LAS / ANS 2010 Symposium

"New Technologies for the Nuclear Fuel Cycle"

Selected Polymers Materials for Nuclear Applications

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Outline

1. ***Nature and Characteristics of Polymers and Elastomers***
2. ***Interaction of Radiation with Organic Materials***
   - ***Changes in physical structure and properties***
   - ***Effects of Radiation on Mechanical Properties of Plastics***

4. ***Selected Application of Polymers in the nuclear Fuel Cycle***
   - ***Nuclear reactors***
   - ***Radioactive waste management***
   - ***Super Absorbent Polymers***
   - ***Polymer applications to decontamination***
   - ***Polymeric Materials for Ultra Centrifuge***

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Nature and Characteristics of Polymers and Elastomers

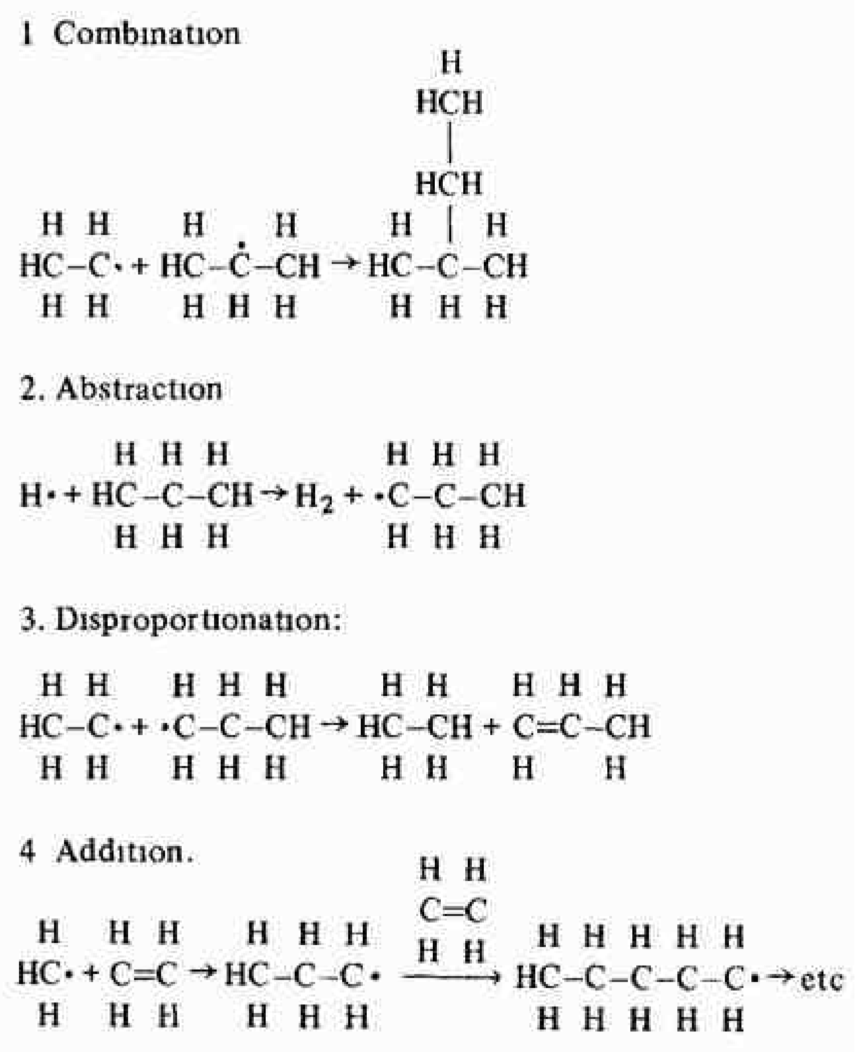
- Elastomer = rubbers (high elasticity)
- Polymer = plastic (plastic behavior , easily shaped at high temperature)
- Long chain molecules made up of numerous repeating units (monomers)
- They can be thermoplastic (can be liquefied reversible over the melting point, repeated molding) or thermoset (rigid network)

- molecule composed of repeating structural units typically connected by ovalent bonds. While *polymer* in popular usage suggests plastic,

Interaction of Radiation with Organic Materials

- Radiation interact with orbital electrons of the atoms of the absorbing medium to ionize or excite them to higher energy levels. This can disrupt the valence bond in organic compounds.
- In hydrovarbons, H-C bonds and C-C bonds are broken most frequentely.

