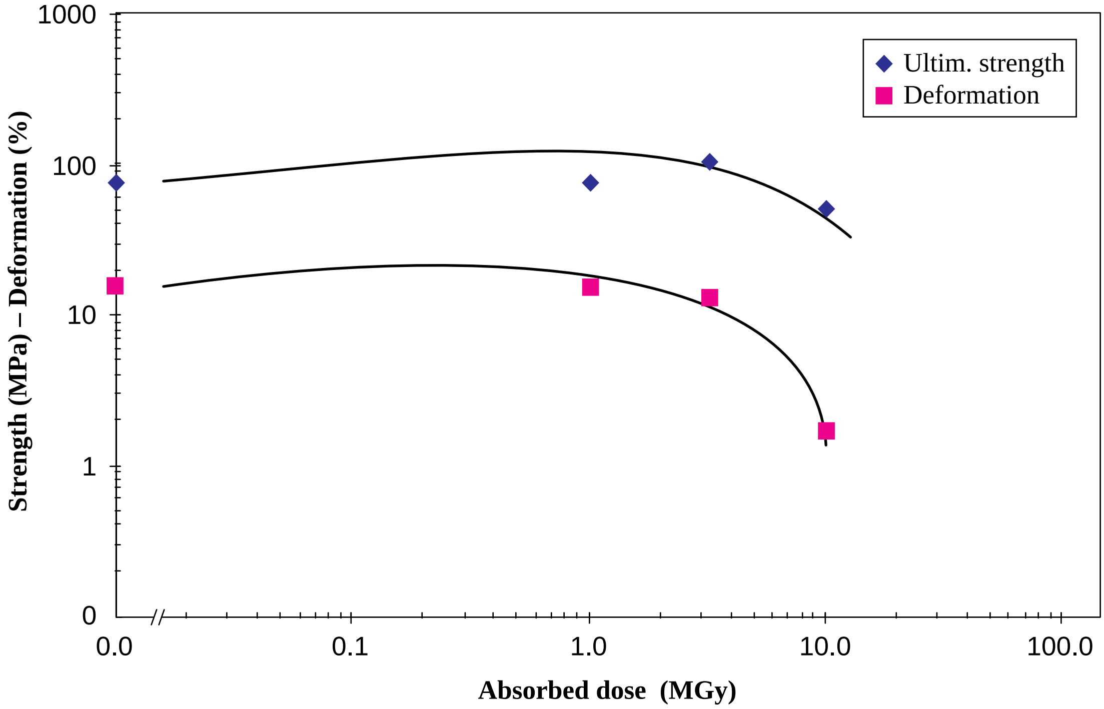
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **76.1**±2.2 | > **15** | **1.84**±0.08 |
| **4.0** | **1** | **77.1**±2.1 | > **15** | **1.84**±0.12 |
| **220** | **3.2** | **107.6**±1.3 | **13.8**±2.4 | **2.42**±0.12 |
| **220** | **10** | **51.9**±13.1 | **1.7**±0.4 | **3.18**±0.06 |

Critical property = deformation

Radiation index (RI) = 6.5 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 530**



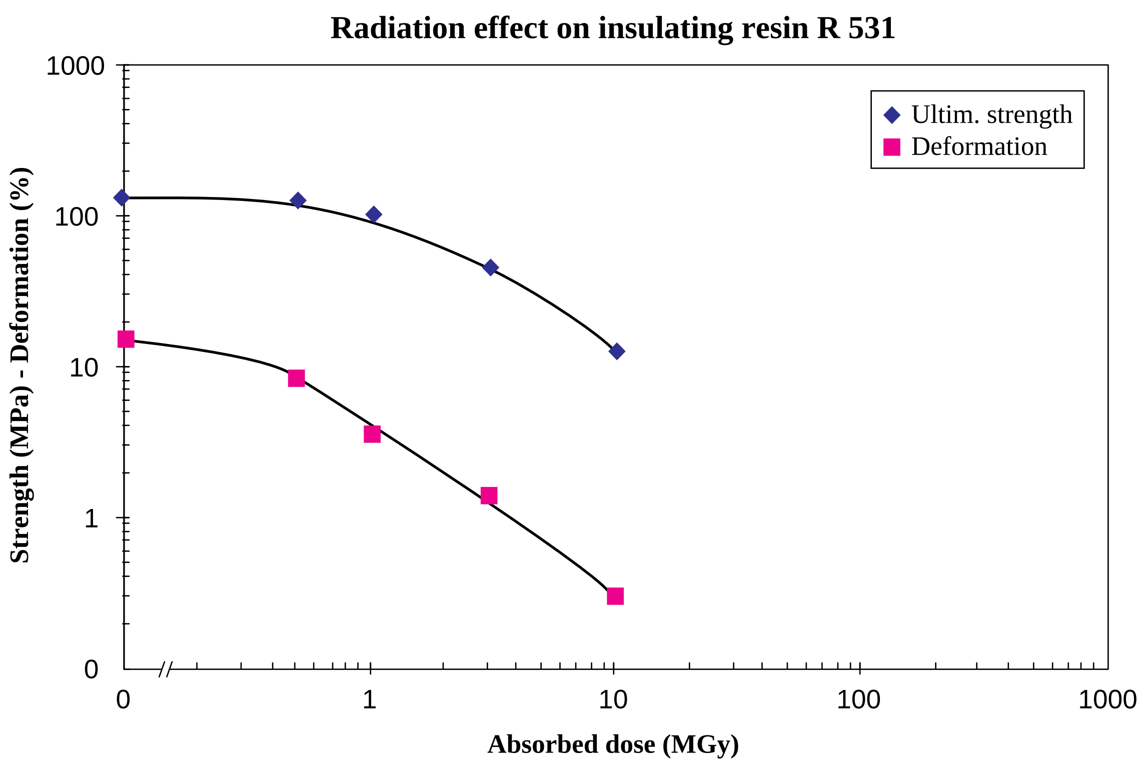
| | | |
|---|---|---|
| Material: | **Polyethylene terephtalate PETP** | TIS No. **R 531** |
| Type | **Ertalyte** | |
| Supplier: | **Erta-Epec** | UL 94: HB |
| Remarks: | no additives | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **135**±2 | **> 15** | **3.28**±0.12 |
| **4.00** | **0.50** | **129**±5 | **8.57**±4.71 | **3.25**±0.06 |
| **4.00** | **1** | **105**±9 | **3.59**±0.52 | **3.20**±0.09 |
| **220** | **3** | **47.4**±7 | **1.44**±0.20 | **3.53**±0.04 |
| **220** | **10** | **13**±*** | **0.31**±*** | **3.66**±*** |

Critical property = deformation

Radiation index (RI) = 5.7 at a mean dose rate of 4 kGy/h




Comment: At 10 MGy, only one sample was tested; the others were already broken.

| | | |
|---|---|---|
| Material: | **Polyethylene terephtalate PETP** | TIS No. **R 532** |
| Type | **Ertalyte TX** | |
| Supplier: | **Erta-Epec** | UL 94: HB |
| Remarks: | = PETP + lubricant | LOI: |

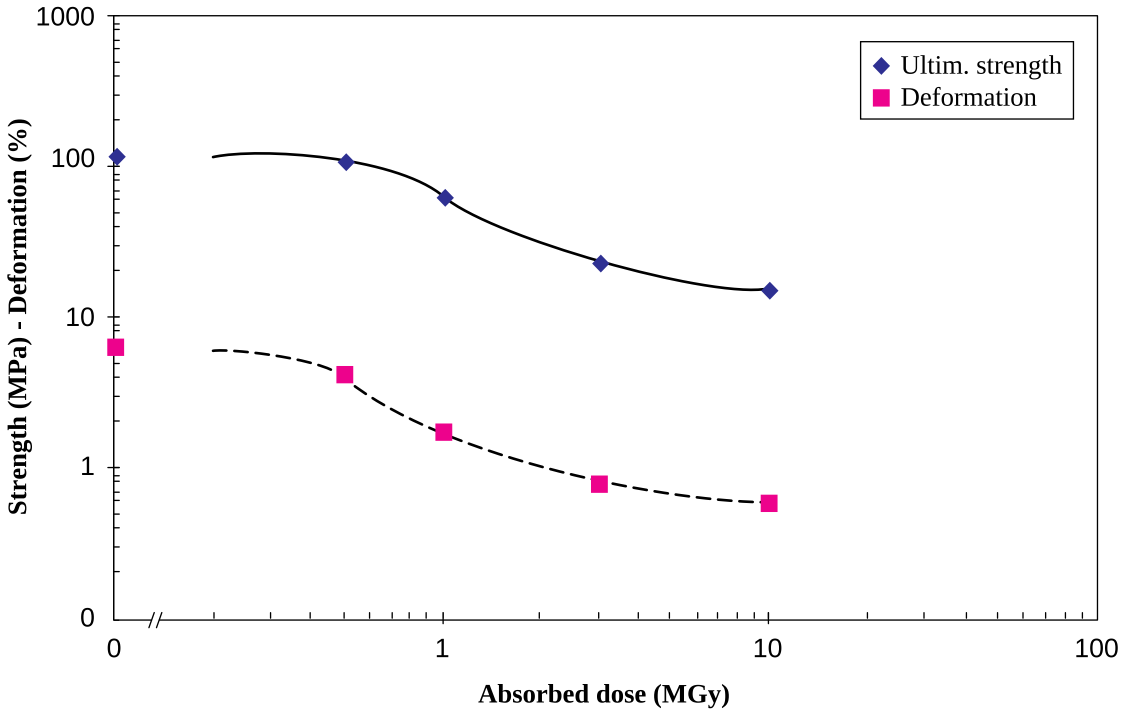
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **120**±4 | **6.37**±0.27 | **3.05**±0.05 |
| **4.0** | **0.50** | **107**±3 | **4.16**±0.11 | **3.20**±0.08 |
| **4.0** | **1** | **64**±14 | **1.75**±0.15 | **3.18**±0.19 |
| **220** | **3** | **24**±3 | **0.77**±0.08 | **3.48**±0.14 |
| **220** | **10** | **15**±1 | **0.57**±0.04 | **3.14**±0.23 |

Critical property = deformation

Radiation index (RI) = 8 at a mean dose rate of 4 kGy/h

**Radiation effect on insulating resin R 532**



| | | |
|---|---|---|
| Material: | **Polyetherimide** | TIS No. **R 533** |
| Type | **Erta PEI** | |
| Supplier: | **Erta-Epec** | UL 94: V-0 |
| Remarks: | based on Ultem 1000 | LOI: |

