How to find radiation hard components?

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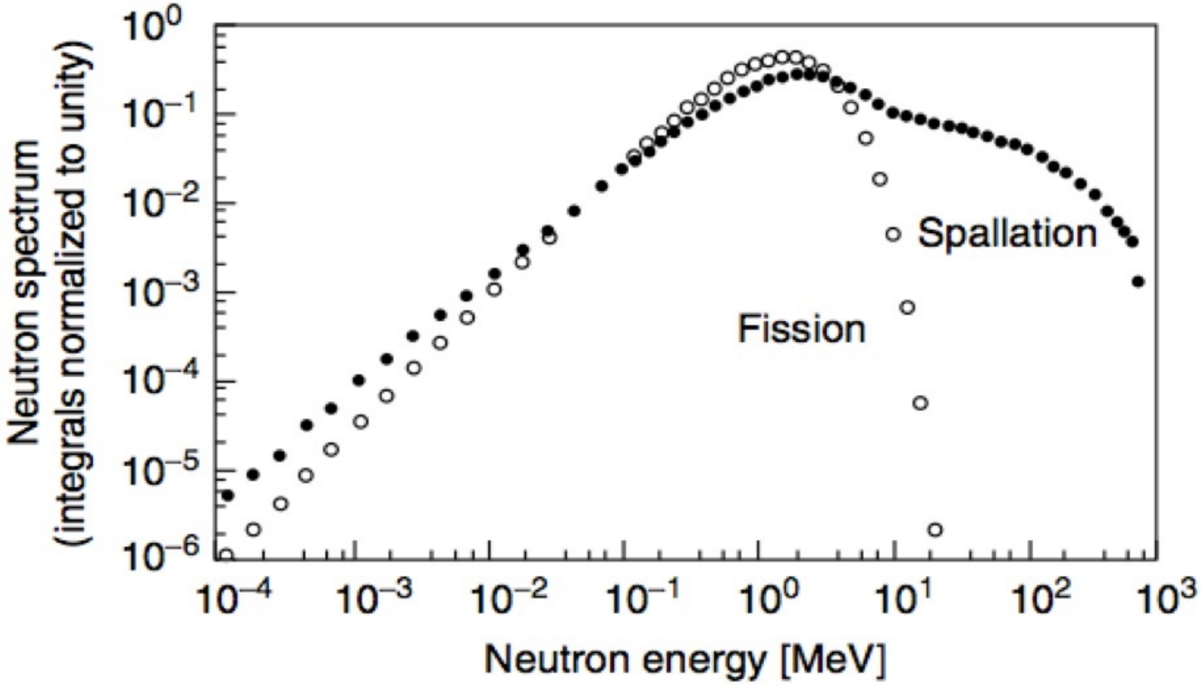
18th September 2018

What are we looking for?

- What components?
  - Motors
  - Feedback systems
  - Limit switches, reference switches
  - Connectors
  - Cables
  - Frontend electronics
- What materials?
  - Conducting materials: Metal (Cu, Al, Fe etc.)
  - Magnets, springs
  - Isolating materials: Polymers, rubber, resins etc.
  - Optical materials: Glass, polymer etc.
  - Electronics: Semiconductors, passive components

What types of radiation do we have ?

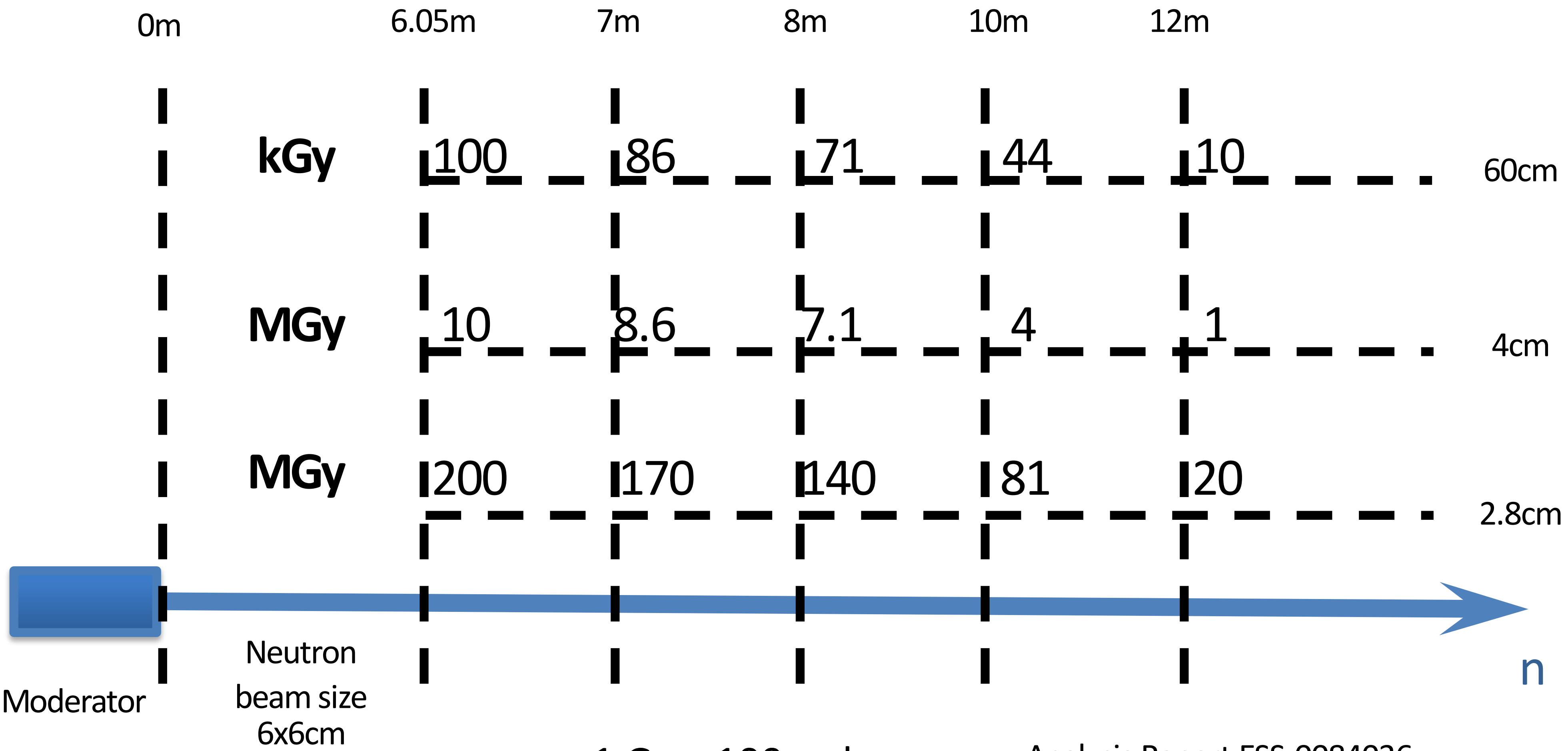
- Applications in Neutron Scattering require resistance to a combination of gamma radiation, neutron radiation and in some cases high temperature.
- All radiation produces some damage, therefore, the issue becomes how much radiation and what kind of radiation can an object sustain while maintaining its operation specification.



- Next problem of Neutron flux is activation of material: not covered in the talk!!

What radiation levels do we expect?

- Total Integrated dose (TID) calculations for sealing materials in bunker area (for 10 years)



1 Gy = 100 rad

Analysis Report ESS-0084036

How to find? 1. Ask your colleagues!

- Other radiation facilities and applications:
- Reactor and Spallation Sources
- Fundamental physics facilities
- Fusion technology projects (ITER)

	Gamma	Thermal n	Fast n	Max. energy
ILL	10^{1+}	1	10^{-5}	20 MeV
SNS			10^{-2}	200 MeV
ESS	1	1	1	200 MeV
CERN			$10^{1+\,*)}$	TeV
ITER	n.a.	n.a.	$10^{6+\,**)}$	14 MeV

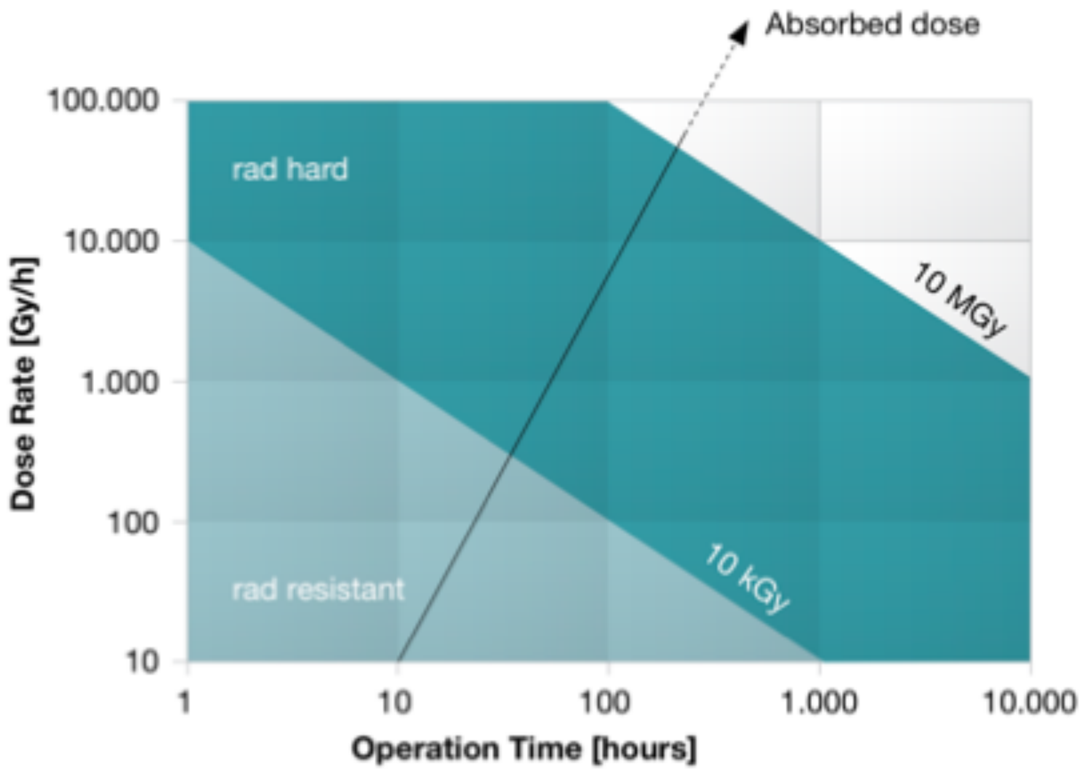
How to find? 2. Ask your supplier!

- Military applications (one shot)
  - Communication electronics
  - Launch control, remote control (robots, drones)
  - Nuclear Event detector
  - Cables, connectors
- Space applications (continuous)
  - Communication electronics
  - Remote control, remote handling
  - Sensors for scientific experiments
  - Cables, connectors
- Nuclear Power Plant (NPP) applications, ITER
  - Remote control of actuators and valves
  - Remote handling of nuclear waste
  - Remote replacement of parts in vacuum (ITER)
- High temperature industrial applications
  - General automation applications > 100°C
- Polymers in medical use
  - Tools and containers to be sterilised with gamma radiation

Radiation dose levels – Wittenstein DC motor
“rad resistant”, 10kGy, “rad hard”, 10MGy

WITTENSTEIN

cyber® special motors
radiation environment



- The brushless servo motors for radiation environment provide outstanding reliability and precision.
- cyber® rad hard motors excel in high total absorbed radiation doses, featuring a high-grade stainless steel housing and specialized materials.
- cyber® radiation resistant motors exclude certain materials for use in low radiation fields.

Radiation dose levels – TE LVDT

"Mild radiation resistance", 100kGy, 10^{12} NVT

✓RoHS

HR-Z SERIES

Mild Radiation Resistance LVDT

FEATURES

- Mild radiation resistance
- Large 1/16" core-to-bore clearance
- Shock and vibration tolerant
- Electromagnetic/electrostatic shielding
- Calibration certificate supplied with each unit

APPLICATIONS

- Mild radiations areas
- High temperature applications
- Process control
- Factory automation
- Applications with large misalignments

TE connectivity

HR SERIES
General Purpose LVDT

RADIATION RESISTANCE

Certain applications require resistance to a combination of gamma radiation, neutron radiation and high temperature. Before considering detailed specifications and suitability for a particular application, a review of the following working definitions and equivalents is appropriate.

Total integrated neutron flux

The total integrated neutron flux (also called neutron fluence) is the neutron flux integrated over time.
Neutron flux: the total distance travelled by all neutrons per unit time and volume
Formula for neutron flux: *number of neutrons/volume x distance/time = neutron density x velocity*
Neutron density: number of neutrons (n) per unit volume

Formula for total integrated neutron flux:
neutron density x velocity x time = neutron density x distance

Unit for total integrated neutron flux:
n/m^3 x m = ***n/m^2*** (n: number of neutrons; m: meter)
or
NVT *(n/cm^2)*
Conversion: *1 NVT = 10^4 n/m^2*

Gamma-ray total integrated dose (TID) radiation

The absorbed dose of ionizing radiation is the amount of energy deposited per unit of mass.

Units: *rad (radiation absorbed dose): radiation that will deposit 0.01 Joule of energy per kilogram of matter*
Gy (Gray): radiation that will deposit 1 joule of energy per kilogram (SI unit)
Conversion: *1 Gy = 100 rad*

All radiation produces some damage, therefore, the issue becomes how much radiation and what kind of radiation can an object sustain while maintaining its operation specification. At best, this can only be an estimate.

When radiant energy falls on an object, equal amounts of energy from different sources may result in greatly differing amounts of damage depending on the form of radiation, i.e. gamma rays, neutrons, etc. These different sources may also result in qualitatively different kinds of damage. One method to quantify these differences is to determine the rate of radiation that a unit can withstand without instantaneous and unacceptable damage. Another method is to determine the total integrated flux that can be absorbed before "wear-out" damage from radiation occurs. The distinction between rate of flux and total integrated flux must be kept clearly in mind.

There is no direct relationship between neutron fluence and gamma radiation. If we assume equal energy dissipation from differing sources, the energy absorbed by the unit will vary with its absorption cross section. If we try to equalize damage, there is even more uncertainty because of the qualitative differences of the damage caused by various forms of radiation.