•Ionic reactions can go by similar paths
•Molecular decomposition reactions takes place



W W Parkinson, O Sisman, Plastics and elastomers
NUCLEAR ENGINEERING AND DESIGN 17 (1971) 247-280.

Changes in physical structure and properties

- **Crosslinking – increases the molecular weight of a polymer, decrease solubility to insoluility and further irradition increase hardness (hard glassy substance);**

- **Scission – opposite to crosslinking, , molecules are broken into smaller fragments, MW decreses and solubility increases, can lead to a viscous flow**

Side reactions are the production of low-molecular-weight fragments and the creation of unsaturation. Fragments are usually gases.

PE produce a gas high in H2, which escapes readily. Other polymers produce gas of higher molecular weight (e.g., CH4, C2H6 etc.) that can be trapped.

Gas yields are given in the following table:
10.Temperature dependece not considered
11.Oxygen effect not considered

Table 1
Gas yields from irradiated plastics and elastomers [1].

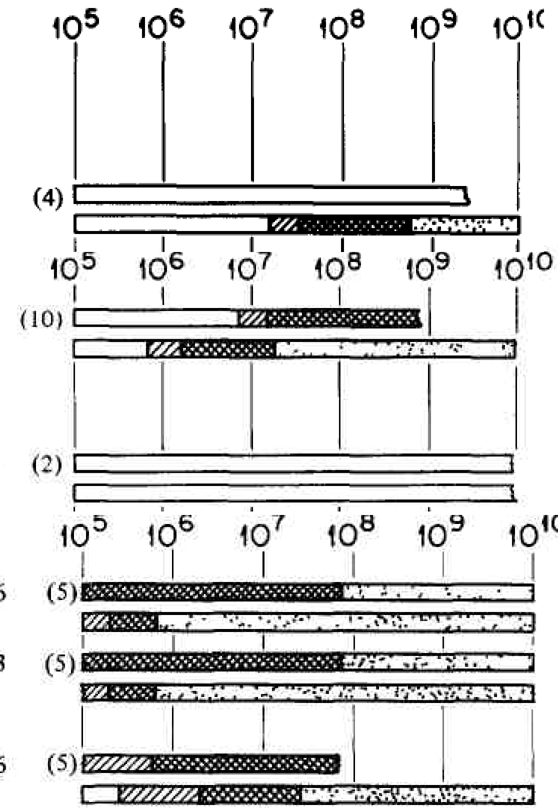
Material	Gas evolved (a)	
	G, or molecules/ 100 eV	ml/g (STP) at 10^9 rads
Polyethylene	3 1	70
Polystyrene	0.08	1.5
Poly(α-methylstyrene)	0.08	1.5
Natural rubber (b)	0.3	7
Styrene-butadiene rubber (b)	0.15	4
Styrene-butadiene plastic	~0.08	~2
Polyisobutylene rubber (b)	0 8	17
Polyamide-nylon	1 1	25
Aniline-formaldehyde polymer	~0 08	~2
Malamine-formaldehyde polymer (cellulose filler)	0.45	10
Urea-formaldehyde polymer (cellulose filler)	0.8	17
Nitrile-butadiene rubber (b)	0.15	5 0
Casein plastic	0.15	4
Poly(methylmethacrylate)	1.5	35
Poly(ethylene terephthalate)	0.15	3
Allyl diglycol carbonate	1 9	40
Polyesters (general)	0 08 to 1 9	2 to 40
Cellulose acetate polymer	0.08	17
Cellulose acetate-butyrate polymer	1 2	28
Cellulose propionate polymer	1 5	35
Cellulose nitrate polymer	4 6	105
Ethyl cellulose polymer	1.5	35
Phenolic plastic (no filler)	0.1	3
Phenolic plastic (cellulose filler)	0.8	17
Phenolic plastic (mineral filler)	<0.08	<2
Silicone elastomer	0.9	20