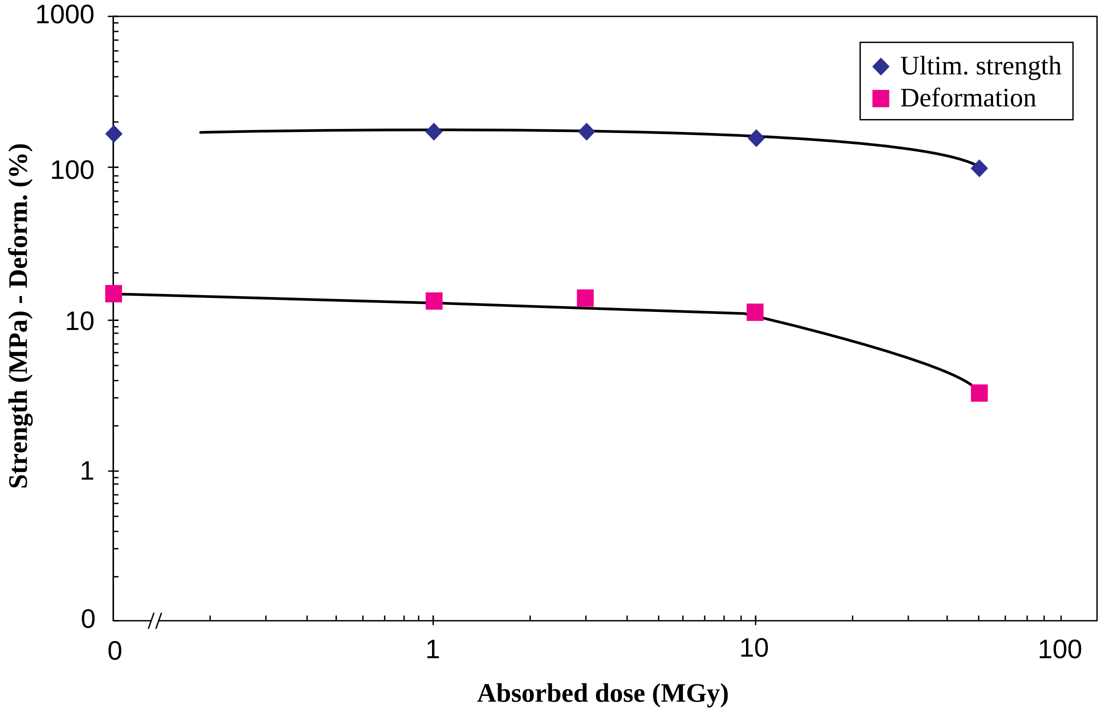
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **171**±1 | > **15** | **3.15**±0.05 |
| **4.0** | **1** | **174**±2 | > **15** | **3.23**±0.08 |
| **220** | **3** | **180**±1 | > **15** | **3.27**±0.07 |
| **220** | **10** | **158**±29 | **10.9**±5.6 | **3.16**±0.02 |
| **220** | **50** | **102**±7 | **3.3**±0.2 | **3.31**±0.04 |

Critical property = deformation

Radiation index (RI) = > 7.7 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 533**



| | | |
|---|---|---|
| Material: | **Polyethersulfone** | TIS No. **R 534** |
| Type | **Erta PES** | |
| Supplier: | **Erta-Epec** | UL 94: V-0 |
| Remarks: | based on Victrex | LOI: |

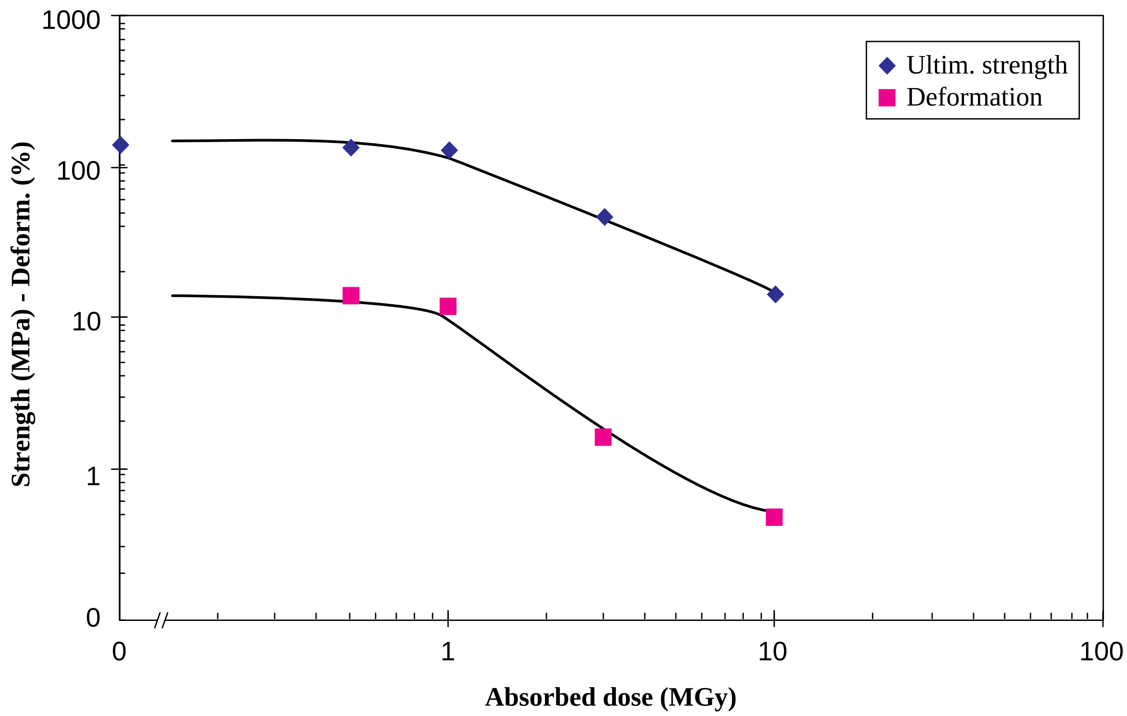
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0.00** | **141**±1 | > **15** | **2.70**±0.05 |
| **4.0** | **0.50** | **134**±1 | > **15** | **2.79**±0.12 |
| **4.0** | **1** | **132**±5 | **11.6**±4.6 | **2.92**±0.07 |
| **220** | **3** | **46.9**±3.4 | **1.7**±0.1 | **3.07**±0.06 |
| **220** | **10** | **14.3**±6.3 | **0.5**±0.2 | **3.28**±0.27 |

Critical property = deformation

Radiation index (RI) = 6.3 at a mean dose rate of 220 kGy/h

**Radiation effect on Erta-PES  R 534**



| | | |
|---|---|---|
| Material: | **Polysulfone** | TIS No. **R 535** |
| Type | **Erta PSU** | |
| Supplier: | **Erta-Epec** | UL 94: HB |
| Remarks: | based on Udel P 3500 | LOI: |

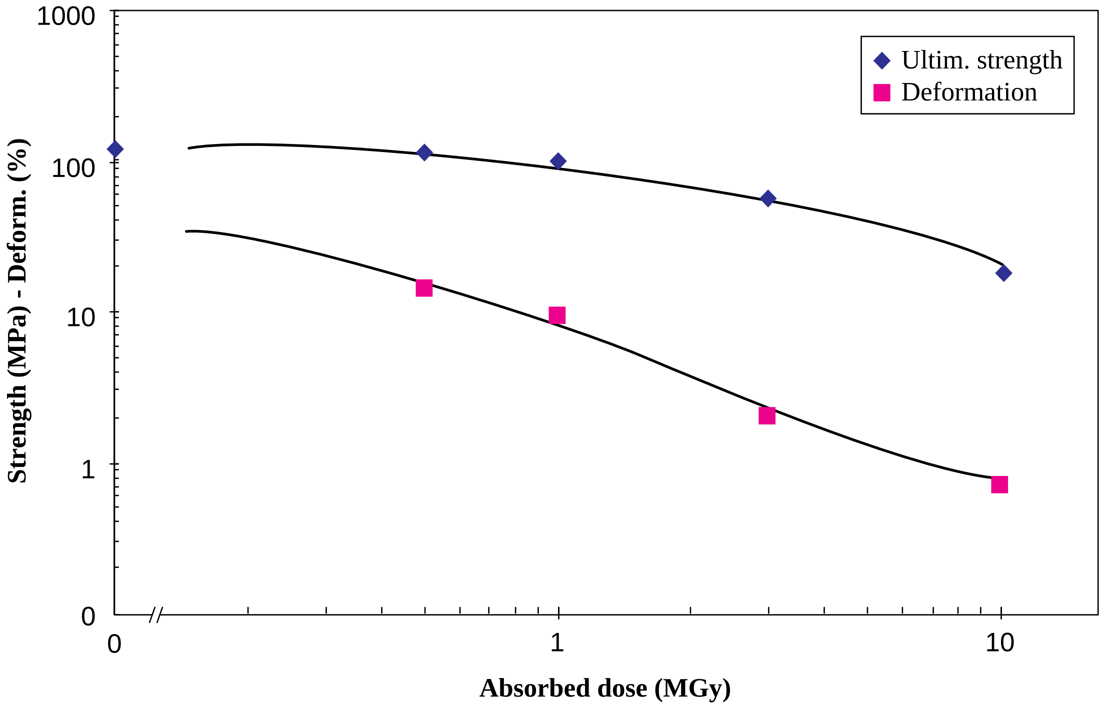
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **120**±1 | > **15** | **2.59**±0.05 |
| **4** | **0.50** | **114**±0.3 | > **15** | **2.70**±0.05 |
| **4** | **1** | **102**±11 | **9.6**±6.7 | **2.75**±0.04 |
| **220** | **3** | **58**±3 | **2.08**±0.11 | **2.95**±0.03 |
| **220** | **10** | **19**±3 | **0.71**±0.09 | **3.02**±0.12 |

Critical property = flexural strength

Radiation index (RI) = 6.5 at a mean dose rate of 110 kGy/h

**Radiation effect on PSU R 535**



| | | |
|---|---|---|
| Material: | **Polyamide PA 6** | TIS No. **R 536** |
| Type | **Ertalon 6 SA** | |
| Supplier: | **Erta-Epec** | UL 94: V-2 |
| Remarks: | extruded | LOI: |

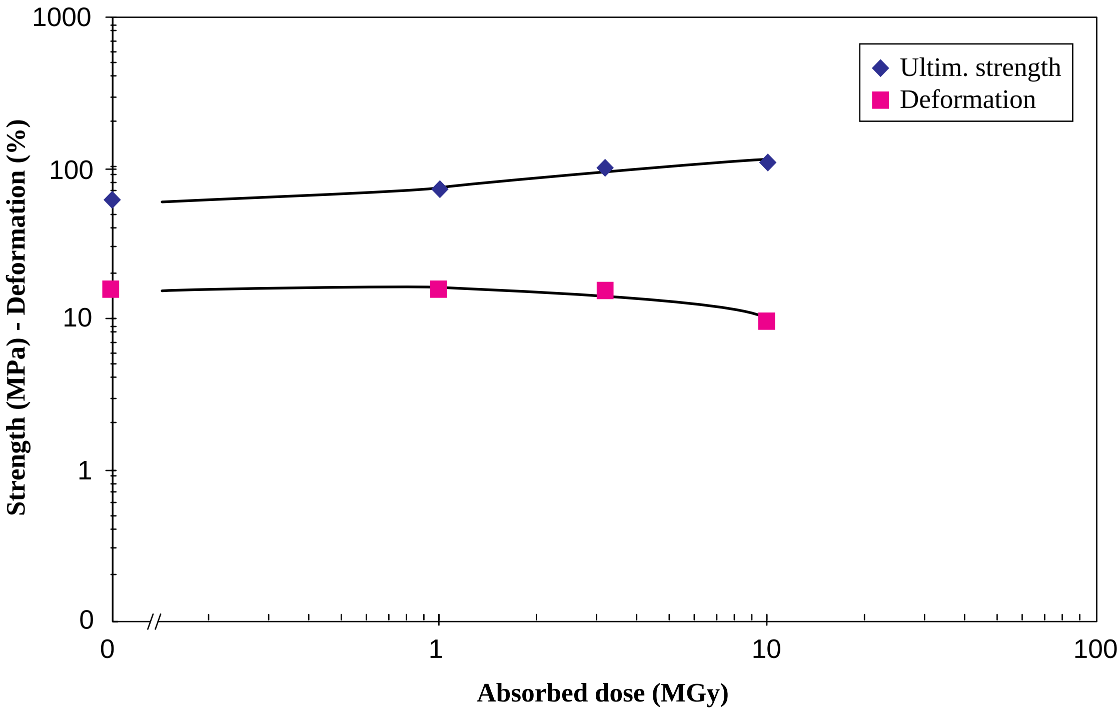
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0.10** | **63.4**±1.7 | > **15** | **1.38**±0.03 |
| **4.0** | **1** | **72.7**±1.0 | > **15** | **1.59**±0.05 |
| **220** | **3.30** | **100.7**±0.9 | > **15** | **2.37**±0.70 |
| **220** | **10** | **109.9**±36 | **9.47**±6.13 | **2.88**±0.04 |