SENSOR SOLUTIONS /// HR-Z Series Rev. A 07/2017 Page 2

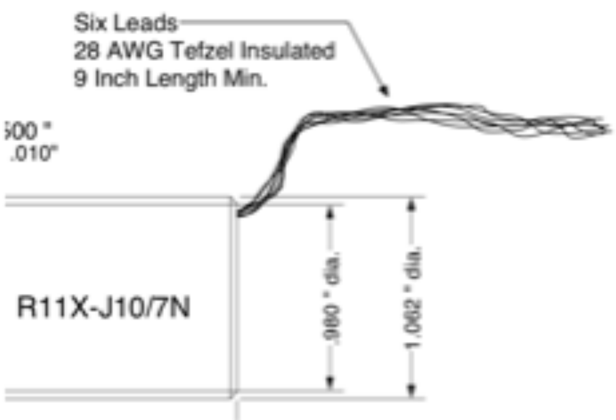
Radiation dose levels – AMCI resolver
“Tefzel insulation for radiation applications”

R11X-J10/7N Specification Sheet

SHEET # 940-2T341

DESCRIPTION

All of AMCI's resolvers are ratiometric, absolute position sensors that reliably operate in harsh environments. The R11X-J10/7N brushless resolver can be used in a wide variety of space critical applications where environmental sealing is not needed. Used in our standard resolver based transducers, the R11X-J10/7N is compatible with all AMCI modules and controllers. The resolver comes with 9 inch leads that have Tefzel insulation for radiation applications.



Radiation dose rate limits for ETFE (tables from different suppliers)

- 100kGy (Lapp cable)
- 1MGy (Nordion)
- 10kGy (AXON 2014)
- 100kGy (in air, AXON 2017)
- 300kGy (in vacuum, AXON 2017)
- 1MGy (crosslinked, AXON)

ADVANCED MICRO CONTROLS INC.

Radiation dose levels – DDC motion electronics for space applications: "radiation tolerant", 1kGy

EUROPEAN SPALLATION SOURCE

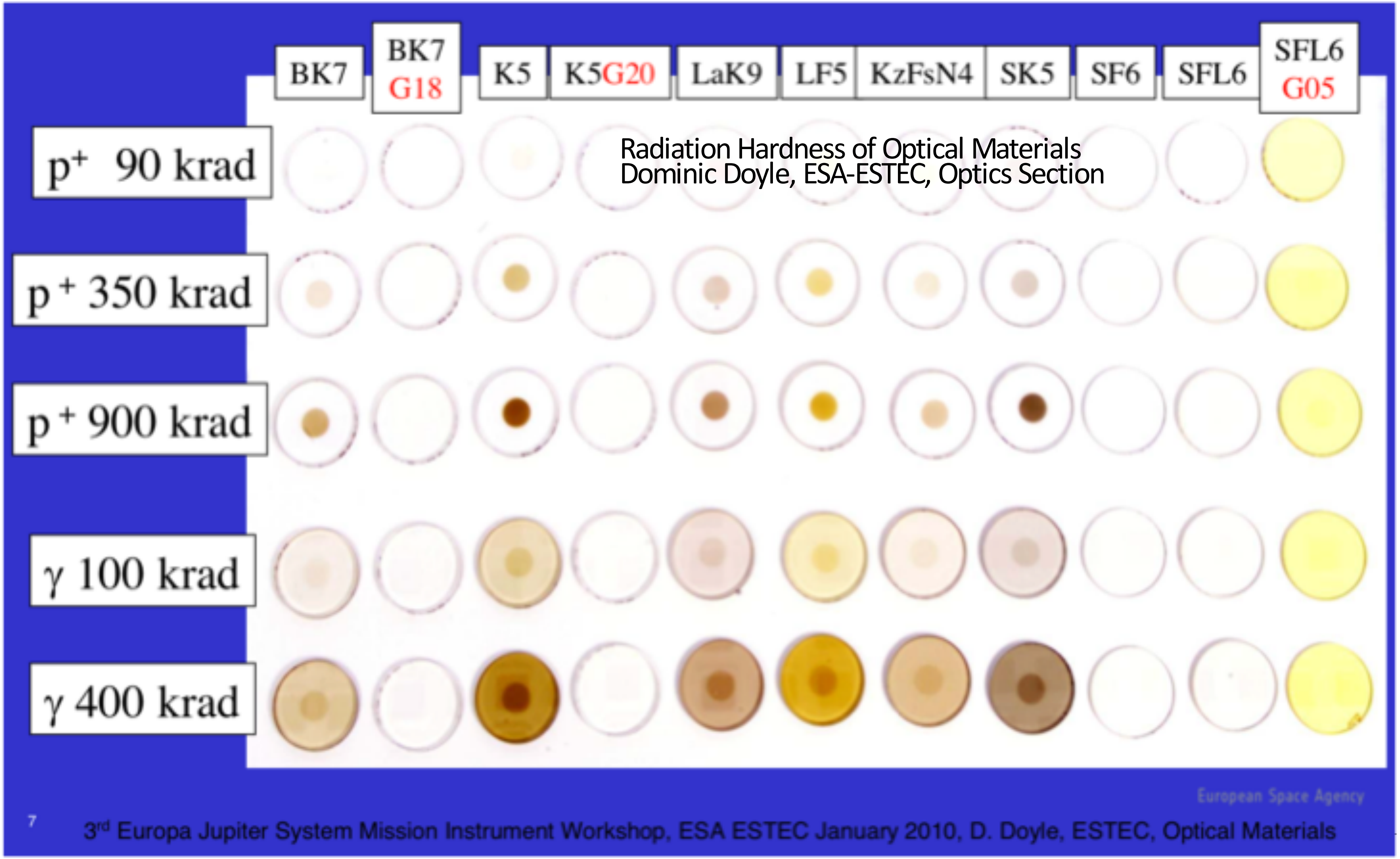
Radiation Tolerant 3-Phase BLDC Motor Torque Controller

Description | **Features** | Documentation | Request a Quote

- Self-Contained 3-Phase Motor Controller
- Operates as Current or Voltage Controller
- 1, 3, or 10 Amp Output Current
- 1.5% Linearity
- 3% Current Regulating Accuracy
- User-Programmable Compensation
- 10 KHz - 100 KHz PWM Frequency
- Complementary Four Quadrant Operation
- Holding Torque Through Zero Current
- Cycle-by-Cycle Current Limit
- Designed to Meet 100 KRad Total Dose, 36MeV SEU Radiation Levels

DDC
Connectivity Power Control

Radiation dose levels – Glas lenses
for space applications: “Radiation-Hard”, 9kGy

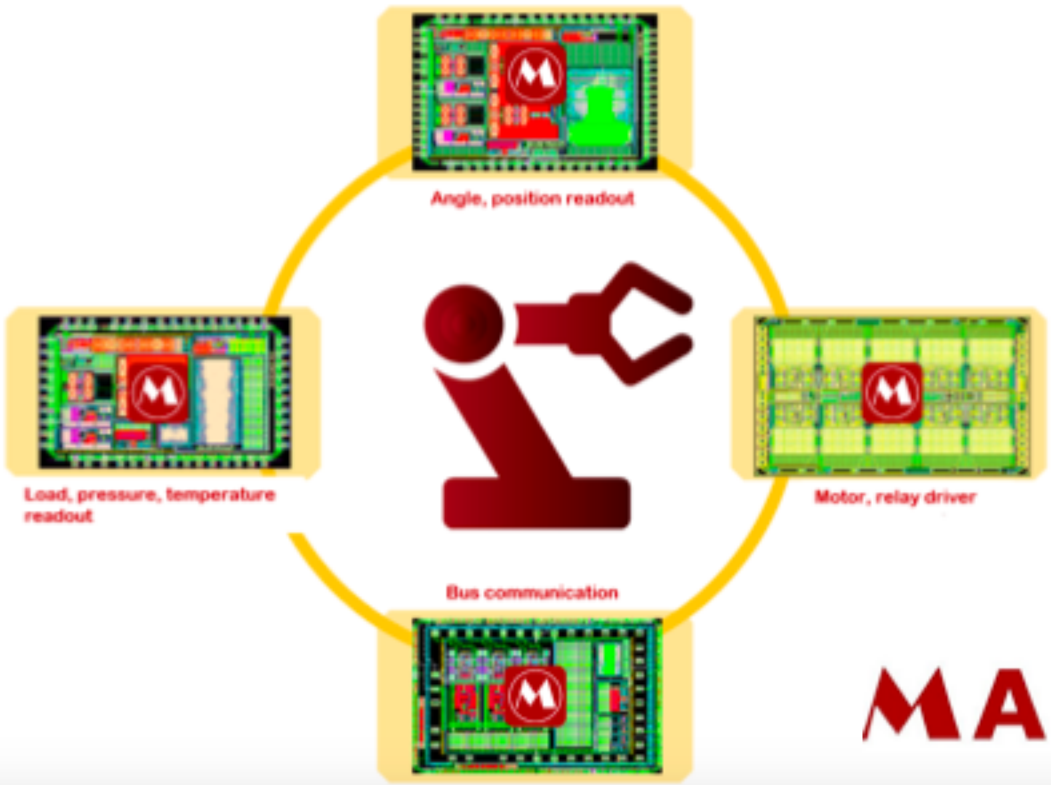


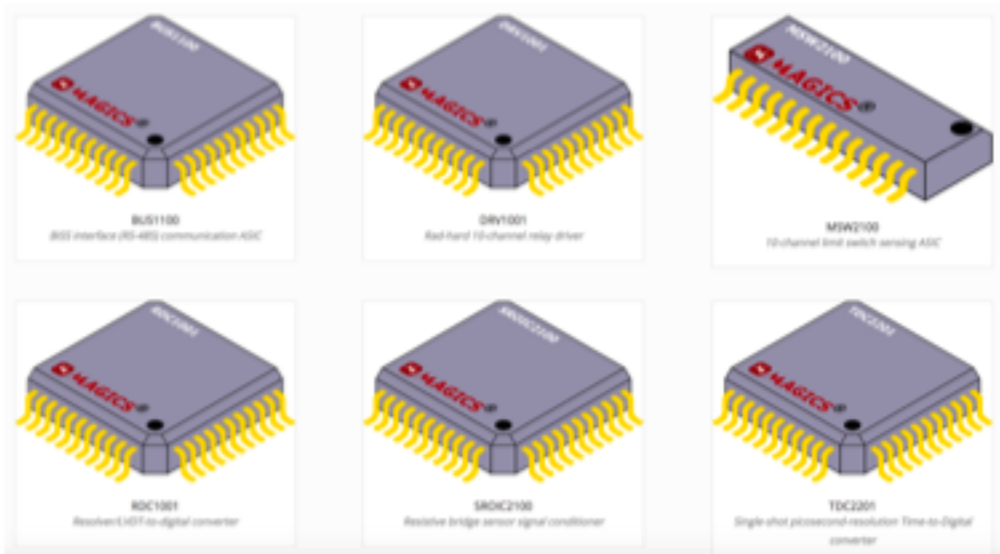
Radiation Hardness of Optical Materials
Dominic Doyle, ESA-ESTEC, Optics Section

Radiation dose levels – MAGICS electronics
for remote handling at ITER: “Rad-hard”, 1MGy, 300kGy/h

EUROPEAN SPALLATION SOURCE

- **A resolver/LVDT to digital converter** to read out angle information from a resolver or linear distortion information from a LVDT.
- **A resistive bridge sensor signal conditioning ASIC** to read out sensors such as RTD, thermocouple, and strain gauge.
- **A 24V 10-channel limit switch conditioning ASIC** to read the status of limit switches connected to it.
- **A 24V 10-channel relay driver ASIC** to drive high-side solid-state or mechanical relays.
- **A bus communication ASIC** to implement the BiSS interface (bidirectional/serial/synchronous) protocol, the SPI master protocol, and the RS485 bus transceiver.





MAGICS®

https://www.magics.tech/portfolio/cases/motor-control/

Radiation dose levels – NAMCO limit switch
for valves in nuclear power plants

- Harsh Environment: “Radiation resistant”, 3.6MGy
- Mild Environment: “Low dose radiation resilience” , < 1MGy

NAMCO	Harsh Environment With Accident Conditions		Harsh Environment Without Accident Conditions		Mild Environment	
Test Conditions	LOCA, HELB, Radiation, Siesmic Resistant		Radiation & Seismic Resistant		Low Dose Radiation & Seismic Resilience	
Model	EA120 - SP	EA120 - DP	EA120 - SP	EA120 - DP	EA120 - SP	EA120 - DP
						
Contacts	SPDT	DPDT	SPDT	DPDT	SPDT	DPDT
Connection Options	Flying Leads	Flying Leads	Flying Leads	Flying Leads	Flying Leads	Flying Leads
	QDC	QDC	QDC	QDC	QDC	QDC

Nuclear qualified components

Meets or exceeds:

- AECL 98-30830-TS 008
- AECL 98-60000-TS 005
- AECL 98-60000-TS-006
- IEEE 323-1983
- IEEE 382-1985
- IEEE 572-1985
- IEEE 344 1975/87/2004
- IEEE 382 1985/1996/2006
- IEEE 323 1974/1983/2003
- **RCC-E (K1 Under Review)**

C7 – Containment Qualified (LOCA)

The C7 proximity switch was designed for use in containment and can withstand a Loss of Coolant Accident (LOCA) event for 1 year. It is certified to meet the highest vibration and submergence requirements in the nuclear industry.
Available SPDT and DPDT

Qualifications

- IEEE 323-2003/1983/1974
- IEEE 344-2004/1987/1975
- IEEE 382-2006/1996/1980
- IEEE 383-2003/1974/1972
- IEEE 572-2004/1985
- Westinghouse AP1000
- RCC-E
- IEC 60780 (1998), 60980 (1989), & 60068 (2007)

CLASSIFICATION SUMMARY

8399 Nuc	K1-K2	K3
SP4522	• Bronze	• Aluminium
SP4813		•
SP4863		•
SP4816	•	

SV7 – HELB/MSIV Qualified

Designed to endure a high energy line break (HELB) environment, the SV7 proximity switch can withstand 260°C (500°F) peak temperature during a HELB and operate continually at a temperature of 204°C (400°F).

Nuclear qualified components

EUROPEAN SPALLATION SOURCE

Meets or exceeds:

- AECL 98-30830-TS 008
- AECL 98-60000-TS 005
- AECL 98-60000-TS-006
- IEEE 323-1983
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Nuclear regulations and qualifications
All qualifications are for safety related components!