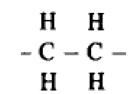
[1] R.O Bolt and J.G. Carroll, Radiation Effects on Organic Materials (Academic Press, New York, 1963)

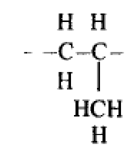
Effects of Radiation on Mechanical Properties of Plastics

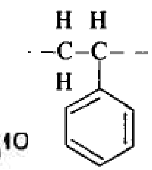
W W Parkinson, 0 Sisman, Plastics and elastomers NUCLEAR ENGINEERING AND DESIGN 17 (1971) 247-280.

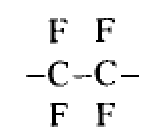
Material	Initial Value[b]	Dose Rate Mrads/hr	Thick-ness, (in.)	Percent of Initial Value Retained at Given Dose (rads)[a,c]
Thermoplastic Polymers				
A. Hydrocarbon Polymers				
1. High-density (linear) polyethylene				
a. Super Dylan:				
Tensile Strength, psi	3000	2	0.12	(4)
Elongation at Break, %	170			
2. Polypropylene (Profax)				
Tensile Strength, psi	4660			(10)
Elongation at Break, %	70			
3. Polystyrene				
a. Clear Polystyrene				
Tensile Strength, psi	1800	2	0.12	(2)
Elongation at Break, %	0.32			
8. Polytetrafluoroethylene (Teflon)				
Tensile Strength, psi	4800	1	0.06	(5)
Elongation at Break, %	400			
Tensile Strength, psi	3900	1	0.03	(5)
Elongation at Break, %	400			
Irradiated in vacuum				
Tensile Strength, psi	4650	1	0.06	(5)
Elongation at Break, %	345			

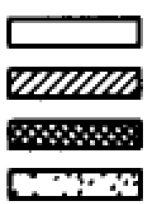












100 to 80% of initial value retained.
80 to 50% of initial value retained.
50 to 10% of initial value retained.
10 to 0% of initial value retained.

Typical use of plastics and elastomers around reactors

Most polymeric materials can be used to radiation environment of at least 109 kGy. Some are useful to 1013 kGy in limited applications. Probably none are much better than this, even with large amounts of mineral filler.

High dose rates cause heating, and properties of plastics and rubbers may be strongly temperature dependent. Also, the radiation-induced change may depend on the temperature, atmosphere, kind of radiation, dose rate, and conditions of stress on the material, and varies widely with chemical structure.

- *Gaskets and seals*
- *Hoses, flexible tubing and diaphragms*
- *Electrical insulation*
- *Thermal insulation*
- *Potting or encapsulating compounds*

Elastomer seal products for the nuclear industry include:

Airlock door seals

Personnel access door seals

Equipment hatch seals

Torus and wet well access hatch seals

Refueling canal hatch seals

Pool gate seals

Airlock shaft seals

Drywell head seals

Inflatable door and valve seals

Googling: elastomer "nuclear reactor"

Seismic isolation using sliding-elastomer bearing pads -R Gueraud, JP Noėl-Leroux, M Livolant, Eng. and Design, 1985

Refueling seal arrangement for nuclear reactor vessel; GE Schukei, AW Viets - US Pat 4,758,402, 1988 - Google Pat.