Critical property = deformation

Radiation index (RI) ~ 7 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 536**



| | | |
|---|---|---|
| Material: | **Polyamide PA 66** | TIS No. **R 537** |
| Type | **Ertalon 66 SA** | |
| Supplier: | **Erta-Epec** | UL 94: V-2 |
| Remarks: | extruded | LOI: |

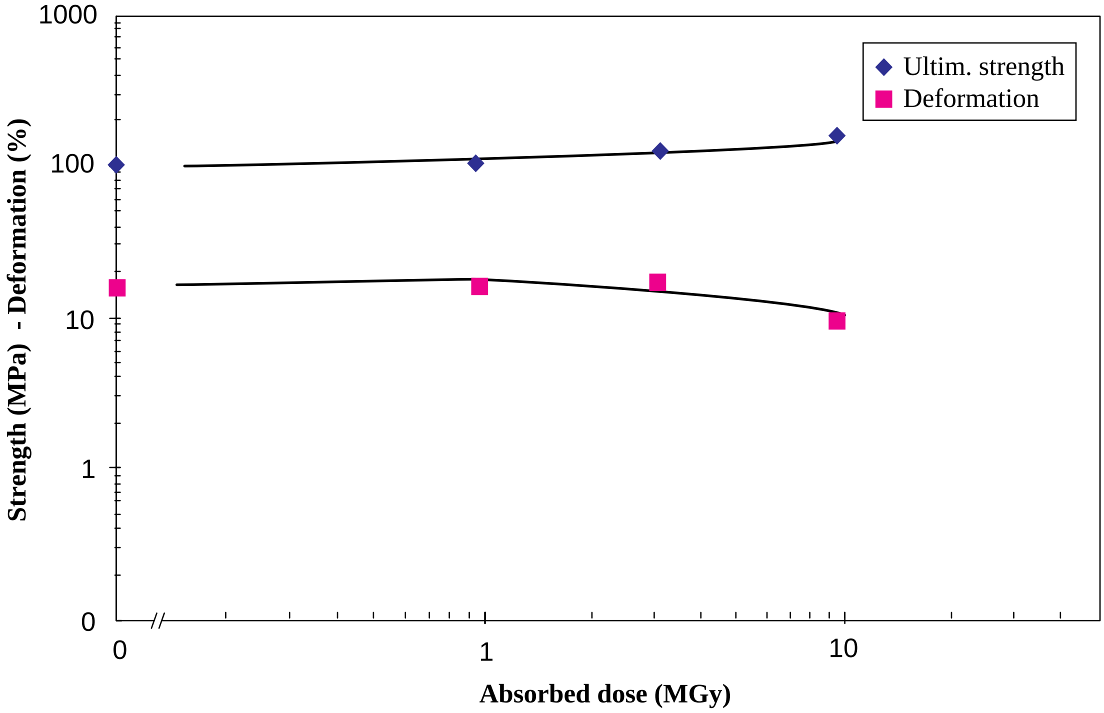
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **102**±3 | > **15** | **2.4**±0.1 |
| **4** | **1** | **110**±1 | > **15** | **2.6**±0.1 |
| **220** | **5** | **125**±10 | **7.7**±2.4 | **3.0**±0.1 |
| **230** | **10** | **67**±16 | **2.1**±0.5 | **3.2**±0.1 |

Critical property = deformation

Radiation index (RI) = 6.5 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 537**



| | | |
|---|---|---|
| Material: | **Polyarylate** | TIS No. **R 542** |
| Type | **ISARYL 15 M** | |
| Supplier: | **Isonova** | UL 94: V-0 |
| Remarks: | moulded | LOI: 33% |

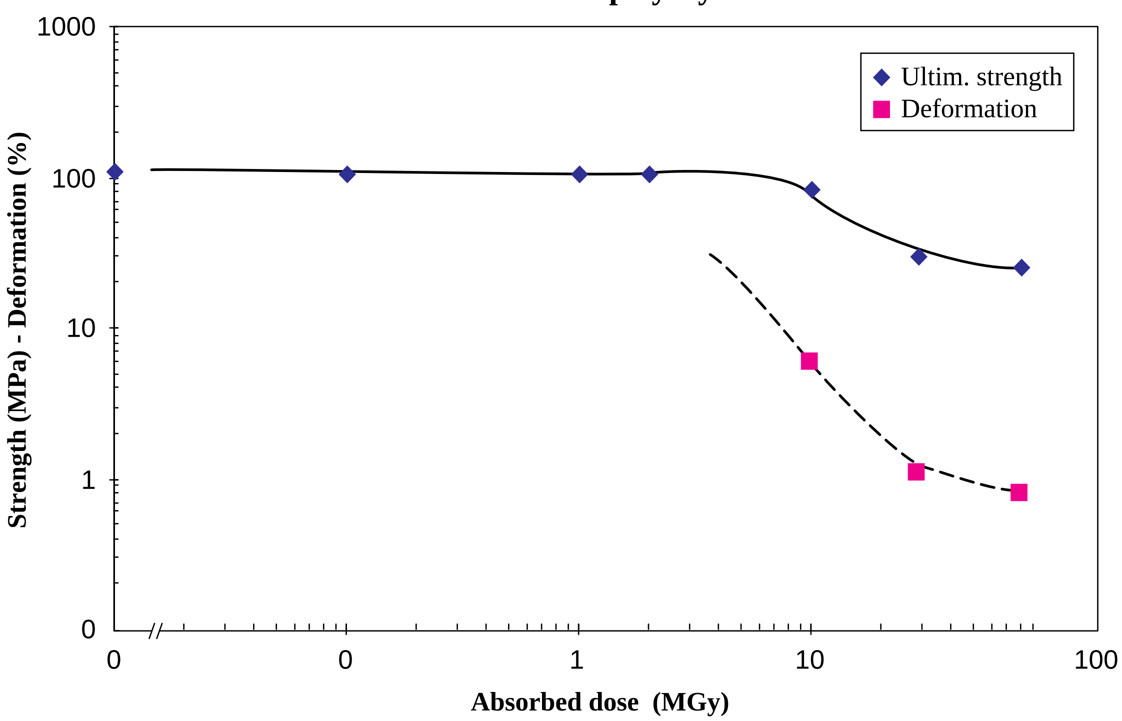
### Radiation test results according to IEC Standard 544 (and ISO 178)

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **110**±4 | > **12** | **2.4**±0.1 |
| **3.6** | **0.1** | **107**±2 | > **12** | **2.4**±0.1 |
| **220** | **1** | **107**±3 | > **12** | **2.5**±0.1 |
| **1.0** | **2** | **105**±2 | > **12** | **2.7**±0.1 |
| **220** | **10** | **83**±11 | **6.1**±5.3 | **2.9**±0.1 |
| **230** | **29** | **31**±13 | **1.1**±0.4 | **3.1**±0.0 |
| **180** | **80** | **26**±5 | **0.8**±0.2 | **3.4**±0.2 |

Critical property = deformation

Radiation index (RI) = 6.3 at a mean dose rate of 220 kGy/h

### Radiation effect on polyarylate R 542



| | | |
|---|---|---|
| Material: | **Polyaryl ether ketone (PAEK)** | TIS No. **R 563** |
| Type | **Stilan/Ultrapek** | |
| Supplier: | **Raychem BASF** | UL 94: n.m. |
| Remarks: | | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

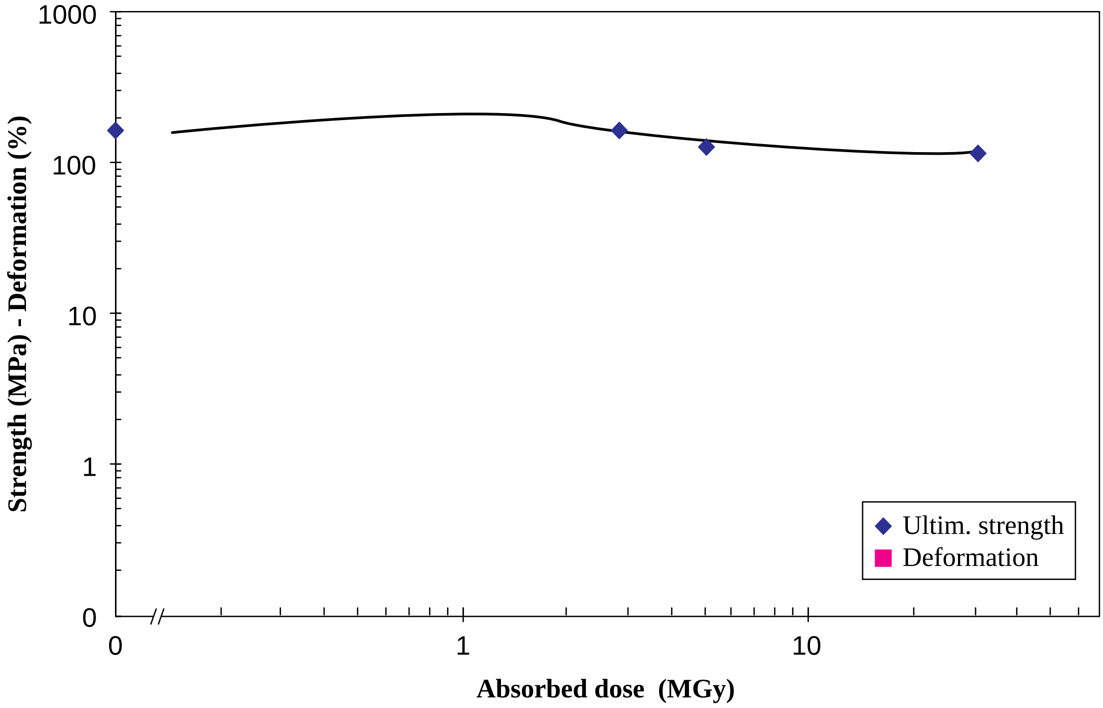
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **153**±4 | > **6** | **5.46**±0.38 |
| **1** | **3** | **153**±7 | > **6** | **5.46**±0.42 |
| **1** | **5** | **132**±2 | > **6** | **4.52**±0.22 |
| **225** | **30** | **117**±5 | > **6** | **4.12**±0.18 |