USA:

IEEE 323 / IEC 60780: IEEE Standard for Qualifying Class 1E Equipment for Nuclear Facilities

IEEE 383: IEEE Standard for Qualifying Electric Cables and Splices for Nuclear Facilities

France:

AFCEN: RCC-E 2012

EDF: CST 74 C 068 00: Cahier des Specifications Techniques - Cable Electriques pour Centrales Nucleaires

Specific nuclear qualifications:

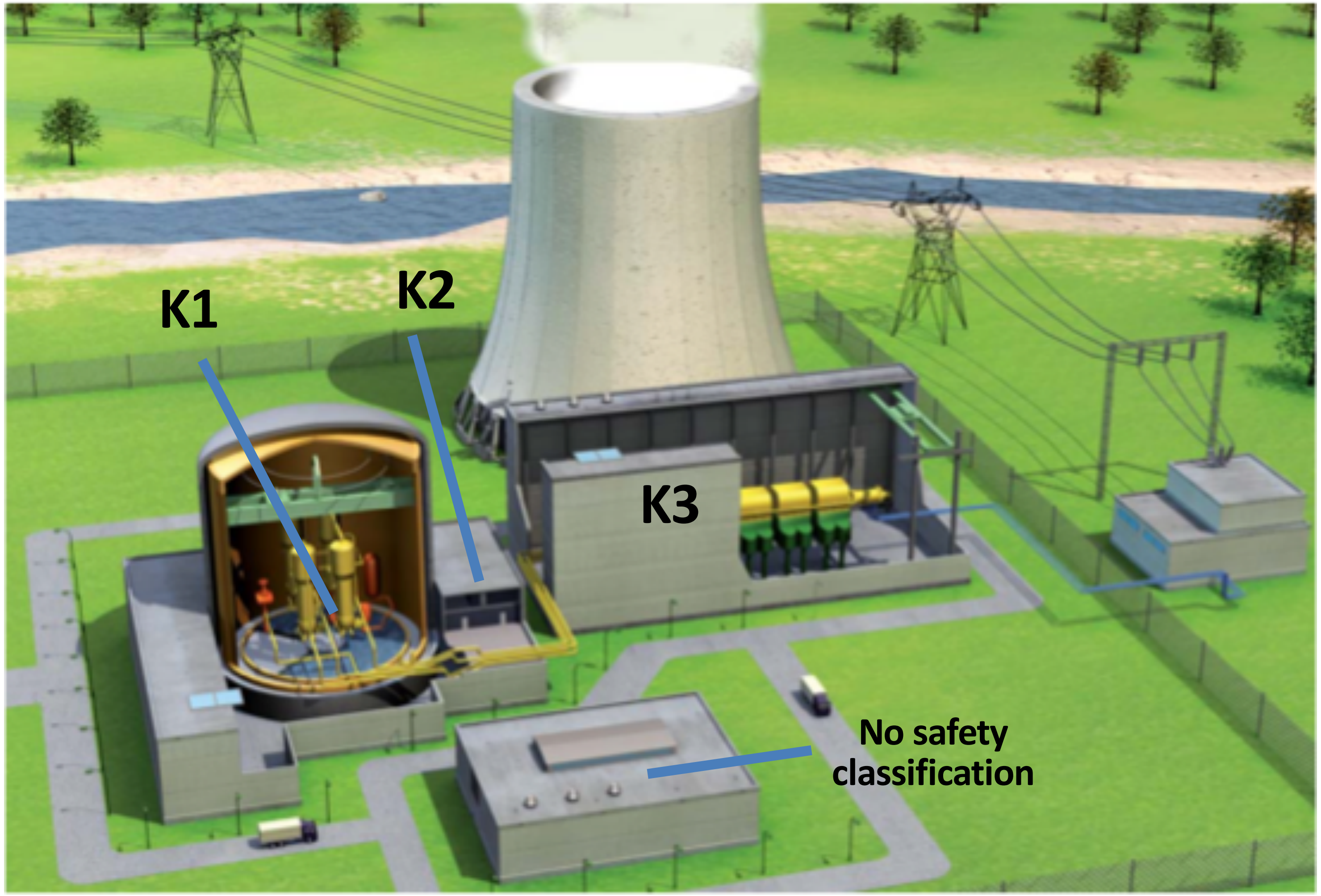
- RCCE: Design and Construction Rules for Electrical Equipment for Nuclear Island
- CST/BTS: Book of technical specifications: Electrical Cables for Nuclear Power Plants
- IEEE 323: for nuclear power plant equipment
- IEEE 383: for (1) thermal aging, (2) radiation, and (3) LOCA test ; with (1) (2) and (3) for last day accident simulation, and (2) and (3) for first day of operation.

SAFETY CLASSIFICATION SYSTEMS COMPARISON

	Safety classified		Not safety classified
American	1E LOCA	1E non LOCA	Non 1E
Russian	K0, K1	K3	
Korean	Q	R	
French	K1	K3	Non Classified

Areas of a nuclear power plant (NPP)

Safety classification according to RCC-E



EPR CST (EDF) 74C068
K3 Standard zone : all external parts EDT-SEPTEN approval cable designs + ageing test for lifetime (10 days – 135°C)
K2 Sensitive zone : Safeguard Building = K3 + 250 kGy (1kGy/h) at 70°C
K1 Sensitive zone : Heart : K1 ADR cables (reactor building) as well as LOCA : = K2 + 600kGy (1kGy/h) at 70°C + accident test (156°C)

Typical 40y-doses in a nuclear power plant

Example Area Classification

	Applicable environmental conditions		
	Maximum values in normal service		Accident conditions
	Temp.	Total 40-yr dose	
A	≤ 40 °C	≤10^2 Gy (0.01 Mrad)	N/A
B	≤ 50 °C	≤5×10^4 Gy (5 Mrad)	N/A
C	≤ 50 °C	≤5×10^4 Gy (5 Mrad)	Applicable
D	Local conditions higher than for C (e.g. hot spots)		

IAEA NP-T-3.6

Example Generic Hot Spots

Reactor type	Hot spot location region	Temperature	Rad. dose rate	Dose (40 yr)
PWR	Steam generator box	47-48 °C (max 100 °C)	0.1 Gy/h	4 Mrad
	Primary loop	50 °C	0.7 Gy/h	25 Mrad
BWR	Drywell neck	100 ± 5 °C	0.5 Gy/h	18 Mrad
	Primary steam relief valve	70 ± 5 °C	0.01 Gy/h	0.4 Mrad
	Power range monitor	80 ± 5 °C	0.24 Gy/h	8 Mrad

IAEA-TECDOC-1188 vol1

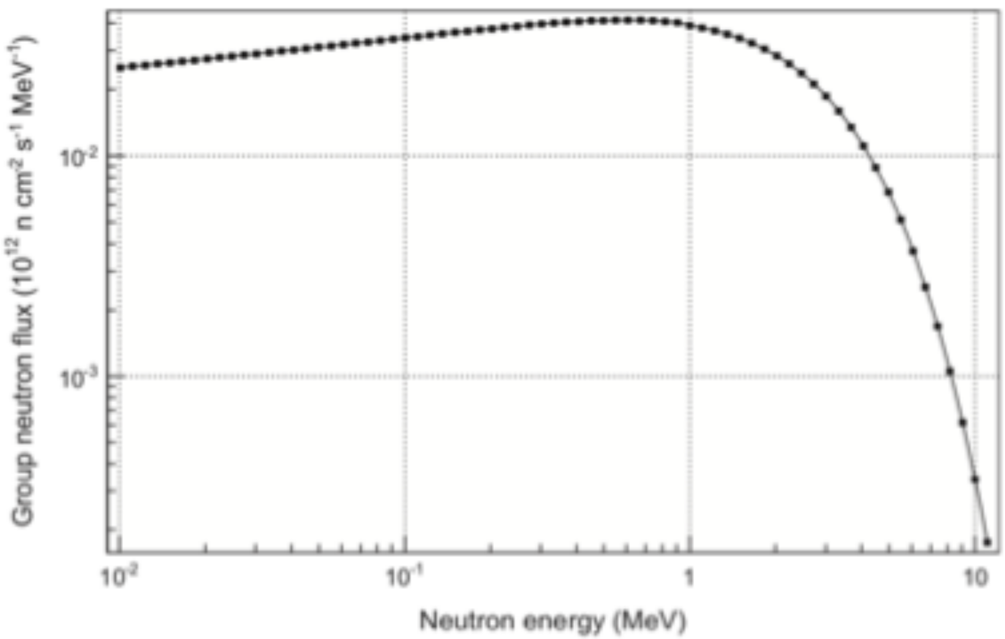
Nuclear qualification
Dose rates for radiation tests

	projec-ted lifetime	Harsh environment (lifetime rad + accident)	Harsh environment (lifetime radiation)	Mild environment (no or very low radiation)	no radiation, no safety requirements
Areas of NPP		Reactor building	Safeguard building	Turbine Hall, Substation	Offices, Workshops
IAEA		C, D	B	A	
IEEE 323		1E LOCA	not specified	1E non-LOCA	non 1E
RCC-E		K1 (severe accident)	K2	K3	no class
IEEE 383	40Y	0,5 + 1,5 MGy	(0,5 MGy)	-	-
IEEE 383	60Y	0,75 + 1,5 MGy	(0,75 MGy)	-	-
CST 74C068	60Y	0,2 + 0,65 MGy	0,2 MGy	-	-

How to find? 3. Choose and test!

- Choose standard components with „promising“ materials.
- Define carefully test environment (radiation type, flux, spectrum, specimen volume, source access etc.) and choose source accordingly.
- Performance tests before >> irradiation >> performance tests afterwards.
- Check with supplier when he introduces changes in material.

IBR-2 reactor in Dubna, Russia



irradiation parameters, expected for 11 days (one cycle) of reactor operation, were estimated:

- Maximal fluence of neutron with energy above 1 MeV when sample is installed at 40 mm apart from the moderator – 10^{18} n cm^{-2}, and for the distance 0.3 m–4·10^{17} n cm^{-2}.
- Maximal absorbed dose in water for the same installation positions: at 40 mm–100 MGy (10^8 J/kg), at 0.3 m–40 MGy.

More details in :

M. Bulavin et.al. Irradiation facility at the IBR-2 reactor for investigation of material radiation hardness, NIM B 343 (2015) 26-29

Cables in radiation environment

Effect of radiation on cables

- Most critical parts of the cables are the insulation of the wire and the sheath around.
- Insulation must have certain dielectric properties and the sheath needs to fulfill additional mechanical requirements.
- Plastics and polymers loosing their flexibility and get brittle.
- Radiation tests are concentrating on that property.
- Most tests of cables are done with a Co60 source (Gamma) and with accelerated lifetime.

Radiation Resistance definition in IEC 60 544

- For flexible plastics and elastomers the most restrictive property is usually the strain or stress at break.
- End-point criterium for «radiation resistance value»: Loss of 50% of the initial strain or stress at break of the material.
- Note that this does not necessarily refer to an end-of-life condition, especially for materials with high initial strain at break (>200%) including TPU, ETFE, crosslinked or uncrosslinked polyolefins.

Test conditions in IEC 60544-4

Type of material	Properties to be tested	Test procedures	End-point criteria [a]
Flexible plastics	Flexural strength	ISO 527	50 %
	Elongation at break	ISO 37	50 %
	Tensile strength at yield	ISO 527	50 %
	Tensile strength at break	ISO 527	50 %
	Impact strength	ISO 179	50 %
	Volume and surface resistivity	IEC 60093	10 %
	Insulation resistance	IEC 60167	10 %
	Electric strength	IEC 60243	50 %
Elastomers	Elongation at break	ISO 37	50 %
	Tensile strength at break	ISO 37	50 %
	Hardness/IRHD	ISO 48	Change of 10 units
	Hardness/Shore A	ISO 868	Change of 10 units
	Compression set	ISO 815	50 %
	Volume and surface resistivity	IEC 60093	10 %
	Insulation resistance	IEC 60167	10 %
	Electric strength	IEC 60243	50 %

Test results for Huber Suhner RADOX 125

Radox 125 - Insulation **CERN Material C-1147; Date 1999**

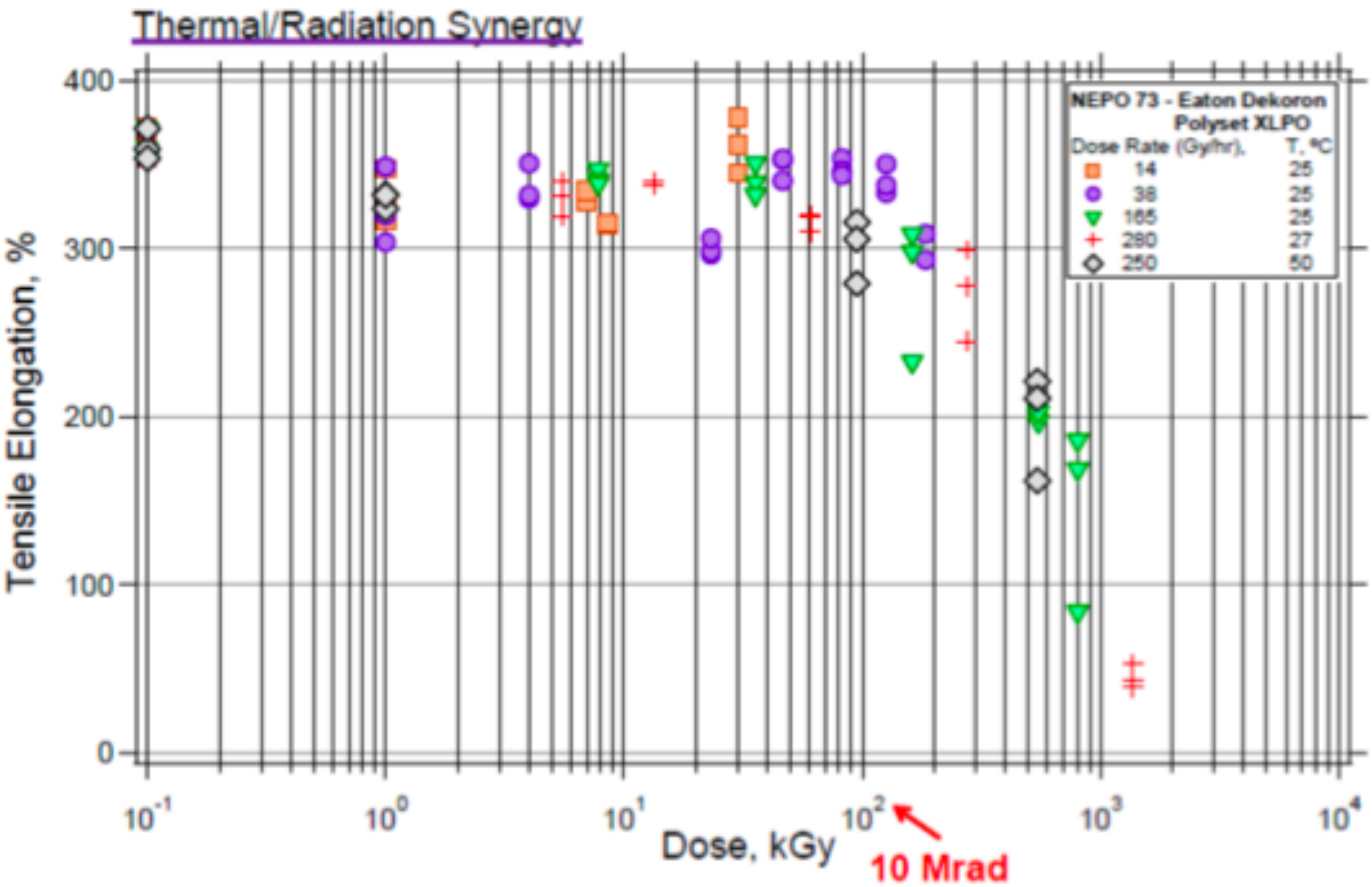
Dose [kGy]	Dose rate [kGy/h]	Tensile Strength [MPa]	Elongation at break [%]	Hardness [Shore D]
0	0	17.7	212	46
200	1.2	18.3	191	48
520	0.8	18.6	140	50
1000	1	18.3	85	52
1000	240	17.8	83	48
3000	230	16.6	42	48