Permanent seal ring for a nuclear reactor cavity; RE Meuschke, WE Desmarchais, LR Katz - US Patent 4,170,517, 1979

Protection of nuclear power plants against seism; C Plichon, R Gueraud, M.Richli, JF Casagrande - Nuclear Tech. 1980

Permanent seal ring for a nuclear reactor cavity; MF Hankinson, JR Marshall - US Patent 4,747,993, 1988 - Google Pat

Aseismic bearing pads:: A new sliding pad technique used in the construction of nuclear power stations for protection against earthquake damage; B Pavot, E Polus - Tribology International, 1979

Multi-segmented sealing ring; AJ Anthony - US Patent 4,070,221, 1978 - Google Patents

Real-time condition monitoring of mechanical face seal; M Zou, I Green - Tribology Series, 1998

Mechanical charact. of seismic base isolation elastomers; RF Kulak, TH Hughes -conf. on structural mech. in reactor, 1991

Device for Sealing a Rotating plug in; R Brandstetter - US Patent 3,867,254, 1975 - Google Patents

Core disruptive accident margin seal; J Garin, JC Belsick - US Patent 4,113,564, 1978 - Google Patents

Top closure for control rod drive for nuclear reactor; JH Raas, JI Schwartz - US Patent 4,076,144, 1978 – G Pat

Nuclear fuel pellet loading apparatus; KS Gerkey - US Patent 4,158,601, 1979 - Google Patents

Method and device for repairing the internal surface of an adapter passing through the head of the vessel of a nuclear reactor; A Domy, C Hebert, L Brayer - US Patent 5,434,895, 1995 - Google Patents

Inflatable reactor vessel stud hole plug; AJ Retz - US Patent 4,671,518, 1987 - Google Patents

Effects of Aircraft Impact on a Seismically Isolated Reactor Building; RF Kulak, B Yoo - SMiRT, 2003 - iasmirt.org

RD activities at Argonne National Laboratory for the application of base seismic isolation in nuclear facilities; RW Seidensticker - 11. post structural mechanics in reactor technology (..., 1991 - osti.gov

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Radioactive waste management practices in India