Critical property = flexural stregth

Radiation index (RI) = > 7.5 at a mean dose rate of 225 kGy/h

Radiation index (RI) = > 6.7 at a mean dose rate of 1 kGy/h

**Radiation effect on PAEK - R 563**




Comment: Samples don’t break.

| | | |
|---|---|---|
| Material: | **Polyimide** | TIS No. **R 568** |
| Type | **Vespel SP-1** | |
| Supplier: | **DuPont** | UL 94: n.m. |
| Remarks: | via Erta-Epec | LOI: |

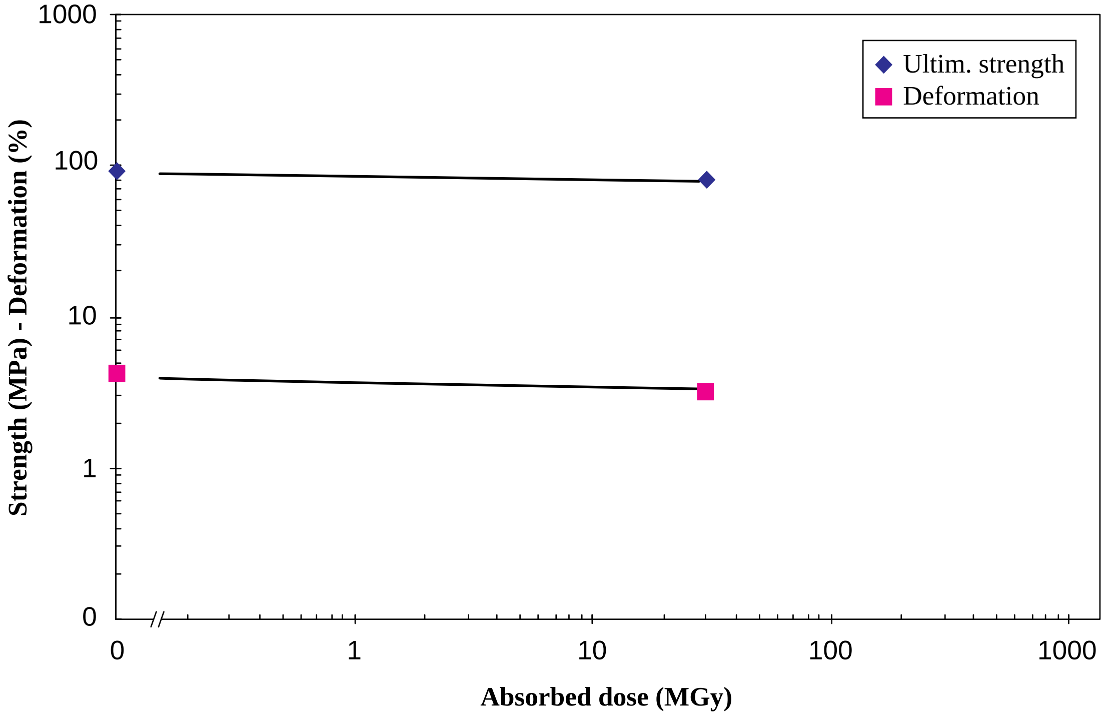
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **91.9**±7.7 | **4.18**±0.64 | **2.52**±1.22 |
| **225** | **30** | **80.8**±15.2 | **3.09**±0.75 | **3.20**±0.07 |

Critical property = flexural strength

Radiation index (RI) = > 7.5 at a mean dose rate of 225 kGy/h

**Radiation effect on Vespel SP-1 - R 568**



| | | |
|---|---|---|
| Material: | **Polyphenylsulfone (PPS) + glass fibres** | TIS No. **R 569** |
| Type | **Ertaxel** | |
| Supplier: | **Erta-Epec** | UL 94: n.m. |
| Remarks: | contains PTFE as lubricant | LOI: |

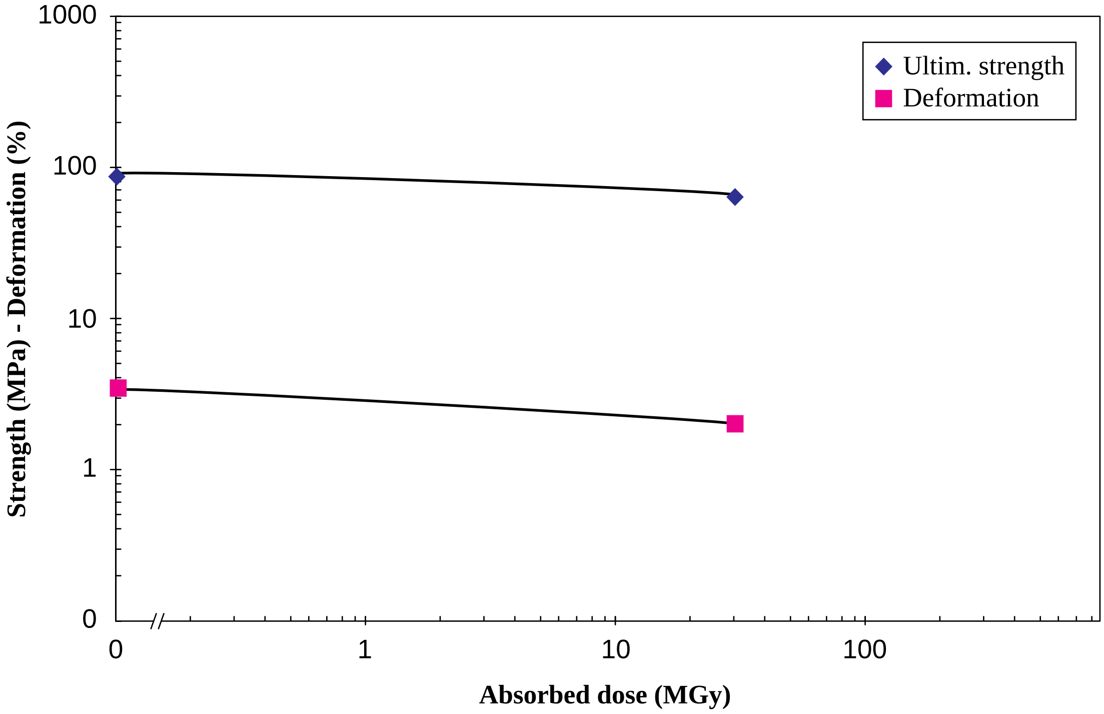
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **89.3**±2.3 | **3.32**±0.04 | **3.29**±0.09 |
| **225** | **30** | **64.5**±2.6 | **1.99**±0.09 | **3.52**±0.13 |

Critical property = flexural strength

Radiation index (RI) > 7.5 at a mean dose rate of 225 kGy/h

**Radiation effect on Ertaxek - R 569**



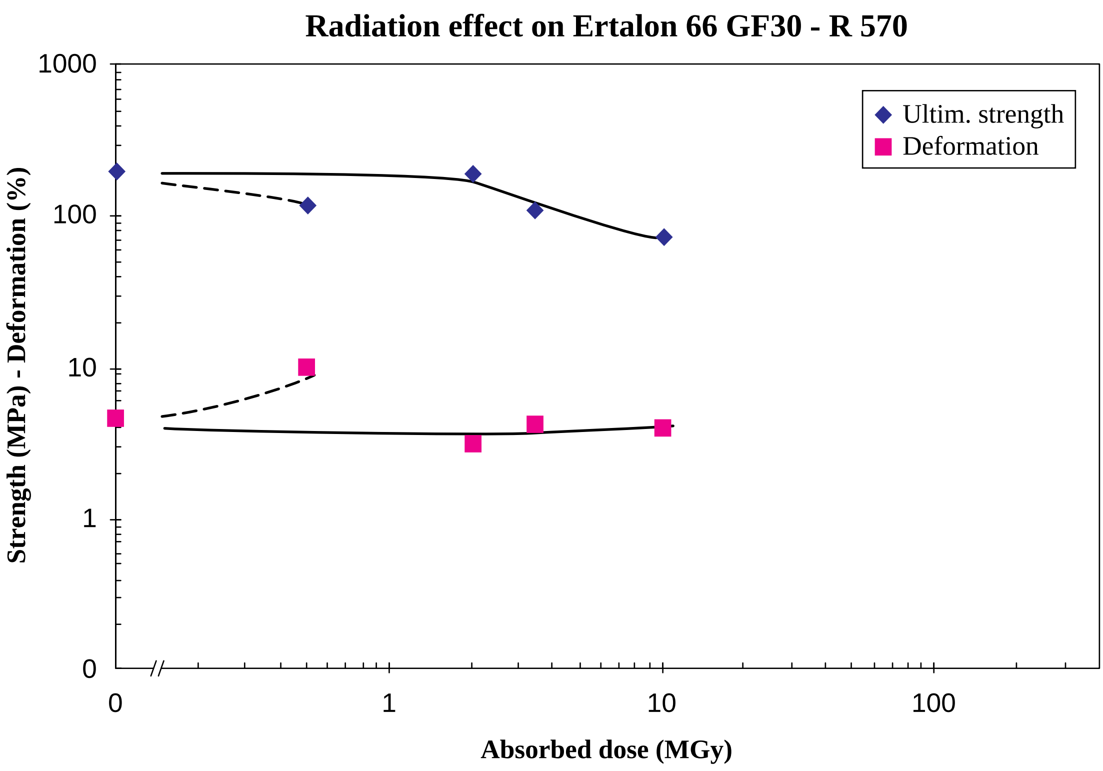
| | | |
|---|---|---|
| Material: | **Polyamide (PA)66 + 30% glass fibres** | TIS No. **R 570** |
| Type | **Ertalon 66 GF 30** | |
| Supplier: | **ERTA** | UL 94: n.m. |
| Remarks: | | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **197**±1 | **4.58**±0.31 | **5.76**±0.27 |
| **0.1** | **0.5** | **117**±8 | **9.95**±1.36 | **3.18**±0.44 |
| **1** | **2** | **188**±2 | **3.11**±0.08 | **6.19**±0.24 |
| **220** | **3.4** | **110**±9 | **4.14**±0.54 | **3.84**±0.30 |
| **240** | **10** | **71**±15 | **3.91**±1.07 | **2.52**±0.18 |

Critical property = flexural strength

Radiation index (RI) 6.7 at a mean dose rate of 240 kGy/h




Comments: Dotted lines correspond to long-term irradiation.
Young’s modulus is also affected by radiation.

| | | |
|---|---|---|
| Material: | **Polyoximethylene resin (POM)** | TIS No. **R 571** |
| Type | **Ertacetal C** | |
| Supplier: | **Erta - Epec** | UL 94: |
| Remarks: | also called acetal resin | LOI: |

