TENNESSEE VALLEY AUTHORITY
CHATTANOOGA, TENNESSEE 37401
400 Chestnut Street Tower II

April 6, 1984

Director of Nuclear Reactor Regulation
Attention: Ms. E. Adensam, Chief
Licensing Branch No. 4
Division of Licensing
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Ms. Adensam:

In the Matter of the Application of	)	Docket Nos.	50-390
Tennessee Valley Authority	)		50-391

Please refer to my letter to you dated March 9, 1984 which provided the results of evaluations assessing the environmental qualification of the safety-related mechanical equipment at the Watts Bar Nuclear Plant. Also transmitted were the complete qualification packages for three components.

Our submittal of March 9, 1984 inadvertently included erroneous information. Specifically, (1) several components were omitted from the initial equipment list and thus were not included in the summary of evaluations, and (2) the lubricant evaluated for the NSSS mechanical equipment was not the lubricant actually used. Enclosed are revised summary sheets 3 and 6 and the proper evaluation for the NSSS equipment lubricants.

Please note that our previous submittal stated that the radiation-sensitive subcomponents of the 12 components identified as category 'D' (material replacement required) would be replaced before exceeding 5-percent power operation. Justifications for interim operation up to 5-percent power operation were provided for these components. It has now been determined that these material change-outs will be performed before fuel load.

If you have any questions concerning this matter, please get in touch with Dave Ellis at FTS 858-2681.

Very truly yours,

TENNESSEE VALLEY AUTHORITY

L. M. Mills

L. M. Mills, Manager
Nuclear Licensing

Sworn to and subscribed before me
this 6th day of April 1984

Paulette H. White
Notary Public
My Commission Expires 9-5-84

Enclosures (2)

A048
1/1

cc: U.S. Nuclear Regulatory Commission (Enclosures)
Region II
Attn: Mr. James P. O'Reilly Administrator
101 Marietta Street, NW, Suite 2900
Atlanta, Georgia 30303

50-390

Revised summary sheets 3 & 6 & proper evaluation for NSS equipment lubricants re environ q-ualification of safety-relatded mechanical equip. due to erroneous info

w/ltr 84/04/06 8404110114

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MECHANICAL EQUIPMENT QUALIFICATION

EQUIPMENT LIST INSIDE CONTAINMENT - HARSH ENVIRONMENT
SYSTEM (Name & Number) CHEMICAL VOLUME AND CONTROL - 62

MEQ ID	TVA LOCATION NO 1	TVA COMPONENT ID NUMBER 2	EQUIPMENT NAME	CONTRACT NUMBER 1	MANUFACTURER & MODEL 3	LOCATION 4	NSSS	BOP	SUBCOMPONENT LISTING SHEET	NOTE
1010	1-8112	1-FCV-62-61-B	GATE MOV	54114	W EMD 4GM72FBH	R-Z/282/716-IC	X		0060-508-001	A
1011	2-8112	2-FCV-62-61-B	•	•	•	•	•		•	A
1012	1-LCV-460	1-FCV-62-69-A	GLOBE AOV	•	FISHER 31A88RG	R-Z/132/716-IC	•		0060-508-006	C
1013	2-LCV-460	2-FCV-62-69-A	•	•	•	•	•		•	C
1014	1-LCV-459	1-FCV-62-70-A	•	•	•	R-Z/130/716-IC	•		•	C
1015	2-LCV-459	2-FCV-62-70-A	•	•	•	•	•		•	C
1016	1-8149 A	1-FCV-62-72-A	•	•	FISHER 21A78RG	R-Z/47/703-IC	•		•	C
1017	2-8149 A	2-FCV-62-72-A	•	•	•	•	•		•	C
1018	1-8149 B	1-FCV-62-73-A	•	•	•	R-Z/48/703-IC	•		•	C
1019	2-8149 B	2-FCV-62-73-A	•	•	•	•	•		•	C
1020	1-8149 C	1-FCV-62-74-A	•	•	•	R-Z/49/703-IC	•		•	C
1021	2-8149 C	2-FCV-62-74-A	•	•	•	•	•		•	C
1021A	N/A	1-FCV-62-76-A	•	•	FISHER 21A88RG	R-Z/48/703-IC	•		•	C
1021B	N/A	2-FCV-62-76-A	•	•	•	•	•		•	C