Radox 125 - Sheath **CERN Material C-619; Date 1989**

Dose [kGy]	Dose rate [kGy/h]	Tensile Strength [MPa]	Elongation at break [%]	Hardness [Shore D]
0		5.9	179	37
200	140	7.9	113	41
500	140	9.4	98	43
1000	140	10.5	75	46
5000	140	14	21	50

Test results for Eaton XLPO

NEPO 73 – Eaton Dekoron Polyset XLPO



More details in the presentation:

Condition Based Qualification
Robert Konnik, Chief Technology Officer,
Marmon Innovation & Technology Group

Review of radiation tests
Combination effects

- In particular, three of the aging assumptions used were found to be overly simplistic.
- Thermal aging was typically carried out at a few high temperatures, then they were modeled with an Arrhenius function to derive an Arrhenius activation energy Ea and finally the results were extrapolated to ambient conditions assuming no change in Ea. Recent studies show that Ea often drops at low temperatures, reducing the extrapolated lifetime.
- For radiation aging, an equal damage, equal dose assumption (e.g., no dose rate effects) was used. Careful studies have now shown that dose rate effects that reduce extrapolated material lifetime are both common and expected and come from several different mechanisms.
- Finally, for simulating combined radiation plus thermal environments, sequential aging (usually thermal aging followed by room temperature radiation aging) was allowed whereas recent studies show that simultaneous aging is usually much more severe.

Compliance with safety class requirements has to be demonstrated for the entire expected lifetime of the reactor. Therefore testing must be done by accelerated ageing methods, representing the design lifetime of the NPP (now 60 years).

More details in:
Kenneth T. Gillen and Robert Bernstein -
Review of Nuclear Power Plant Safety Cable Aging Studies with Recommendations for Improved Approaches and for Future Work, SAND 2010-7266

US suppliers for nuclear cables

Environmental Qualification Data Base (EQDB)

	Supplier	Material	Total Integrated Dose x 10^6 Gy (MRads)	DBA Peak Temp °C (°F)	Referenced Report
1	Brand Rex	XLPE w/CSPE Jacket	2 (200)	196 (385)	FIRL F-C5120
2	Rockbestos	Firewall III, XLPE w/Neoprene Jacket	2 (200)	172 (341)	ROCK 5804 R3 7/2/87
3	Raychem	Flamtrol XLPE	2 (200)	181 (357)	FIRL F-C4033-1
4	Samuel Moore	Dekoron Polyset, XLPO, w/CSPE jacket	2 (200)	191 (375)	EQ-CBL-017
5	Anaconda	Y-Flame-Guard FR-EP, EPR w/CPE jacket	2 (200)	196 (385)	FIRL F-C4836-2 1/78
5a	Anaconda	Flame-Guard EP, EPR, w/individual CSPE jacket and overall CSPE jacket	2 (200)	174 (346)	FIRL F-C4350-2
6	Okonite	Okolon, EPR w/CSPE jacket	2 (200)	171 (340)	OKONITE RPT 266R-1
7	Samuel Moore (Single Conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE jacket	2 (200)	191 (375)	NTS 558-1088
7	Samuel Moore (Multi-conductor)	Dekoron Dekorad Type 1952, EPDM, w/individual CSPE and overall CSPE jackets	2 (200)	191 (375)	NTS-558-1088
8	Kerite	FR w/FR jacket	2 (200)	163 (325)	FIRL F-C2737 041570
8a	Kerite	FR w/FR jacket	2 (200)	163 (325)	FIRL F-C2737 041570
9	Rockbestos	RSS-6-104/LE Coax	2 (200)	174 (345)	ROCK QR-6802 R1
10	Rockbestos	Firewall Silicone	2 (200)	171 (340)	ROCK QR-7801 3/2/78
11	Champlain	Polyimide, Kapton	1.4 (140)	171 (340)	Note 1
12	BIW	Bostrad 7E, EPR	2 (200)	171 (340)	BIW TR# B915 REV 1

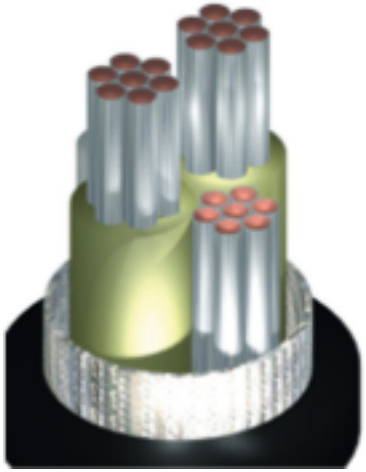
Manufacturer	Insulation
Rockbestos Firewall III	XLPE
Brand-Rex	XLPE
Raychem Flametrol	XLPE
Anaconda Y Flame-Guard FR	EPR
Okonite FMR	EPR
Samuel Moore Dekoron	EPDM
BIW Bostrad 7E	EPR
Kerite HTK	~EPR

More details in this presentation:
Leo Fifield, PhD (PNNL):
LWRS Cable Aging and Cable NDE

Certified cable IEEE-323, class 1E

HABIA

Habiatron Q



Application

Designed for use in Class 1 safety systems such as primary pumps, safety valves, volume controls and emergency shut-down systems; Habiatron Q cables are independently qualified for an operational life of 60 years with a conductor temperature of up to +90°C and a jacket temperature of up to +70°C. Cables are rated to 600V in a dry post-LOCA environment and 300V in submerged conditions at elevated conditions.

- Flame retardant: IEEE 1202-2006, IEC 60332-1-2 and UL 1581 VW-1
- Smoke generation: IEC 61034-2
- Toxicity: IEC 60754-2
- Radiation tolerant: 2.3 x 10^6 Gy
- Operational life: Qualified for 60 years according to IEEE 383-2003 with a 90°C conductor temperature.

HFI 260 / HFS 105 XL B, Class 1E multicore cables <600V 40 Years at +90°C

Construction

Conductor	Tin Plated Copper (TPC)	Dielectric	HFI 260 (PEEK)	Voltage (<1.0mm²) Voltage (>1.0mm²)	300/500V AC Uo/U 600/1000V AC Uo/U
Screen	Optional Copper / Polyester foil (F) Optional Tin Plated Copper braid (T)	Sheath	HFS 105 XL B	Test voltage	3000V AC
Colour code	Natural & numbered			Sheath	Black

Description	Construction no. / size CSA	conductor Ø	insulation Ø	cabled Ø	shield/s Ø	sheath/s Ø	weight g/m	Electrical amps at 40°C max	MBR fixed mm	Article Number
M/TPC 1.0 STQ 3	3x 1.00	1.20	1.84	4.0	4.2	5.8	68	13	44	700044363
M/TPC 2.5 STQ 3	3x 2.50	1.95	2.65	5.7	5.9	7.9	146	25	59	700044366
M/TPC 10 STQ 3	3x 10.00	3.93	4.83	10.4	10.6	13.2	506	68	99	700044369

Certified cable RCC-E, class K1

Prysmian

EUROPEAN SPALLATION SOURCE

DESCRIPTIF DU CABLE ***CABLE DESIGN***

TENSIONS ASSIGNEES / *RATED VOLTAGES* : 0,3 / 0,5 (0,6) kV Uo/U(Um) suivant / *according to* CEI 60038 & CEI 60183

AME / *CONDUCTOR*

- âme cuivre nu recuit, ronde, câblée, , classe 5,

stranded, circular, plain annealed copper conductor, class 5,

conforme à / *according to* CEI 60228 ; NF C 32-013 ; HD 383

- température / *temperature* 90°C en régime permanent / *in continuous duty*

250°C en court-circuit / *in short circuit*

ISOLATION / *INSULATION* CEI 60502

ruban séparateur facultatif / *optional separator tape*

PR : couleur NOIRE / ***XLPE*** *: BLACK colour*

Repérage des conducteurs, voir page suivante / *Cores identification, see next page*

ASSEMBLAGE / *LAYING UP*

avec bourrage non hygroscopique ou ruban synthétique

with non hygroscopic filler or synthetic tape

GAINE INTERNE / *INNER SHEATH* CEI 60502

Polyoléphine / *polyolephine*

GAINE EXTERIEURE / *OUTER SHEATH* CEI 60502

Polyoléfine réticulé SH : couleur GRISE / *LSOH Cross linked Polyolefine : GREY colour*

Tested with 850 kGy

CÂBLES de CONTRÔLE
CONTROL CABLES

CABLES POUR CENTRALES NUCLEAIRES
NUCLEAR POWER PLANT CABLES

AME CUIVRE ROUGE CLASSE 5 GAINE GRISE 0,3/0,5(0,6)kV
PLAIN COPPER CLASS 5 CONDUCTOR GREY SHEATH 0,3/0,5(0,6)kV

K1 LSOH RCC-E

CST 74 C 068 00 & CEI 60502-1
remplace / *replaces* HN 33-S-25 HN 32 S 01

QUALIFICATION : REP 900MWe 1300MWe N4 & EPR niveau B6000 *level* 1E Q1

Custom cable for ESS PSS systems

Huber Suhner

EUROPEAN SPALLATION SOURCE

RADOX 125 BK ESS
Multicore cables screened

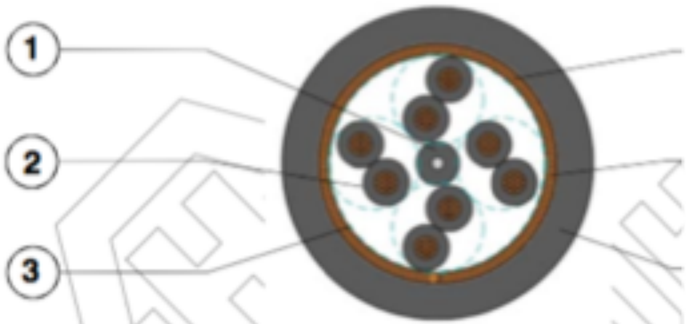
Technical Data :

Conductor resistance at 20 °C		≤ 40.1	Ω / km
Voltage rating U_0/U		450 / 750	V
Test voltage, 50 Hz, 1 min		2 500	V
Temperature range	fixed	- 40 ... +125	°C
Minimum temperature	flexing	- 25	°C
Maximum conductor temperature at short circuit (max. 5s)		+ 280	°C
Min. bending radius	fixed	4 x cable dia.	
	flexing	5 x cable dia.	