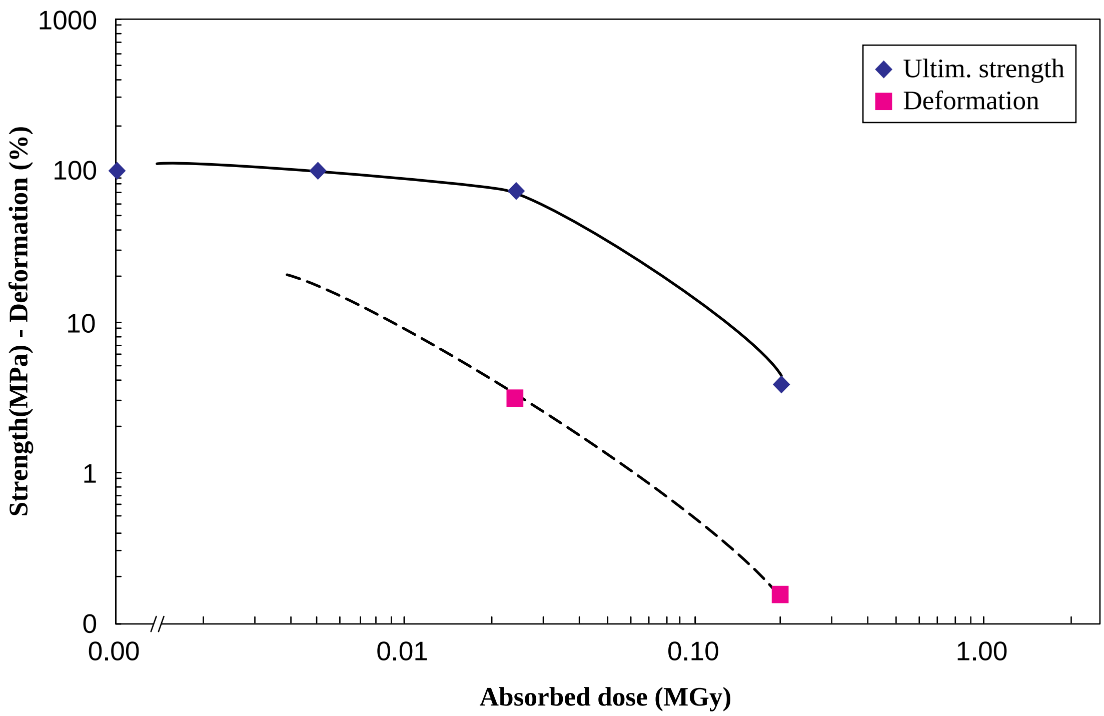
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **101**±2 | > **15** | **3.09**±0.04 |
| **0.01** | **0.005** | **101**±2 | > **15** | **2.95**±0.06 |
| **0.04** | **0.024** | **74**±3 | **3.07**±0.21 | **3.00**±0.14 |
| **4** | **0.200** | **4**±0.6 | **0.15**±0.01 | **2.72**±0.30 |

Critical property = deformation

Radiation index (RI) = ≈ 4 at a mean dose rate of 40 kGy/h

**Radiation effect on Acetal resin (POM) - R 571**




**Comment: Should not be used in a radiation environment.**

Material: **Polyethylene Cestidur** TIS No. **R 572**
Type **Borolene 4505**

Supplier: **ERTA** UL 94: n.m.
Remarks: LOI:

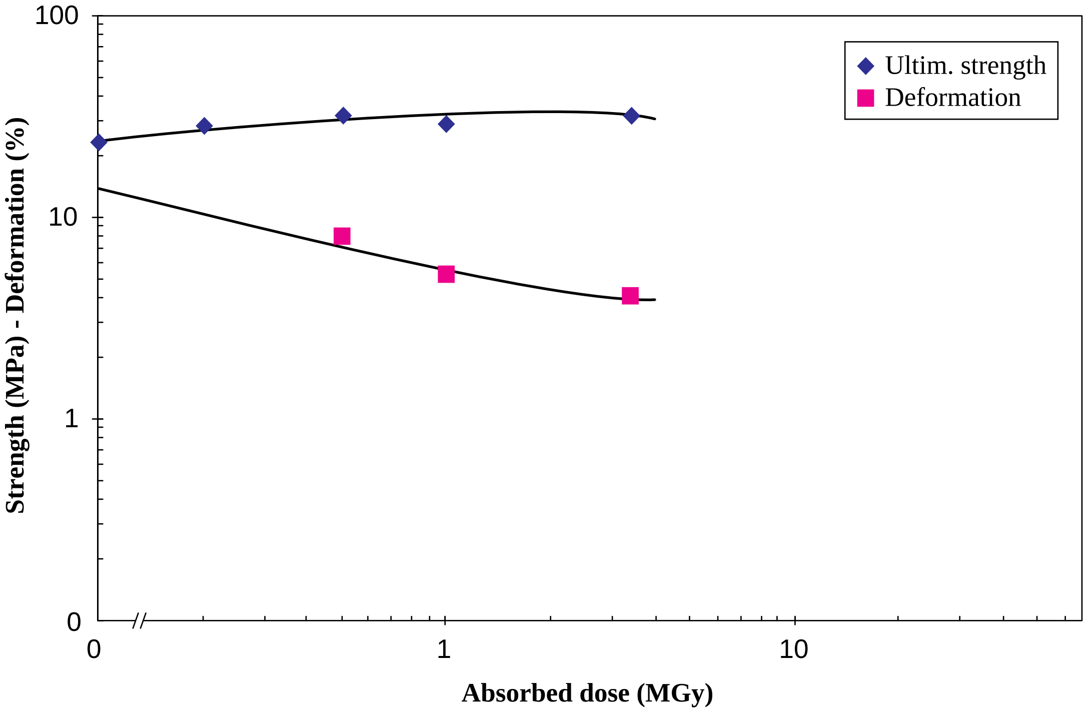
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **23.8**±0.2 | > **15** | **1.11**±0.06 |
| **4** | **0.2** | **28.7**±0.9 | > **15** | **1.47**±0.07 |
| **4** | **0.5** | **32.3**±0.4 | **7.90**±0.30 | **1.63**±0.02 |
| **1** | **1** | **28.9**±0.6 | **5.24**±0.43 | **1.62**±0.05 |
| **220** | **3.4** | **31.4**±0.7 | **4.01**±0.15 | **1.49**±0.06 |

Critical property = deformation

Radiation index (RI) = ~ 5.7 at a mean dose rate of 1 kGy/h

**Radiation effect on Cestidur PE - R 572**




Comment: Samples do not break before 0.5 MGy.

| | | |
|---|---|---|
| Material: | **Polyethylene Cestidur** | TIS No. **R 573** |
| Type | **Cestilene HD 1000** | |
| Supplier: | **ERTA - EPEC** | UL 94: n.m. |
| Remarks: | | LOI: |

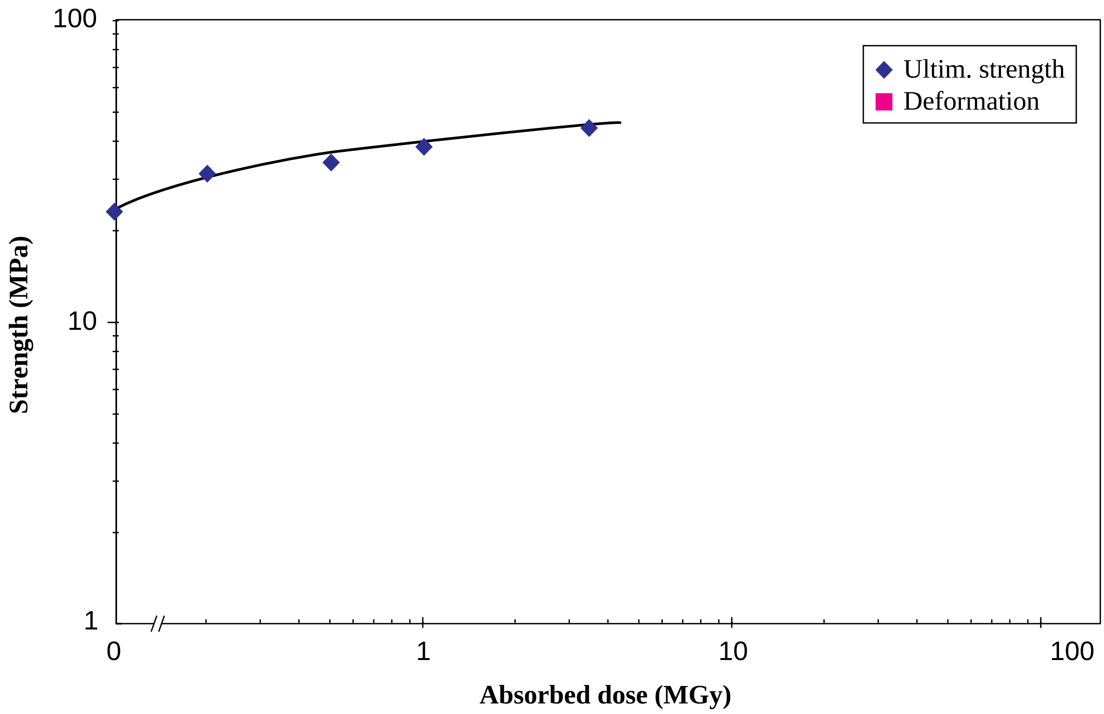
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **23.3**±0.5 | > **15** | **0.81**±0.01 |
| **4** | **0.2** | **31.2**±0.8 | > **15** | **1.18**±0.04 |
| **4** | **0.5** | **34.4**±1.1 | > **15** | **1.29**±0.06 |
| **1** | **1** | **38.6**±0.4 | > **15** | **1.56**±0.07 |
| **220** | **3.4** | **44.7**±0.8 | **8.6**±0.9 | **1.34**±0.07 |

Critical property = deformation

Radiation index (RI) = ~ 6 at a mean dose rate of 220 kGy/h

**Radiation effect on Cestidur PE - R 573**



| | | |
|---|---|---|
| Material: | **Polyethylene Cestidur** | TIS No. **R 574** |
| Type | **Cestilene HD 500** | |
| Supplier: | **ERTA - EPEC** | UL 94: n.m. |
| Remarks: | | LOI: |