K. Raj et al. / Nuclear Engineering and Design 236 (2006) 914–930

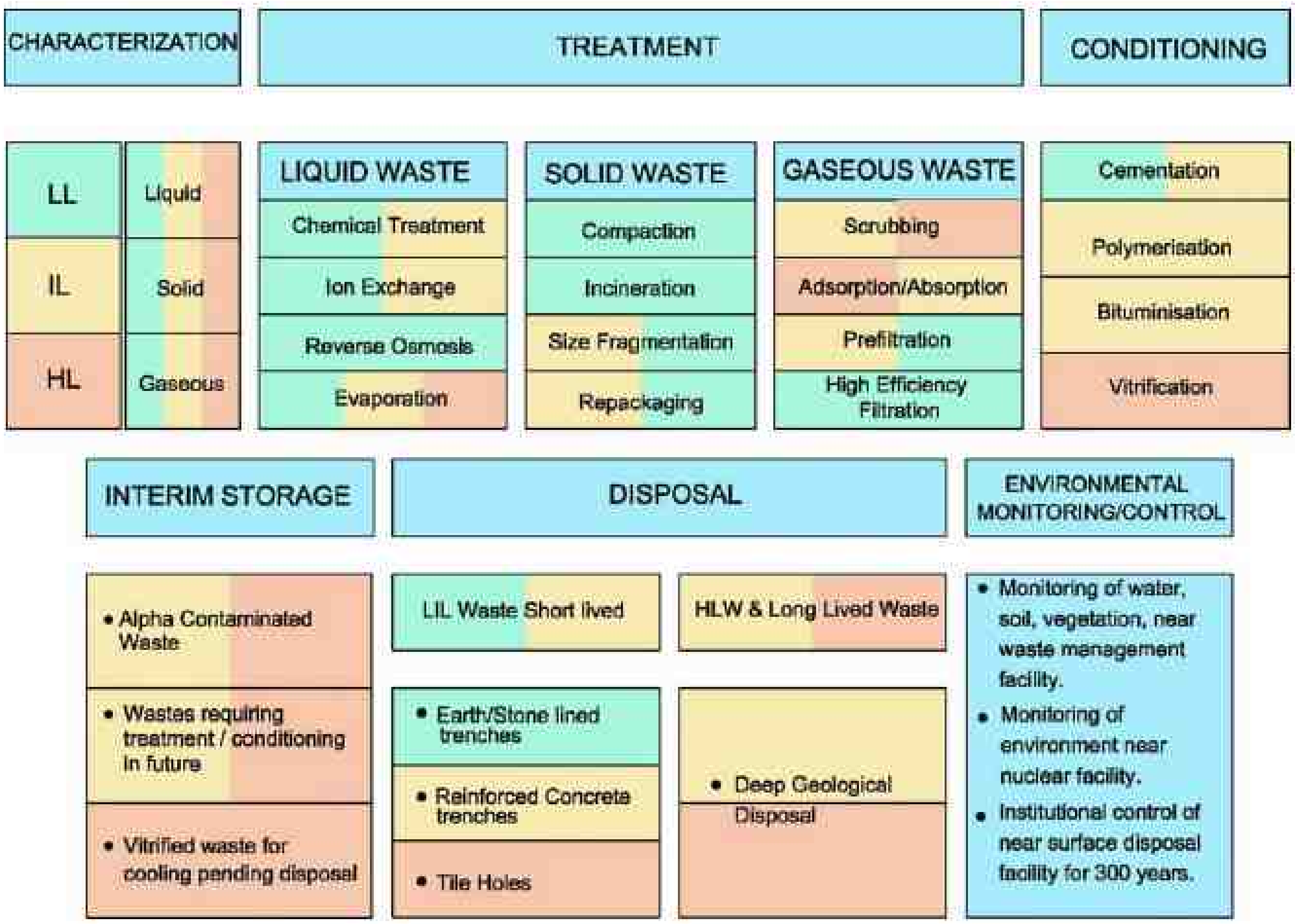

Fig. 1. Management of radioactive waste.

Polymer applications to decontamination from ***Combined methods for liquid radioactive waste treatment*** *Final report of a co-ordinated research project. 1997–2001*

View of strippable coating onto red brick, ceramic and metal surfaces (Figs. 4-8).

Fig. 4. Brick surface.

Fig. 5. Ceramic surface.

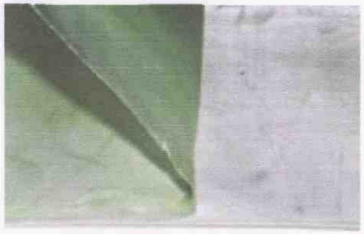

Fig. 6. Metal surface.

Figs. 7 and 8. Strippable coatings with metal oxides.

For the tests PVA-based strippable coatings were selected and doped with aggressive agents: decontamination coatings (DC) and pickling-decontamination coatings (PDC). More than 160 real and artificially contaminated specimens were tested. Tables 8, 9 and 10 present the results of decontamination by strippable polymeric coatings currently employed.

Table 8. Decontamination efficiency for real stainless steel specimens contaminated with ^{137}Cs

Formulation	*Initial activity, Bq*	*Residual activity, Bq*
DP-1	$1*10^3 \pm 1*10^2$	background*
DP-2	$1*10^3 \pm 1*10^2$	background
PD-1	$1.1*10^3 \pm 1*10^2$	background
PD-2	$1.2*10^3 \pm 1*10^2$	background

* an average of 5 parallel experiments

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SUPER ABSORBENT POLYMERS

Based on sodium polyacrylate and similar molecules. Uses:

(5) to absorb liquid in otherwise “dry wastes;”
(6) and to convert a liquid to a solid for the purpose of simplifying transportation or further processing (e.g. to feed the liquid into an incinerator as a solid waste).