The cables pass the following tests:

Fire protection in buildings	**Fulfilled**	**EN 50525**
Vertical flame spread	50 < L ≤ 540 mm	EN 60332-1-2
Vertical flame spread, bunched	L ≤ 2.5 m	EN 60332-3-24
Smoke density	T ≥ 60 %	EN 61034-2
Corrosivity of combustion gases	pH ≥ 4.3, C ≤ 10 µS/mm	EN 50267-2-2
Amount of halogen acid gas	HCl + HBr ≤ 0.5 %	EN 50267-2-1
Content of fluorine	HF ≤ 0.1%	EN 60684-2, 45.2
Approach to		Def Stan 61-12 Part 5

General composition of cable :



1. Center / Filler (if necessary) RADOX 125
2. Cores (for details see table) Conductor: stranded tin plated copper
   Insulation: RADOX 125 extruded irradiation crosslinked polyolefin
   Two cores twisted
   Colours: black, yellow numbered
3. Wrapping (if necessary) Tape
4. Screen Tin plated copper braid, opt. covering : ≥ 80%
5. Wrapping Tape
6. Sheath RADOX 125 M extruded irradiation crosslinked polyolefin,
   Colour : black

Cables in Radiation Environment
Helukabel

EUROPEAN SPALLATION SOURCE

TOPFLEX®-PUR

Part no.	No.cores x cross-sec. mm²	Core marking 0,14 mm²	Core marking 0,5 mm²	Sheath colour	Outer Ø approx. mm	Cop. weight kg / km	Weight approx. kg / km	AWG-No.
22847	(3 x (2 x 0,14) + (2 x 0,5))	DIN 47100	WH, BN	Grey	8,3	78,0	103,0	26

Technical data

- **Temperature range**
  flexing -30°C to +80°C
  fixed installation -40°C to +80°C
- **Nominal voltage**
  TOPFLEX®-PUR 350 V
  Tachofeedback-cable-C-PUR 450 V
  Incremental Feedback-cable-C-PUR 250 V
- **Test voltage**
  core/core 2000 V
  core/screen 1000 V
- **Insulation resistance**
  min. 20 MOhm x km
- **Minimum bending radius**
  flexing 10x cable Ø
  fixed installation 5x cable Ø
- **Coupling resistance**
  max. 250 Ohm/km
- **Radiation resistance**
  up to 100x10⁶ cJ/kg (up to 100 Mrad)

Cable structure

- Bare copper-conductor, to DIN VDE 0295 cl.6, extra fine-wire, BS 6360 cl.6, IEC 60228 cl.6
- Core insualtion of PP
- Part No. 22847 Cu-screen of single pairs or single cores and PETP (polyethylene terephthalate) sheath
- Core identification see table below
- Single cores or pairs stranded in layer with optimal lay-length (pairs part no. 22818)
- Drain wire
- Tinned copper braided screen, approx. 85% coverage
- Outer sheath of special PUR, matt
- Sheath colour see table below

Properties

- Special PUR outer sheath low adhesion
- **Resistant to**
  Oils and fats
  Acids and alkalis
  Hydraulic fluids
  Oxygen and ozone
  UV-radiation
  Hydrolysis
  Microbial attack
  Water and weathering effects
- The high abrasion resistance and notch resistance meet the highest requirements
- The materials used in manufacture are cadmium-free and contain no silicone and free from substances harmful to the wetting properties of lacquers

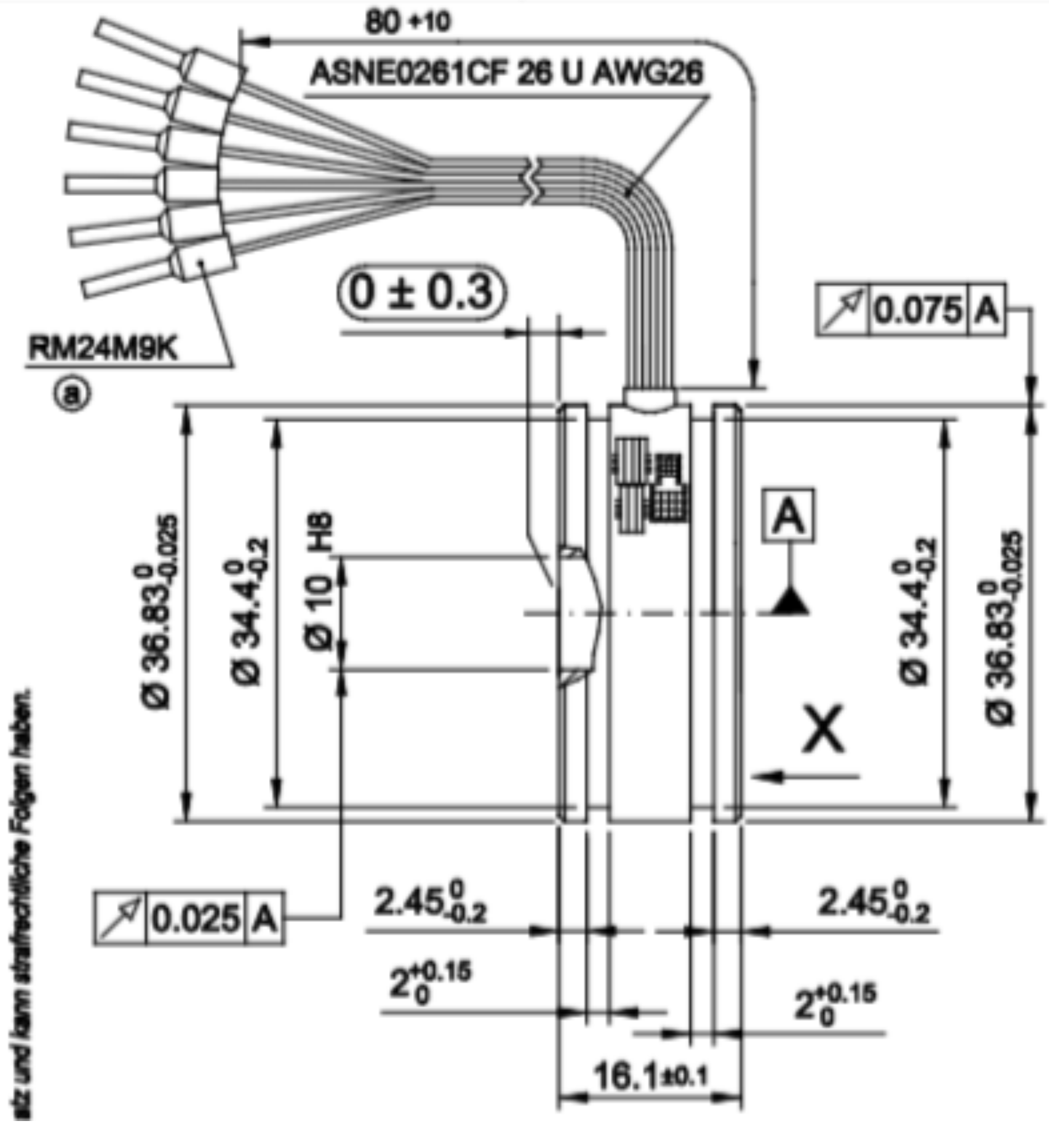
Note

- For extreme applications extending beyond

Cables for aircraft and space applications
ASNE0261CF – Drake, Nexans

- Some cables according to ASN-E026x (Airbus) and other aircraft specs are composed of Polyimide (Kapton) isolations

- ASNE0261CF cable is used by LTN for a CERN-application resolver specified to 40 MGy



Example of customised cable
Axon

- Rad hard cables for ITER
  - Temperature : 4K to 200°C
  - Ultra high vacuum
  - Rad : 50 MGy (high energy neutrons + gamma)
  - Expected life span : 30 years
  - Maintenance : impossible
  - Voltage up to 30kV

Cables in Radiation Environment
Air (standard atmosphere)

Some typical numbers from suppliers:

Lapp-Kabel (PU)	0.5 MGy
Lapp-Kabel (EPR)	1 MGy
Helukabel (PU, HM2, TM7)	1 MGy
Huber+Suhner RADOX® (RX125-XLPolyolefin Copolymer)	1 - 3 MGy
Marmon (XLPE + CSPE, certified to Class 1E, IEEE-323)	2 MGy
Habiatron (XLPolyolefin, certified IEEE-323 + 383)	2.3 MGy
Axon (Poliax®-PEI)	3 MGy
Huber+Suhner RADOX® (TPU)	5 MGy
Axon (Neutrax®-PEEK)	5 MGy
Axon (Kapton®-Polyimide)	10 - 20 MGy

Lessons Learned

1. Understanding the material mix of the component is key; not always easy to get from the supplier and absolutely crucial for the activation analysis.
2. Best way of avoiding problems in high radiation environment is to avoid optics and electronics as materials.
3. In the last time quite a number of high performance plastics emerged in the market (PEEK, PEI, PPS, PPA, TPU) to accompany PI (Kapton) as isolation in radiation environment.
4. Nuclear qualified components are often too expensive as they cover more requirements than necessary (safety, temperature, shock, water level).
5. Often suppliers offer cheaper “brothers” of the nuclear components with similar properties in terms of radiation hardness (examples of this in Kristinas talk on Wednesday).
6. Some suppliers give dose numbers “for free” with their standard products.
7. For very high doses you need to take a customized solution from a specialized supplier.
8. Using standard components with a “promising” material mix requires tests campaigns under carefully chosen conditions.

Thank You!

How to find radiation hard components?

Additional slides

thomas.gahl@esss.se

DENIM 2018, PSI, Switzerland

18th September 2018

Cables in Radiation Environment

Use of cables and wires exposed to ionising radiation

Ionising radiation normally only occurs in defined applications and when it is supposed to, meaning that materials with the appropriate resistance can be specially adapted to the prevalent conditions of the application in advance.
Cables are therefore normally only tested for radiation resistance if their intended usage includes exposure to ionising radiation. This means that for all other cables, indications can only be made for the radiation resistance of typically used materials. While these indications are not representative of the resistance of the whole cable, the values can still act as a rough guide and make it possible to compare the cables with one another.

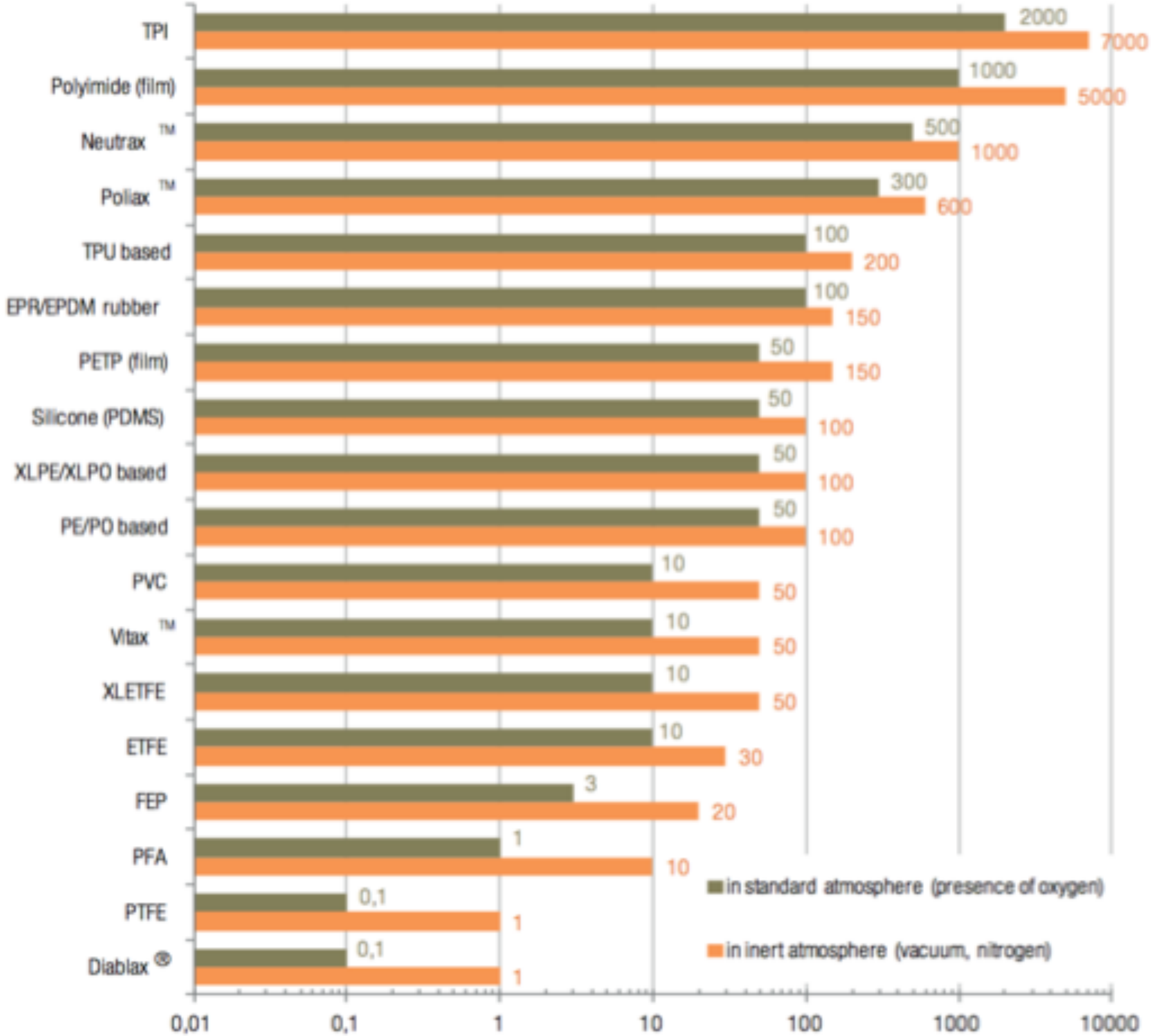
The radiation resistance of materials is defined using the Radiation Index (RI) in IEC 60544-4 and refers to the point at which the elongation at break is reduced to ≥50% of the original value.

Cables in Radiation Environment - AXON

MATERIALS	PRIMARY INSULATION AND JACKETING								
	POLIAX™	NEUTRAX™ PAEK BASED	TAPED POLYIMIDE	TPI POLYIMIDE	ASC3-92I TPO BASED	ASC3-55J TPO BASED	AXOTHERM® SILICONE BASED	TPUE850HVO TPU BASED	EVALUATION CRITERIA
OPERATING TEMPERATURE	+130°C	+200°C +250°C	+250°C	+240°C	+70°C	+70°C	+180°C	+125°C	-
FLAME RETARDANT	YES	YES	YES	YES	YES	YES	YES	YES	-
SMOKE EMISSION	Dm = 283 VOF4 = 30	Dm = 20 VOF4 = 1	-	-	Dm = 200 VOF4 = 8	Dm = 248 VOF4 = 64	Dm = 74 VOF4 = 85	Dm =253 VOF4 = 512	Dm <300 VOF4 < 100
TOXICITY OF GAS EMISSION	ITC = 10	-	-	-	ITC = 4	ITC = 3	ITC = 1.6	ITC = 32	ITC < 10
CORROSIVITY OF FUMES	pH = 7.1	-	-	-	pH = 7.85	pH = 5.2	pH = 4.7	pH = 8.9	pH > 4.5
TENSILE STRENGTH AT BREAK (MPa)	30	100	170	90	14	13	6.5	35	-
ELONGATION AT BREAK (%)	100	30 - 100	120	90	230	150	220	600	-
RESISTANCE TO OIL	VERY GOOD	EXCELLENT	VERY GOOD	VERY GOOD	VERY GOOD	VERY GOOD	AVERAGE	GOOD	-
RADIATION RESISTANCE (Mrad)	300 - 600	500 - 1000	1000 - 5000	2000 - 7000	50 - 100	50 - 100	50 - 100	100 - 200	IEC 60544

ASC = AXON' SPECIAL COMPOUND

Cables in Radiation Environment - AXON



Radiation resistance based on IEC 60544-4

Absorbed dose in Mrad = 10 kGy

Cables in Radiation Environment - AXON

Radiation resistance, temperature resistance and Halogen free, LSZH behaviour

	RADIATION RESISTANCE (*)		TEMPERATURE RATING (°C)	HALOGEN FREE LSZH
	IN STANDARD ATMOSPHERE	IN INERT ATMOSPHERE		
TPI - EXTRUDED POLYIMIDE	2000 Mrad (20 MGy)	7000 Mrad (70 MGy)	240	YES
TAPED POLYIMIDE	1000 Mrad (10 MGy)	5000 Mrad (50 MGy)	250	YES
NEUTRAX™ (PAEK BASED)	500 Mrad (5 MGy)	1000 Mrad (10 MGy)	240	YES
POLIAX™	300 Mrad (3 MGy)	600 Mrad (6 MGy)	135	YES
TPU - THERMOPLASTIC ELASTOMER	100 Mrad (1 MGy)	200 Mrad (2 MGy)	125	YES
PE/PO and XLPE/XLPO based	50 Mrad (500 kGy)	100 Mrad (1 MGy)	100	YES
ETFE	10 Mrad (100 kGy)	300 Mrad (3 MGy)	155	NO

*limits based on IEC 60544 - worst case scenarios (gamma + low dose rate) and end-point criteria (-50% strain or stress at break).