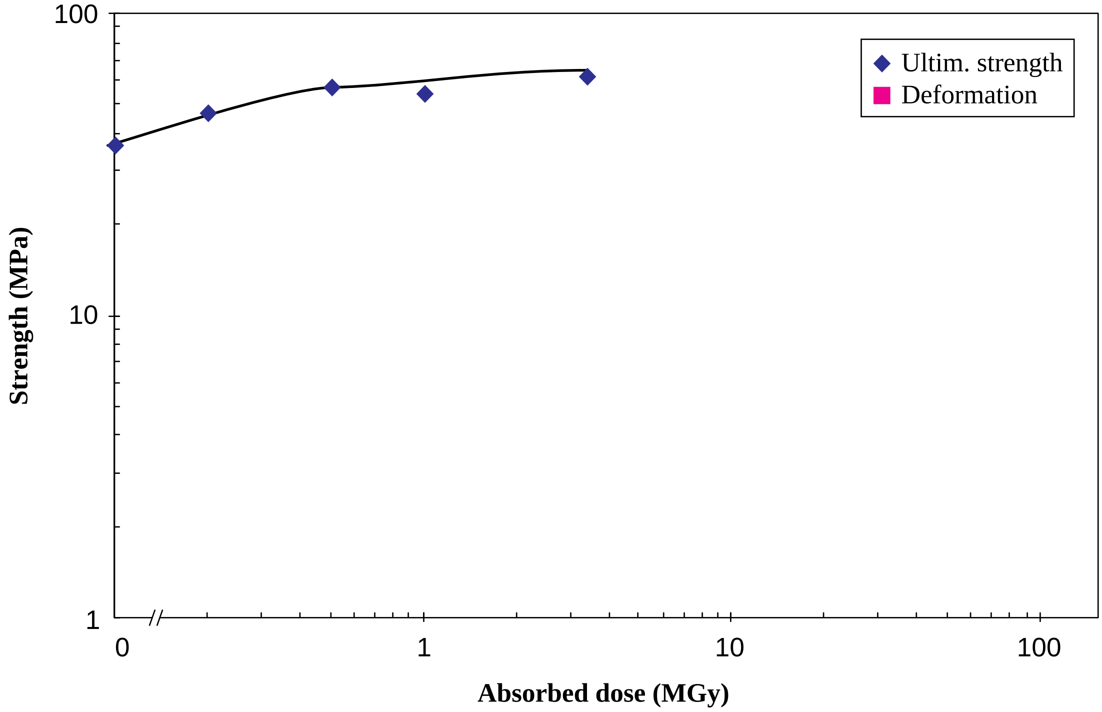
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **37.1**±0.8 | > **15** | **1.69**±0.08 |
| **4** | **0.2** | **46.9**±0.4 | > **15** | **2.10**±0.04 |
| **4** | **0.5** | **57.6**±0.5 | > **15** | **2.47**±0.08 |
| **1** | **1** | **54.6**±1.7 | > **15** | **2.31**±0.10 |
| **220** | **3.4** | **61.7**±0.9 | **9**±0.3 | **2.02**±0.03 |

Critical property = deformation

Radiation index (RI) = ~ 6.5 at a mean dose rate of 220 kGy/h

**Radiation effect on Cestidur PE - R 574**




Comment: Samples do not break before 3.4 MGy.

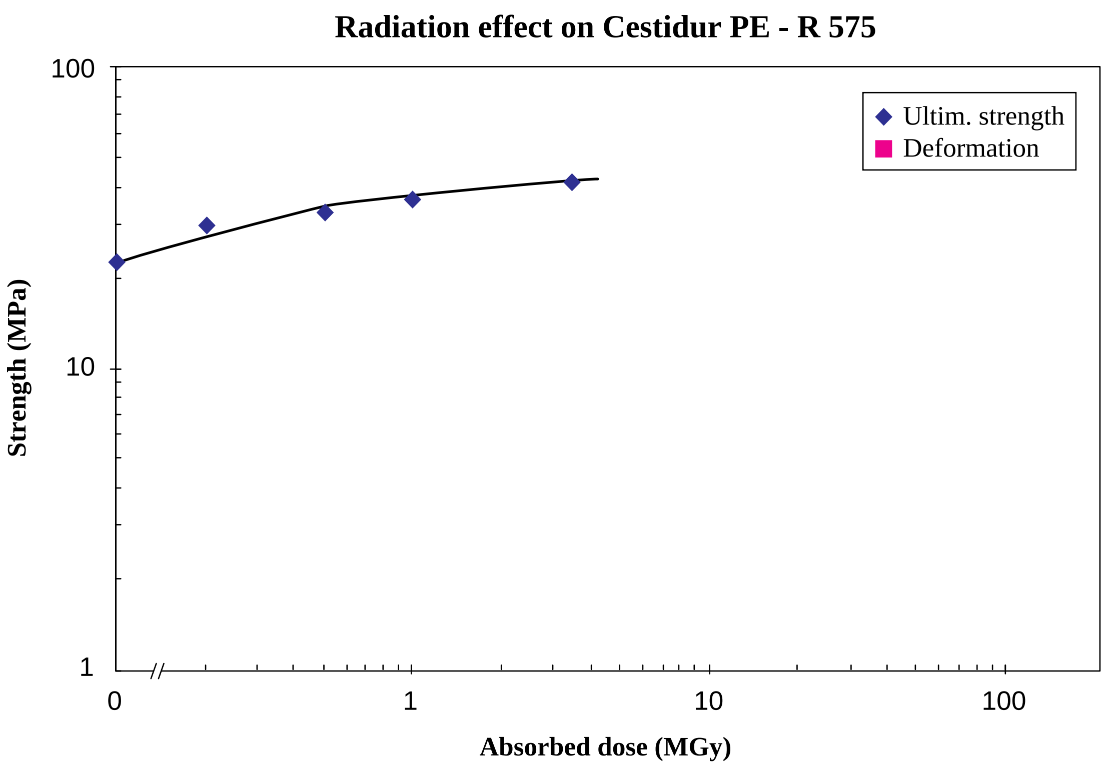
| | | |
|---|---|---|
| Material: | **Polyethylene Cestidur** | TIS No. **R 575** |
| Type | | |
| Supplier: | **ERTA - EPEC** | UL 94: n.m. |
| Remarks: | | LOI: |

### Radiation test results according to IEC Standard 544 (and ISO 178)

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **22.7**±0.2 | > **15** | **0.78**±0.01 |
| **4** | **0.2** | **30.0**±0.3 | > **15** | **1.09**±0.04 |
| **4** | **0.5** | **33.1**±0.4 | > **15** | **1.20**±0.04 |
| **1** | **1** | **36.3**±0.2 | > **15** | **1.39**±0.05 |
| **220** | **3.4** | **41.7**±0.3 | **9.3**±0.1 | **1.19**±0.03 |

Critical property = deformation

Radiation index (RI) = > 6.5 at a mean dose rate of 220 kGy/h




Comment: Samples do not break before 3.4 MGy.

| | | |
|---|---|---|
| Material: | **Polyethylene Cestidur** | TIS No. **R 576** |
| Type | **Cestitech** | |
| Supplier: | **ERTA - EPEC** | UL 94: n.m. |
| Remarks: | | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

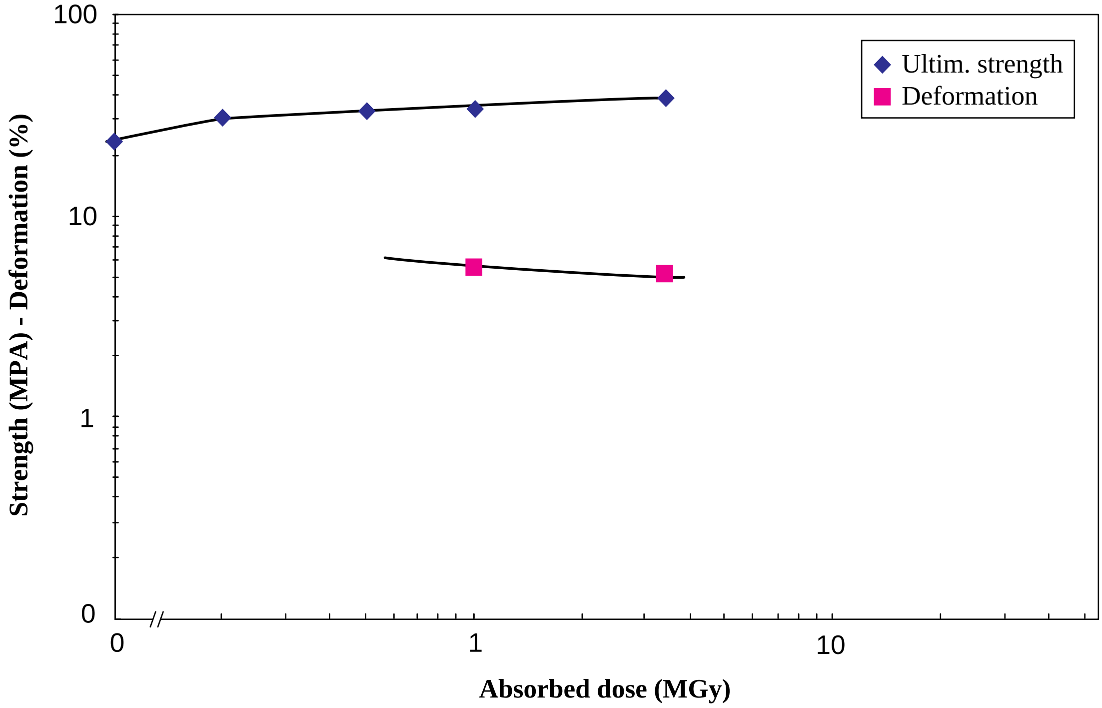
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **23.4**±0.6 | > **14** | **0.83**±0.05 |
| **4** | **0.2** | **31.1**±0.2 | > **14** | **1.15**±0.05 |
| **4** | **0.5** | **33.4**±1.2 | > **14** | **1.26**±0.11 |
| **1** | **1** | **34.7**±1.2 | **5.46**±0.53 | **1.56**±0.06 |
| **220** | **3.4** | **38.8**±0.6 | **5.10**±0.31 | **1.43**±0.03 |

Critical property = deformation

Radiation index (RI) = 5.9 at a mean dose rate of 1 kGy/h

Radiation index (RI) = 6.4 at a mean dose rate of 220 kGy/h

**Radiation effect on Cestidur PE - R 576**




Comment: Samples do not break before 1 MGy.

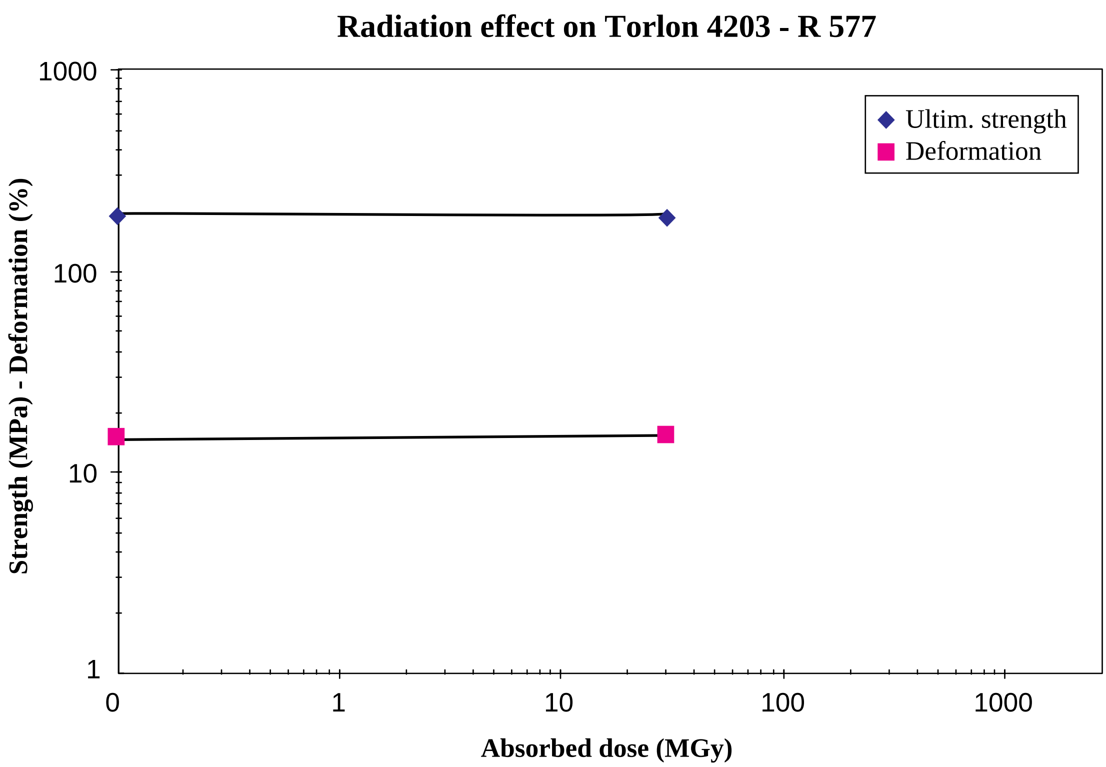
| | | |
|---|---|---|
| Material: | **Polyamide imide (PAI)** | TIS No. **R 577** |
| Type | **Torlon 4203** | |
| Supplier: | **DSM EPP** | UL 94: n.m. |
| Remarks: | | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **188**±3 | **14.96**±0.09 | **4.06**±0.03 |
| **225** | **30** | **191**±2 | **15.04**±0.05 | **4.27**±0.06 |