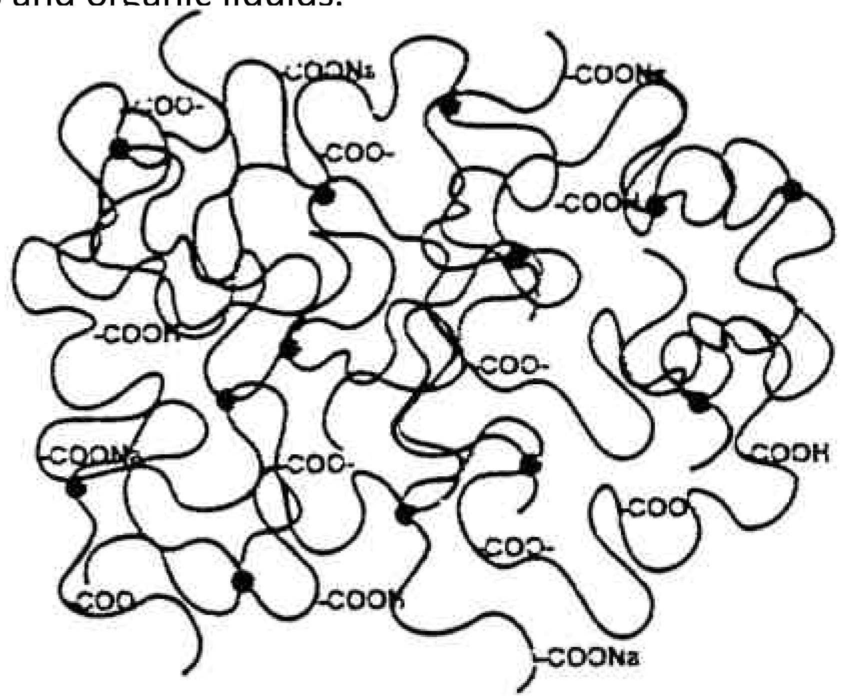
When mixed with liquids, they have the ability to absorb several hundred times their weight in liquid. The original liquid is locked in the molecular structure along with any disolved or suspended solids. Formulations are available for aqueous and organic liquids.

benefits of technology

— High absorption capacity (typically several 100:1)
— Waste form can be incinerated later, as solid waste.
— Only very small increase in volume compared to original liquid volume.
— Requires only simple equipment.

Significant limitations,

— High radiation fields may cause damage to polymer.



US Department of Energy Laboratory
Water Treatment Plant Waste Solidification
Problem: How to solidify LLRW water for transport across country to the Hanford Nuclear Reservation (WA) without doubling/tripling waste volume?

The LLRW is solidified in steel B-25 boxes.

The waste is pure liquid and contains contaminants of radioisotopes. About 100 lbs of *Waste Lock® is* first added to the bottom of the box.

The polymer swells as liquid is added. More polymer is added to the top of the gel and then more liquid added to the fresh polymer.

In this step-by-step/layered approach, the entire liquid content of the B-25 box is solidified to meet EPA Paint Filter Test Requirement.

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Polymeric Materials for Ultra Centrifuge

Table 1 Estimated design characteristics of important centrifuge generations.

		Rotor characteristics					
Type	**Original Machine**	**Deployment Period**	**Material**	**Speed**	**Diameter**	**Length**	**Separative Power**
Values in parentheses are author's estimates.							
	Zippe	1940s-50s	Aluminum	350 m/s	7.4 cm	0.3 m	0.44 SWU/yr
P-1	SNOR/CNOR	1960s-70s	Aluminum	350 m/s	10 cm	2.0 m	2-3 SWU/yr
P-2	G-2	1960s-70s	Maraging steel	485 m/s	15 cm	1.0 m	5-6 SWU/yr
P-3	4-M	Early 1980s	Maraging steel	(485 m/s)	n/a	2.0 m	12 SWU/yr
P-4	SLM (TC-10)	Late 1980s	Maraging steel	500 m/s	15 cm	3.2 m	21 SWU/yr
	TC-11	Late 1980s	Carbon fiber	(600 m/s)	n/a	(3.0 m)	n/a
	TC-12	1990s	Carbon fiber	(620 m/s)	(20 cm)	(3.0 m)	40 SWU/yr
	TC-21	2000s	Carbon fiber	(770 m/s)	(20 cm)	(5.0 m)	100 SWU/yr
	AC100	2000s	Carbon fiber	(900 m/s)	(60 cm)	(12.0 m)	330 SWU/yr

Most carbon fiber are produced from PAN and coated with epoxides

Fluorinated rubber (viton®) and PTFE (teflon®) seals and perfluorinated fluids for vacuum pumps and compressors in centrifuge cascade

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