These values can only serve as a general guideline; exact nature of materials (chemical structure, molecular weight, presence and nature of additives) and environmental conditions such as temperature, humidity and dose rate influence the radiation behaviour of materials.

Cables in Radiation Environment - RADOX

		Thermoplastics		Crosslinked materials					
Abbreviation [1]		LSFH	TPU	CR	RX 125A	RX 125M	RX 125TM	REMS	REMS FH
CENELEC type			TMPU	EM2					
Mechanical characteristics									
Tensile strenght	N/mm^2	≥ 9.0	≥ 25	≥ 10	≥ 10	≥ 9	≥ 10	≥ 15	≥ 10
Elongation at break	%	≥ 125	≥ 300	≥ 300	≥ 125	≥ 125	≥ 125	≥ 300	≥ 125
Abrasion resistance		good	very good	good	good	good	good	good	good
Flexibilty [2]		satisf.	satisf.	very good	satisf.	good	good	good	good
Electrial characteristics									
Volume resistivity at 20 °C	Ωcm	10^{13}	10^{12}	10^{10}	10^{14}	10^{12}	10^{12}	10^{12}	10^{12}
Dielectric constant at 1 kHz		5	7	8	4.8	6	5	4.8	5.5
Fire characteristics									
Flame retardant		yes	no	yes	yes	yes	yes	yes	yes
Halogen free		yes	yes	no	yes	yes	yes	no	yes
Corrosive combustion gases		no	no	yes	no	no	no	yes	no
Smoke generation		low	average	stark	low	low	low	stark	low
Resistance to									
Ionizing radiation	kGy	1000	5000	500	1000	1000	1000	1000	1000

More details

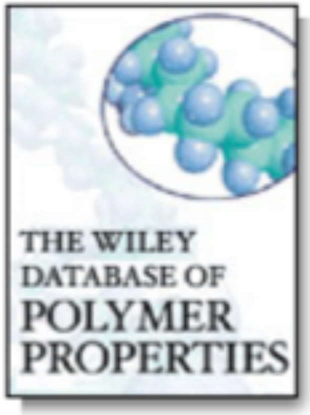
Radiation Resistance of Plastics and Elastomers

Tadao Seguchi, Yosuke Morita

Published Online: 15 APR 2003

DOI: 10.1002/0471532053.bra047

Database Title



Wiley Database of Polymer Properties

Additional Information **(Hide All)**

How to Cite | Author Information | Publication History

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Japan Atomic Energy Research Institute (JAERI), Takasaki Radiation Chemistry Research Establishment, Takasaki, Gunma, Japan

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Published Online: 15 APR 2003

More details


CERN 89-12
Technical Inspection
and Safety Commission
31 December 1989

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

COMPILATION OF RADIATION
DAMAGE TEST DATA

PART I, 2nd EDITION:
Halogen-free cable-insulating materials

INDEX DES RÉSULTATS D'ESSAIS
DE RADIORÉSISTANCE

Ire PARTIE, 2e ÉDITION:
Matériaux d'isolation de câbles exempts d'halogène

H. Schönbacher and M. Tavlet

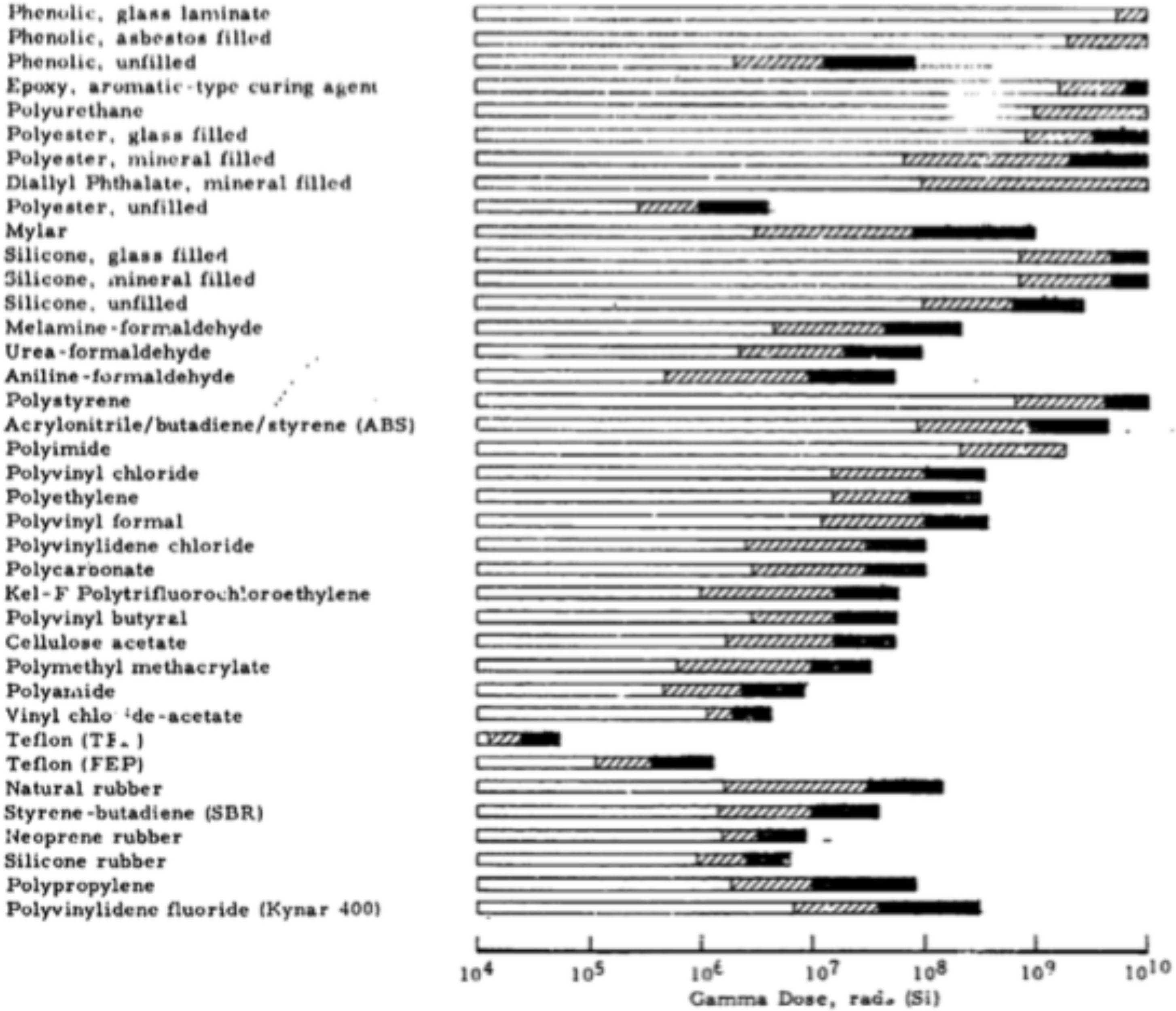
GENEVA
1989

Tavlet, M. and Ilie, S.

"Compilation of Radiation Damage Test Data
PART I: Halogen-free cable-insulating materials"
CERN, Geneva, 2nd Edition 1989

Radiation resistance of polymers – Publication NASA (1969)

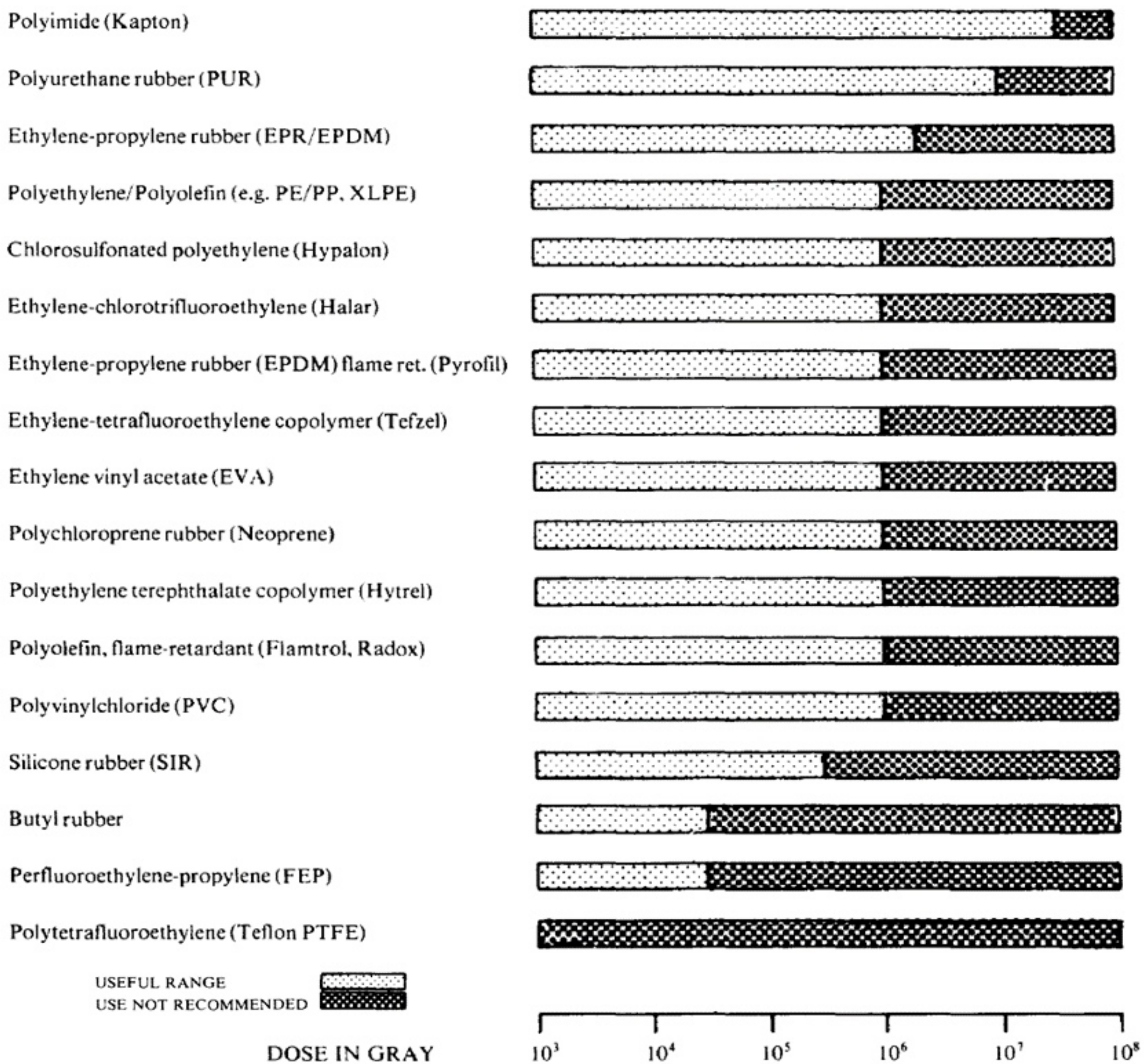
EUROPEAN SPALLATION SOURCE



from:
C. L. Hanks and D. J. Hamman, "*Report on the Effect of Radiation on Electrical Insulating Materials*", NASA, 1969

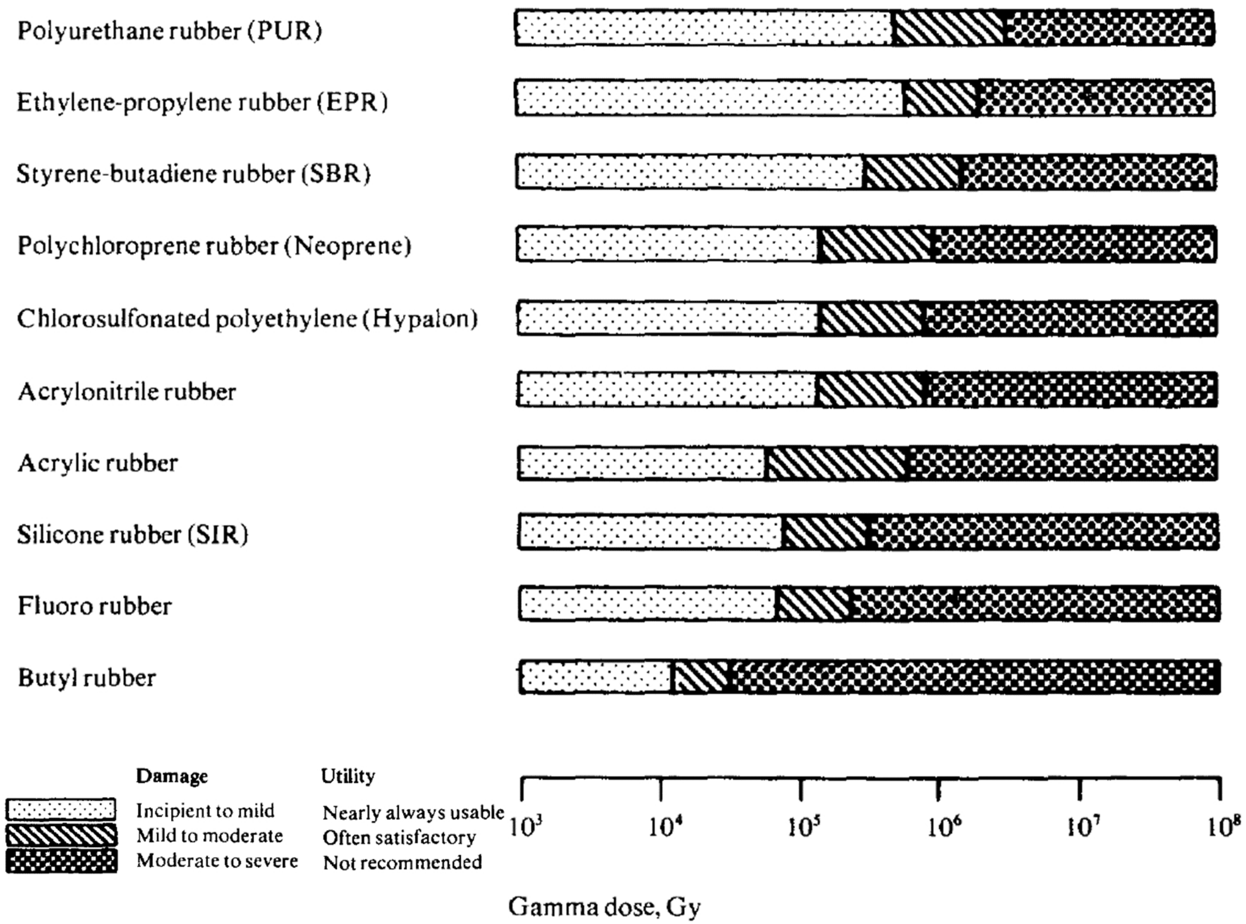
as reference in ESS-0039408 *"NOSG Handbook"*