Critical property = flexural strength

Radiation index (RI) = > 7.5 at a mean dose rate of 225 kGy/h



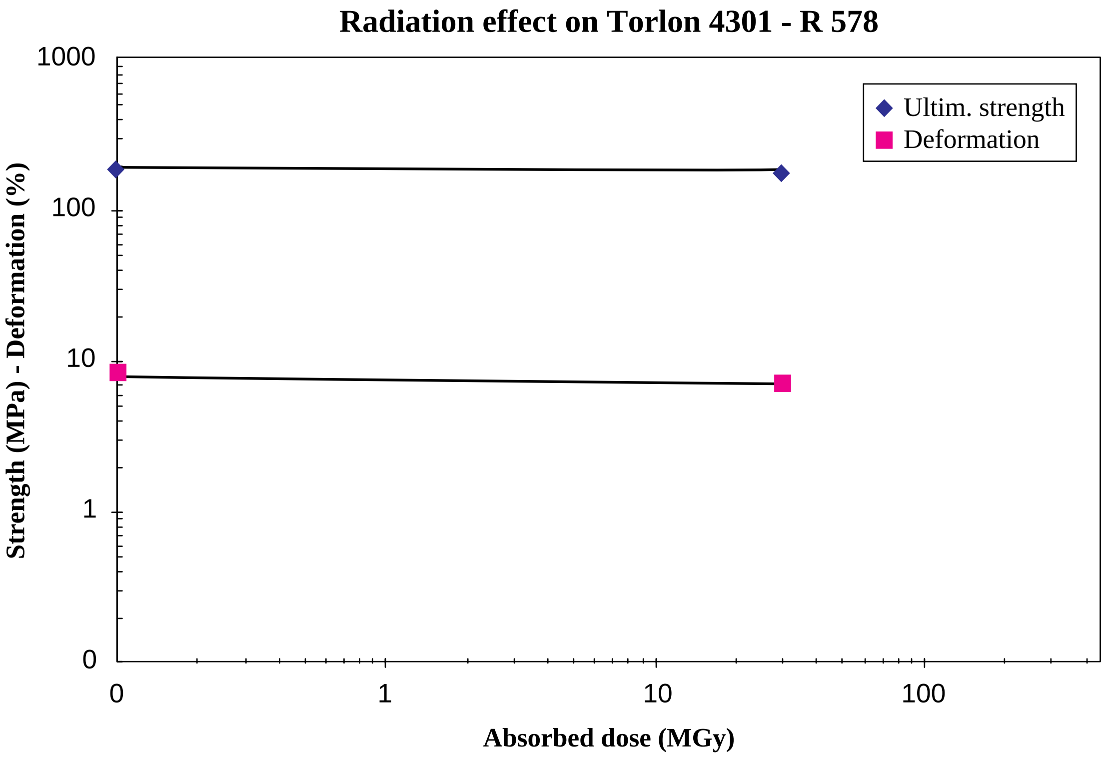
| | | |
|---|---|---|
| Material: | **Polyamide imide (PAI)** | TIS No. **R 578** |
| Type | **Torlon 4301** | |
| Supplier: | **DSM EPP** | UL 94: n.m. |
| Remarks: | | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **182**±4 | **7.88**±0.59 | **6.12**±0.13 |
| **225** | **30** | **181**±4 | **6.71**±0.50 | **6.01**±0.11 |

Critical property = flexural strength

Radiation index (RI) = > 7.5 at a mean dose rate of 225 kGy/h



# R

| | |
|---|---|
| Resofil | trade name of Micafil for phenolic resin, see Ref. [25]; RI < 5.7 |
| Rilsan | trade name of Atochem for polyamide; RI ~ 6 |
| Ryton | trade name of Phillips Petroleum Company for polyphenil sulfide (PPS), see Ref. [25] |

# S

| | |
|---|---|
| Samicanit | trade name of Isola for Mica and glass reinforced epoxy resins, see Ref. [25] |
| Samicapor | trade name of Isola for GFRP, see epoxy resin |
| Samicatherm | trade name of ANSALDO for Mica and glass reinforced epoxy resins, see Epoxy resin and Ref. [25] |
| Scotchcast | trade name of 3M for epoxy base compounds, see epoxy |
| Silicone resins | see Ref. [25]; RI > 7.7 |
| Siltem | trade name of General Electric Plastics for polyimide-silicones copolymer also for polyetherimide-siloxane copolymer, see also polyetherimide |
| Sintimid | trade name of Lenzing& Planzee for polyimide, see polyimide |
| Stilan | trade name by Raychem for PAEK |
| Styrene | |

Silicone-polyimide copolymer

## List of materials classified under letter S

| TIS number | Material name | Type | Mechanical properties | | | |
|---|---|---|---|---|---|---|
| | | | UTS (MPa) | Deform. (%) | Modulus (MPa) | RI |
| 544 | Silicones-polyimide copolymer | Siltem 1550 | 70.52 | > 10 | 1.84 | 6.5 |
| 418 | Styrene: cross-linked copolymer | PolypencoQ.200.5 | 89.7 | 4.3 | 3.2 | > 5.7 |

| | | |
|---|---|---|
| Material: | **Silicones-polymide copolymer** | TIS No. **R 544** |
| Type | **Siltem 1550** | |
| Supplier: | **General Electric Plastics** | UL 94: V-0 |
| Remarks: | | LOI: |

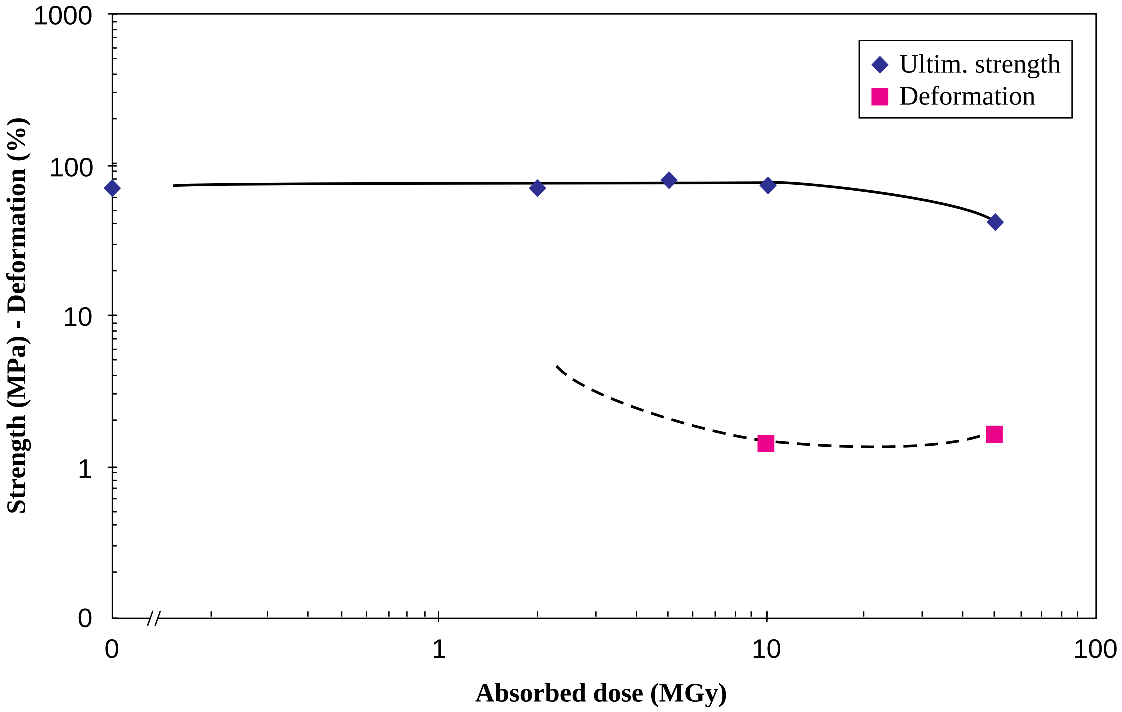
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **70.5**±0.6 | > **10** | **1.84**±0.01 |
| **1** | **2** | **71.2**±1.0 | > **10** | **1.96**±0.04 |
| **220** | **5** | **78.8**±3.2 | > **10** | **1.95**±0.10 |
| **220** | **10** | **74.8**±3.6 | **1.41**±0.10 | **5.88**±0.33 |
| **220** | **50** | **42.2**±1.3 | **1.66**±0.03 | **2.72**±0.10 |

Critical property = deformation

Radiation index (RI) = > 7.7 at a mean dose rate of 220 kGy/h

**Radiation effect on Siltem - R 544**



| | | |
|---|---|---|
| Material: | **Styrene: cross-linked copolymer** | TIS No. **R 418** |
| Type | **Polypenco Q.200.5** | |
| Supplier: | **Cellpack** | UL 94: |
| Remarks: | translucent | LOI: |

**Radiation test results according to IEC Standard 544 (and ISO 178)**

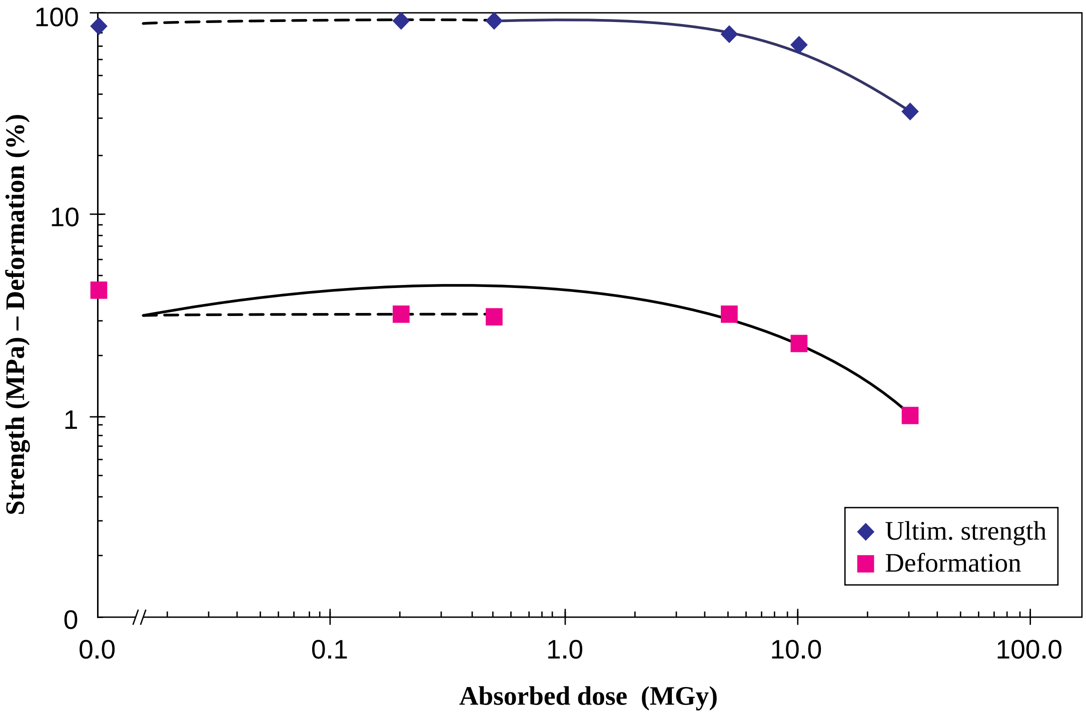
| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0.0** | **89.7**±6.4 | **4.3**±0.1 | **3.2**±0.1 |
| **0.1** | **0.2** | **96.6**±2.8 | **3.3**±0.1 | **3.2**±0.1 |
| **0.1** | **0.5** | **96.6**±1.5 | **3.2**±0.0 | **3.3**±0.1 |
| **160** | **5** | **83.1**±8.0 | **3.3**±1.0 | **3.3**±0.1 |
| **160** | **10** | **73.4**±5.5 | **2.3**±0.2 | **3.3**±0.1 |
| **160** | **30** | **33.1**±4.7 | **1.0**±0.1 | **3.2**±0.1 |

Critical property = deformation

Radiation index (RI) = 7.0 at a mean dose rate of 160 kGy/h

Radiation index (RI)= > 5.7 at a mean dose rate of 100 Gy/h

**Radiation effect on insulating resin R 418**




Comment: Dotted lines correspond to long-term irradiation.

# T

| | |
|---|---|
| Tedur | trade name of Bayer for polyphenylene sulfide, see PPS |
| Teflon | trade name of Dupont for PTFE; very sensitive to radiation; not to be used in radiation environments |
| Tefzel | trade name of Dupont for ETFE |
| Torlon | trade name of Polypenco for polyamide-imide, see PAI |

# U

| | |
|---|---|
| Udel | trade name of General Electric Plastics for polysulfone, see polysulfone |
| Ultem | trade name of General Electric Plastics for polyetherimide, see polyetherimide |
| Ultraform | trade name of BASF for acetal resin, see POM |
| Ultramid | trade name of BASF for polyamides |
| Ultrapek | trade name of BASF for polyaril-ether-ketone |
| Univolt | trade name of Dietzel Electro for PPO based plastics |

# V

| | |
|---|---|
| Varnish | |
| Vectra | trade name of Hoechst for liquid crystal polymer, see LCP |
| Veridur | trade name of BBC Baden for Silicone resin, see Ref. [25] |
| Vespel | trade name of Dupont for polyimide, see PI |
| Vetresit | trade name of MICAFIL for cycloaliphatic-epoxy, see epoxy resin |
| Vetronite | trade name of Von Roll Isola for epoxy resins, see epoxy resin |
| Victrex | trade name of ICI for polyether (-ether)-ketone, see PEEK |
| Vicotex | trade name of CIBA-GEIGY for carbon fibre reinforced epoxy laminate, see CFRP, and Ref. [35] for behaviour at cryogenic temperature |

## List of materials classified under letter V

| TIS number | Material name | Type | Mechanical properties | | | |
|---|---|---|---|---|---|---|
| | | | UTS (MPa) | Deform. (%) | Modulus (MPa) | RI |
| 519 | Varnish 4.302 | | 100 | 4.5 | 3.09 | > 7 |

| | | |
|---|---|---|
| Material: | **Varnish 4.302** | TIS No. **R 519** |
| Type | | |
| Supplier: | **Isola** | UL 94: n.m. |
| Remarks: | ex SIB 775 | LOI: |

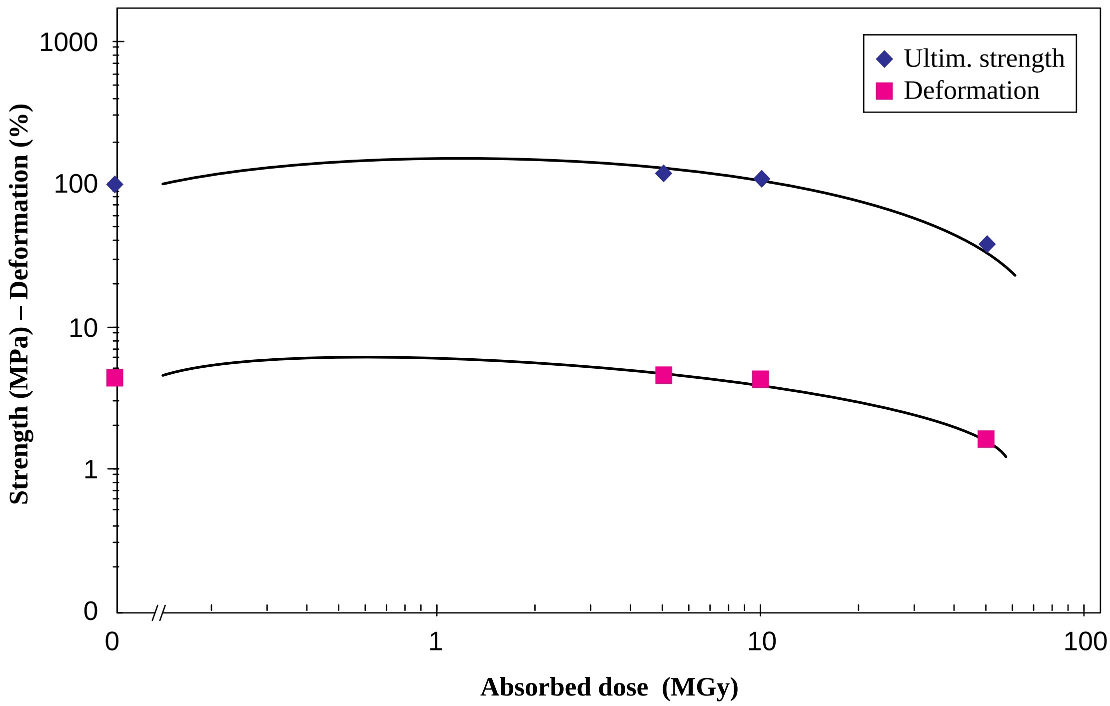
**Radiation test results according to IEC Standard 544 (and ISO 178)**

| Dose rate (kGy/h) | Dose (MGy) | Ultim. strength (MPa) | Deformation ε (%) | Modulus (GPa) |
|---|---|---|---|---|
| **0** | **0** | **100**±30 | **4.5**±1.7 | **3.09**±0.11 |
| **220** | **5** | **122**±7 | **4.54**±0.59 | **3.4**±0.1 |
| **220** | **10** | **112**±37 | **4.22**±1.77 | **3.56**±0.02 |
| **220** | **50** | **38.6**±3.6 | **1.60**±0.97 | **3.79**±0.09 |

Critical property = flexural strength

Radiation index (RI) = > 7.1 at a mean dose rate of 220 kGy/h

**Radiation effect on insulating resin R 519**



## APPENDIX 4

**List of abbreviations used in the present volume**
(for chemical abbreviation of polymers, see Tables 2a and 2b)

| | |
|---|---|
| ASTM | American Society for Testing and Materials |
| B | breadth of the samples (mm) |
| CEI | Commission Electrotechnique Internationale |
| D | maximum deflexion during the test (mm) |
| $\varepsilon$ | deformation = $\varepsilon = \frac{6DT}{L^2}$ (%) |
| F | deflexion interval in linear flexural curve (mm) |
| IEC | International Electrotechnical Commission |
| ISO | International Organization for Standardization |
| L | distance between supports of the flexion test = 67 mm |
| LOI | Limit of Oxygen Index (%) |
| M | flexural modulus = $M \text{ (or } E) = \frac{P \cdot L^3}{4 F B \cdot T^3}$ (MPa) |
| P | strength interval in linear flexural curve (N) |
| $P_x$ | maximum strength (N) |
| RI | radiation index (see definition in Section 3 of the text) |
| S | flexural strength = $S = \frac{3 Px \cdot L}{2 B \cdot T^2}$ (MPa) |
| T | thickness of the samples (mm) |
| TIS | Technical Inspection and Safety Commission at CERN |
| UL | Underwriters' Laboratories |
| VPI | vacuum press impregnated composite |

## APPENDIX 5

### List of suppliers of base materials, of transformers, and of some users who gave samples to CERN

| | |
|---|---|
| Agro AG | Korbackerweg 2, CH–5502 Hunzenschwil |
| Angst & Pfister (seller) | 52, route du Bois-des-Frères, 1219 Genève-le-Lignon |
| Ansaldo (magnet maker) | 8, via Lorenzi, I–16152 Genova |
| BASF | D–6700 Ludwigshafen |
| Bayer AG | D–Dormagen |
| Cellpack AG | CH–5610 Wölen |
| Ciba-Geigy AG | CH–4002 Basel |
| Ciba-Geigy Marienberg | Postfach 1253, D–6140 Bensheim 1 |
| Ciba-Geigy Brochier | ZI Les Chartinières, BP 27, F–01121 Montluel |
| Ferrettite (DFC) | ZI de Nogent, BP 6, F–60104 Creil |
| Dornier GmbH | D–88039 Friedrichshafen |
| DuPont de Nemours | 2, ch. du Pavillon, P.O. Box, 1218 Genève |
| Ebo AG | Zürichstrasse 103, CH–8134 Adiswil |
| Elektro Isola AS | 197 Grønlandsvej, DK–7100 Vejle |
| Elin (magnet maker) | Penzinger Strasse 76, A–1141 Vienna |
| Enka AG | Postfach 100149, D–5600 Wuppertal 1 |
| Erta Epec | Industriepark Noord, B–8700 Tielt |
| FA.BA. | 2, via delle Fabbriche, I–16158 GE-Voltri |
| General Electric Plastics | 1 Plasticslaan, P.O. Box 117, NL–4600 Bergen/Zoom |
| ICI | P.O. Box 6, Welwyn Garden City, Herts. AL7 1HD, UK |
| Isola Werke | CH–4226 Bretenbach |
| Isovolta / Isonova | A–2355 Wiener Neudorf |
| L.E. Pink Eng. Ltd | Rose Kiln Lane, Reading RG2 0HP, UK |
| Micafil AG | Badenerstrasse 780, CH–8048 Zürich |
| Permali Composites | 8, rue A. Fruchard, F–54320 Maxéville |
| Shell | Bederstrasse 66, CH–8002 Zürich |
| Sintimid | Postfach, A–4860 Lenzing |
| Solvay | Rue de Ransbeek, B–1120 Bruxelles |
| Stesalit AG | CH–4234 Zullwil |
| YLA | 2970C Bay Vista Court, Benicia, California 94510 |
| 3M GmbH | Eggstrasse 93, Postfach, CH–8803 Rüschlikon |