CERN 1982-10 – Cable insulation



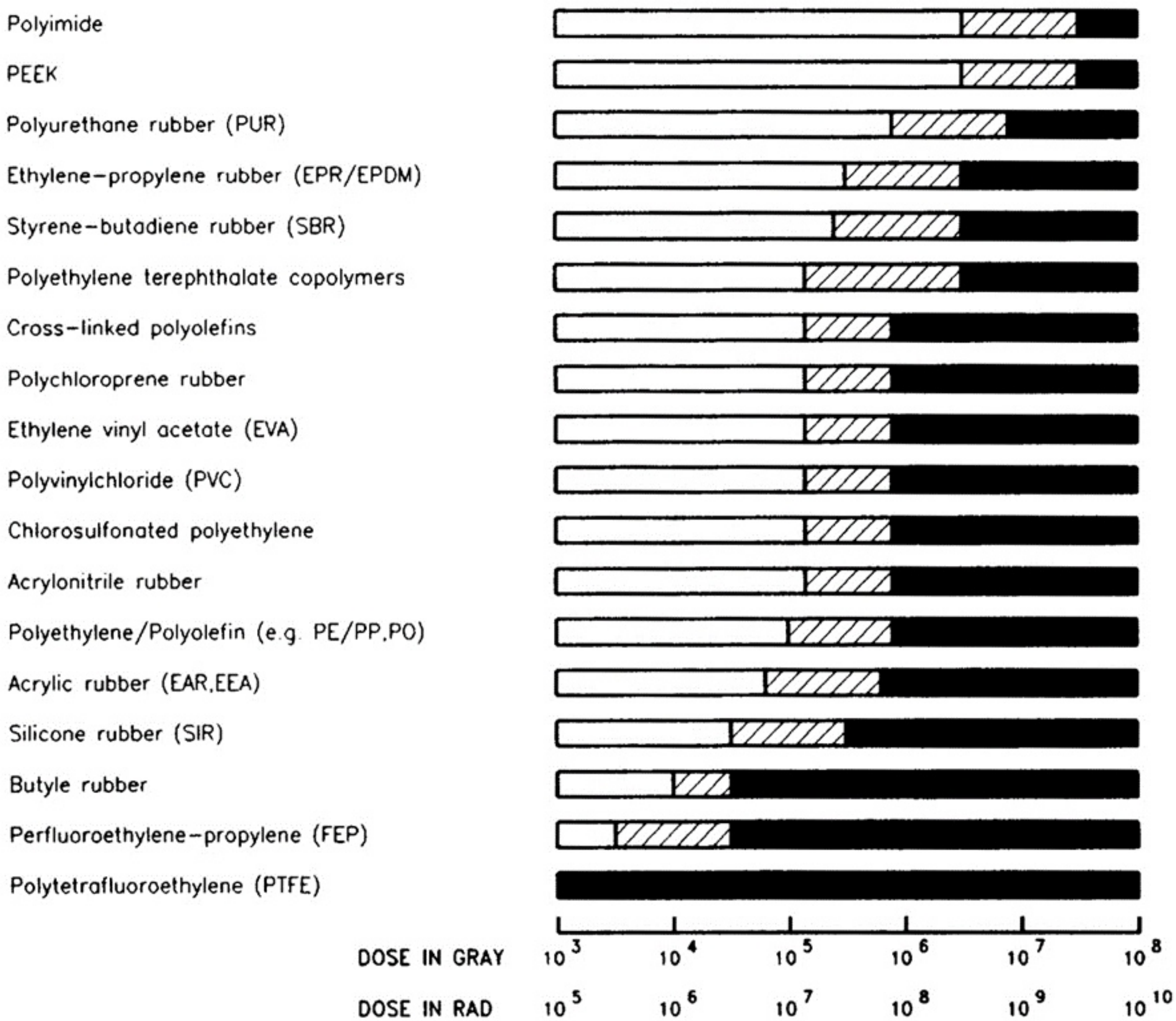
https://radiation-damage.web.cern.ch/content/radiation-damage

CERN 1982-10 – Elastomers



https://radiation-damage.web.cern.ch/content/radiation-damage

CERN 1989-12 – Overview



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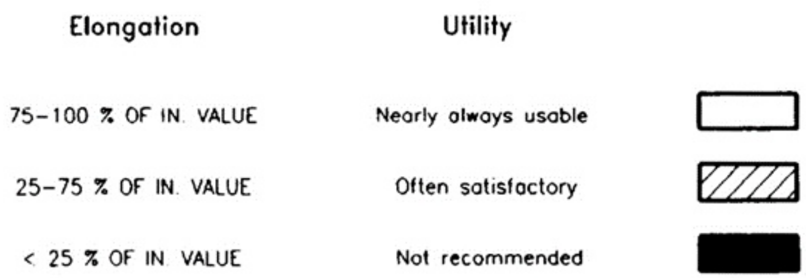


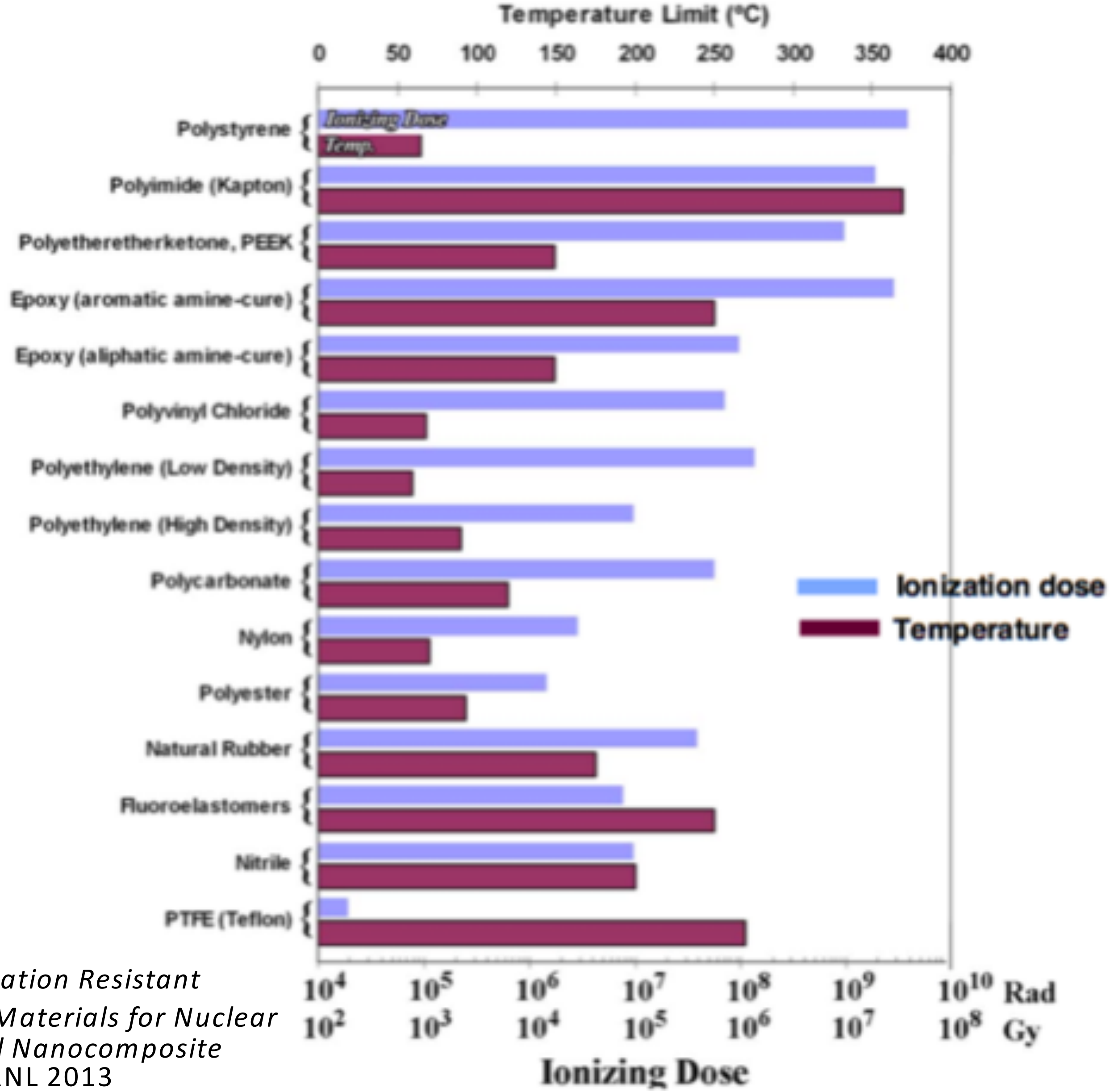
Radiation resistance of polymers – Publication CERN (1999)

Materials	Dose limits in air
Specially formulated aromatic epoxy composites	300 MGy
Cyanate ester resins	300 MGy
Poly-ether-imide (PEI) resins	50 MGy
PEI as wire insulation (*Siltem*)	3 MGy
Specially formulated EPR/EPDM insulated cables	2 MGy
Specially formulated EVA insulated cables	0.5 MGy
Usual polyolefin insulated cables	0.1 MGy
Polyimide (*Kapton H*) films and wire insulation	50 MGy
Polyarylate (*Isaryl*) films	10 MGy
PEEK (amorphous) films and wire insulation	3 MGy
PETP (*Mylar*) films	0.5 MGy
Polypropylene films	30 kGy
Polyamide 66 (*Nylon*) hoses or pieces	300 kGy
Acetal resins (POM) (*Delrin*) hoses or pieces	30 kGy
FEP insulated wires	30 kGy
PTFE insulated wires	1 kGy

from:
M. Tavlet and S. Ilie, “*Behaviour of Organic Materials in Radiation Environment*”, IEEE 2000

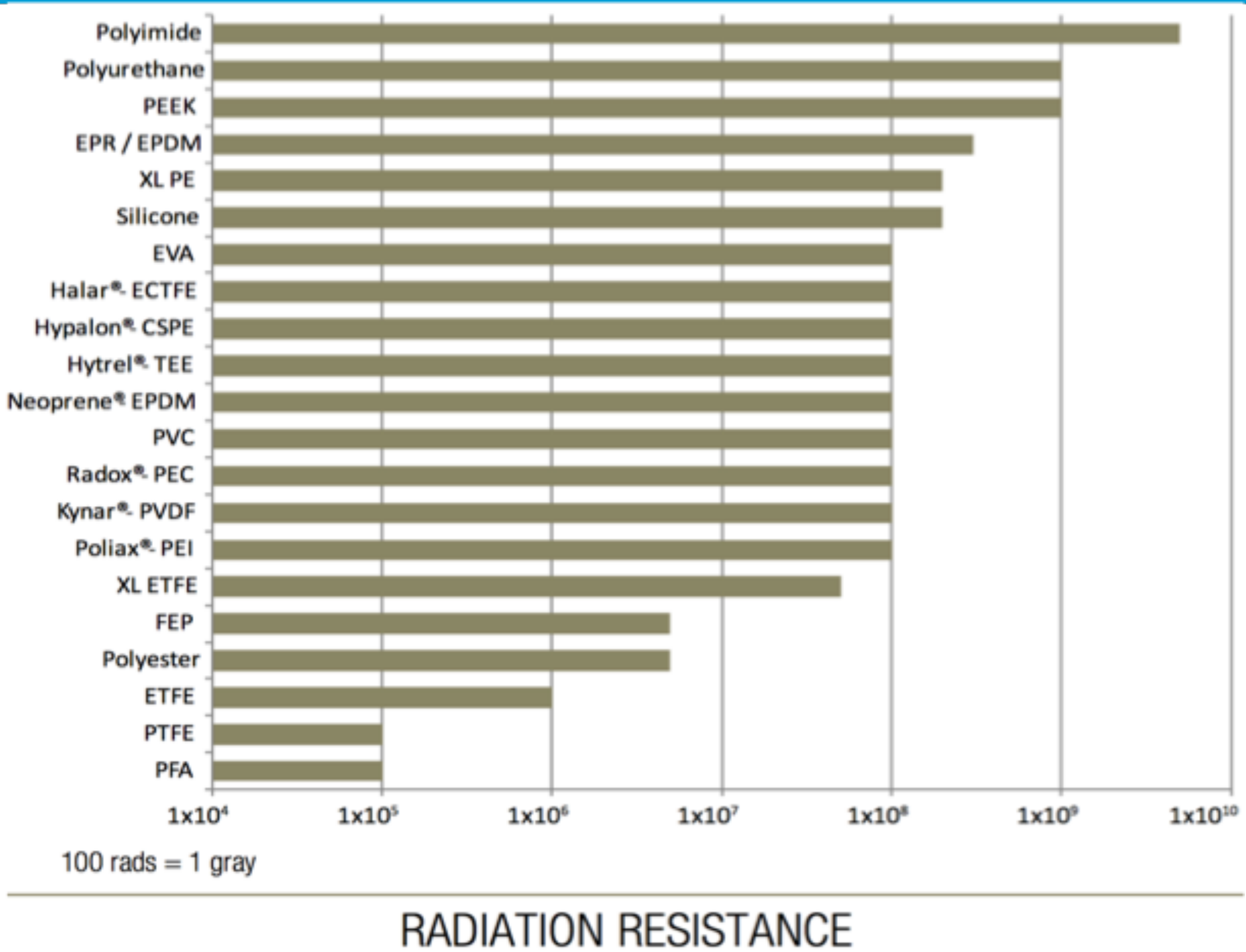
Radiation resistance of polymers – Presentation ORNL (2013)

- **Current materials utilized in instrument and power cable in nuclear reactors**
  - » **PEEK**
  - » **EPR**
  - » **CSPE**
  - » **SiR**
  - » **XLPE/XLPO**
- **Base dielectric materials of interest**
  - » **PVA, XLPVA**
  - » **PE, XLPE**
  - » **PI**



Duckworth, R., "*Radiation Resistant Electrical Insulation Materials for Nuclear Reactors Using Novel Nanocomposite Dielectrics* ", DOE-ORNL 2013

Radiation resistance of polymers – AXON (2014)



Radiation resistance of polymers – AXON (2014)

Radiation resistance

	INSULATION RADIATION RESISTANCE	TEMPERATURE	HALOGEN FREE LSZH (*)
POLYIMIDE	$5x10^9$ RADS	-50°C / +400°C	YES
NEUTRAX	$1x10^9$ RADS	-50°C / +200°C	YES
POLYURETHANE	$1x10^9$ RADS	-40°C / +125°C	YES
XLPE	$2x10^8$ RADS	-40°C / +125°C	YES
POLIAX	$1x10^8$ RADS	-40°C / +130°C	YES
ETFE	$5x10^7$ RADS	-90°C / +155°C	-

Radiation resistance of polymers - LAPP

Resistance of plastics to ionising radiation

Material-type	Radiation resistance in Gy approx.	Radiation resistance in rad approx
PVC	8×10^5	8×10^7
PE LD	1×10^5	1×10^7
PE HD	7×10^4	7×10^6
VPE (XLPE)	1×10^5	1×10^7
PA	1×10^5	1×10^7
PP	1×10^3	1×10^5
PETP	1×10^7	1×10^7
PUR	5×10^5	5×10^7
TPE-E	1×10^5	1×10^7
TPE-O	1×10^5	1×10^7
NR	8×10^5	8×10^7
SIR	2×10^5	2×10^7
EPR	1×10^6	1×10^8
EVA	1×10^5	1×10^7
CR	2×10^5	2×10^7
ETFE	1×10^5	1×10^7
FEP	3×10^3	3×10^5
PFA	1×10^3	1×10^5
PTFE	1×10^3	1×10^5

Radiation resistance of polymers - LAPP

EUROPEAN SPALLATION SOURCE

Resistance of plastics to ionising radiation

Material-type	Radiation resistance in Gy approx.	Radiation resistance in rad approx
PVC	8×10^5	8×10^7
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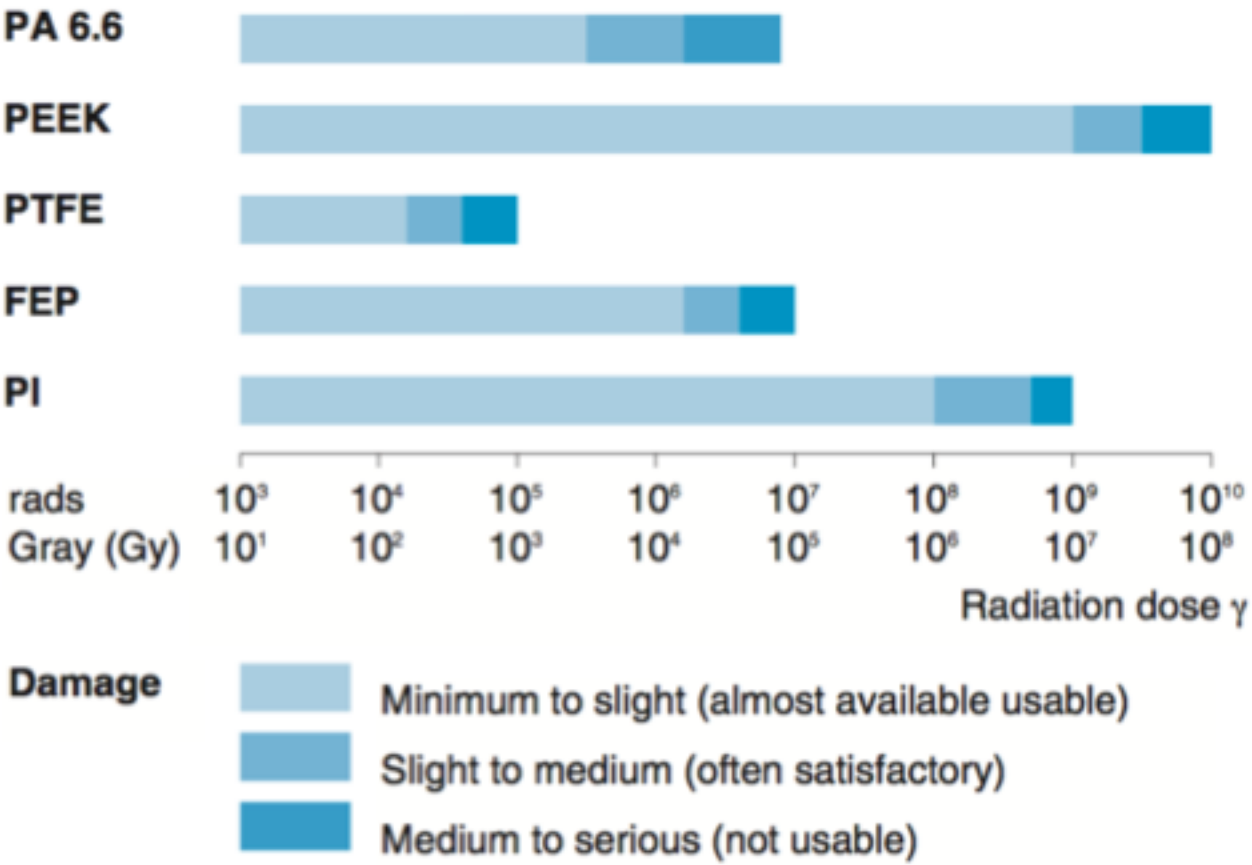
VPE (XLPE)	1×10^5	1×10^7
PA	1×10^5	1×10^7
PP	1×10^3	1×10^5
PETP	[illegible]	1×10^7
PUR	[illegible]	5×10^7
TPE-E	[illegible]	1×10^7
TPE-O	[illegible]	1×10^7
NR	[illegible]	8×10^7
SIR	2×10^5	2×10^7
EPR	1×10^6	1×10^8
EVA	1×10^5	1×10^7
CR	2×10^5	2×10^7
ETFE	1×10^5	1×10^7
FEP	3×10^3	3×10^5
PFA	1×10^3	1×10^5
PTFE	1×10^3	1×10^5

PVC	0.8 MGy
PU	0.5 MGy
NR (Nat. Rubber)	0.8 MGy
EPR (≈EPDM)	1.0 MGy

Radiation resistance of polymers - LEMO



Note: technical data in this chapter provide general information on plastics used by LEMO as electrical insulators. LEMO reserves the right to propose new materials with better technical characteristics, and to withdraw, without notice, any material mentioned in the present catalogue or any other publications edited by LEMO S.A. and/or its subsidiaries. LEMO SA and its subsidiaries use only plastic granules, powder or bars supplied by specialized companies, and thus cannot in any case take responsibility with regard to this material.

Radiation resistance of vacuum cables - VACOM

Description VACOM ordercode	Enameled solid wire KAP-LACK-D-...	Film-wrapped solid wire KAP-BAND-D-...	Film-wrapped stranded wire KAP-BAND-L-...
■ Conductor material	Copper (bare)	Copper (silver-plated)	
■ Insulation	Polyimide (Kapton®) enamel	Polyimide (Kapton®) film	
■ Temperature resistance	-269 °C to 260 °C *, (short-term to 350 °C **)	-75 °C to 200 °C *, (short-term to 250 °C **)	
■ Radiation resistance	10^7 Gy (10^9 Rad)	10^5 Gy (10^7 Rad)	
■ Dielectric strength	2 kV DC	1 kV DC	
■ Range of application	min. $1 \cdot 10^{10}$ mbar (possibly bakeout required)	min. $1 \cdot 10^{10}$ mbar (possibly bakeout required)	
■ Recommended connections	Clamp connection	Clamp/Solder/Crimp connection	

More cables available on request, e. g. flat ribbon cable, coaxial cable, high voltage cable.

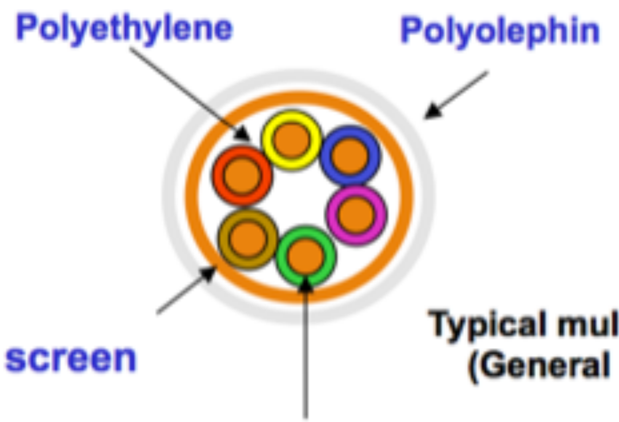
Higher resistance of the "enameled" wire is probably due to the fact that it is applied on solid wire and intended for fixed installations, i.e. it works also with a slightly damaged isolation.

EUROPEAN SPALLATION SOURCE

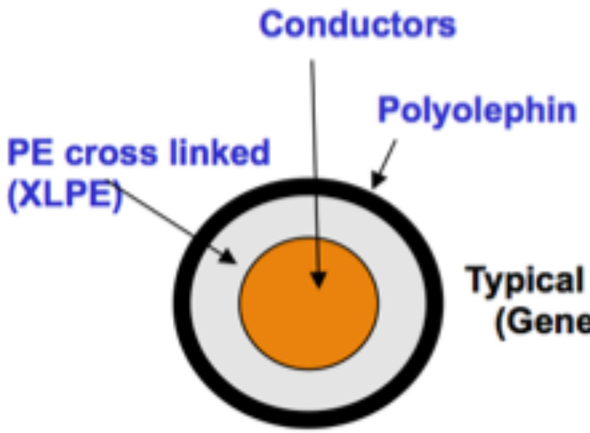
Concerning the resistance to radiations, the requirements for all types of cables are the following:

-Retention of functional capabilities up to the specified Radiation Index (up to an integrated radiation dose of 5 ×10 5 Gy for general purpose cables and 10 7 Gy for special radiation resistant cables).

Requested by cable Technical Specifications:

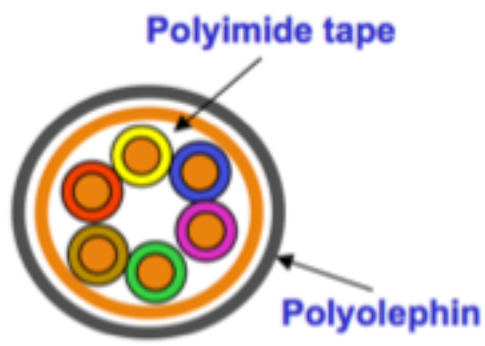


Typical multi wire control cable (General purpose)



Typical unipolar power cable (General purpose)

Typical multi wire control cable (Sp. radiation resistant cable)

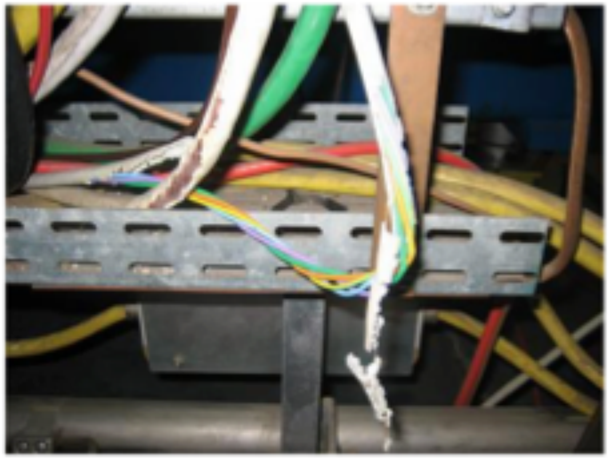


Cable code	Price (CHF/m)		Ratio
	Normal	Radiation resistant	
NE48	5.3	43	8.2
NE4	1	5.4	5.4
NG28	5.7	31	5.5
NF12	2.5	15	6
SVA3	1.74	5.1	3

Example of radiation damages.

Not irradiated | **$5x10^6$ Gy** | **10^7 Gy**

In the SPS tunnel:

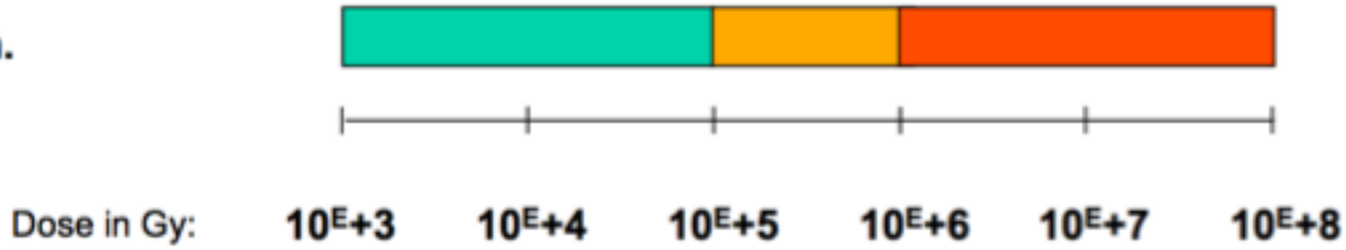


Example of radiation damages.

Classification of materials according to their radiation resistance.

(Comp. of radiation damage test data : M. Talvet – H. Schönbacher - 1989)

Polyethylene/Polyolefin.



From 1990 to 1996, cables sample have been irradiated in situ in LSS6. Mechanical tests have been done by TIS.

Conclusion:

- For the SPS cables irradiated about 0.1 MGy, the inner insulations were falling apart. The degradation of the sheath was less pronounced.