R1

For References see Page 1

Prepared by: JK Date: 2/10/84

Reviewed by: CMR Date: 2-10-84

Revision 1

MECHANICAL EQUIPMENT QUALIFICATION

EQUIPMENT LIST OUTSIDE CONTAINMENT - HARSH ENVIRONMENT
SYSTEM (Name & Number) CHEMICAL VOLUME AND CONTROL - 62

MEQ ID	TVA LOCATION NO [1]	TVA COMPONENT ID NUMBER [2]	EQUIPMENT NAME	CONTRACT NUMBER [1]	MANUFACTURER & MODEL [3]	LOCATION [4]	NSSS	BOP	SUBCOMPONENT LISTING SHEET	NOTE
1058	1-8497	1-CKV-62A-519-S	CHECK VALVE	54114	W EMD 3C78		X		0060-508-012	A
1059	2-8497	2-CKV-62A-519-S	"	"	"		"		"	A
1059A	1-8481 A	1-CKV-62A-525-A	"	"	W EMD 4C78		"		"	A
1059B	2-8481 A	2-CKV-62A-525-A	"	"	"		"		"	A
1059C	1-8481 B	1-CKV-62A-532-B	"	"	"		"		"	A
1059D	2-8481 B	2-CKV-62A-532-B	"	"	"		"		"	A
1060	1-8442	1-CKV-62B-930	"	"	W EMD 3C72		"		"	A
1061	2-8442	2-CKV-62B-930	"	"	"		"		"	A

R1

For References see Page 1

Prepared by: [signature] Date: 2/10/84

Reviewed by: CNR Date: 2-10-84

Revision 1

TVA EVALUATION OF LUBRICANT FOR NSSS EQUIPMENT

It has been determined that the only lubrication used on NSSS equipment is a turbine oil with a viscosity of 150 at 100°F and grease. The turbine oil is Ideal Plus manufactured by ARCO. It is used in the lubrication system for the containment spray, residual heat removal, spent fuel pit cooling system, centrifugal charging and safety injection pumps. The grease is NLGI-2 and must meet TVA specification 18.009. It is used in the lubrication of the couplings for the containment spray, centrifugal charging and safety injection pumps.

The table below is a cross-reference between the environmental and the MEQ ID.

	1	2	3
Max. temp.	110	218	128
40-yr Nor. Rad.	1E6	1E6	5E2
Total Rad.	1.1E7	1.1E7	1.05E4

1 - MEQ ID - 1296-1307
2 - MEQ ID - 1308-1311
3 - MEQ ID - 1312-1314

Pump	MEQ ID
Centrifugal Charging	1296-1299
Safety Injection	1300-1303
Containment Spray	1304-1307
Residual Heat Removal	1308-1311
Spent fuel Pit Cooling	1312-1314

Material capabilities of the Ideal Plus turbine oil is as follows:

Threshold (RADS) - 9E6
15% Property Change (RADS) - 9E7
47% Property Change (RADS) - 2.7E8

Radiation information was obtained from TVA reference M-27-1.

Per ARCO specification sheet A.R.CO.-2100-219A G8, Ideal Plus is designed for applications where oil is exposed to temperatures in the 500-700°F range. Oil has outstanding resistance to oxidation at high temperatures (up to 400°F).

Based on the above, the subject turbine oil is acceptable for use under this qualification program.

Material capabilities of the NLGI-2 grease is as follows:

Threshold (RADS) - 1E7
20% Property Change (RADS) - 6E7

Radiation information was obtained from BOP reference 170-83, Lubrication Fundamentals, J. George Willis, Mobil Oil Corporation, and TVA reference M-27-1.

TVA Standard Procurement Specification 18.009 requires two elevated temperature tests. The wheel bearing test is done at a temperature of 220°F for 6 hours and the high temperature beater test is done at a temperature of 320°F for 6 hours.

Based on the above, the subject grease is acceptable for use under this qualification program.

Prepared By Thomas R. Witmer Date 3-13-84

Reviewed By J W Hodges Date 3-13-84

Revision 1

Ideal® Plus Oil

Atlantic Richfield Company is introducing a new rust and oxidation inhibited petroleum lubricating oil at the top of its gas turbine oil line. Called Ideal® Plus Oil, it is designed specifically for use in the latest gas turbines where oil is exposed to temperatures in the 500-700° F. range.

Chief Features of Ideal Plus Oil

High temperature anti-oxidants developed for this product by Atlantic Richfield Company are designed to provide:

Excellent thermal stability —even when used in the latest model, most demanding gas turbines;

Tolerance for "heat soak" following turbine shutdown, for maximum resistance to carbon formation in interior bearings;

Outstanding resistance to oxidation at high temperatures —which helps to extend service life beyond normal oil change period;

Long TOST (Turbine Oil Stability Test) life. This product has been undergoing tests for more than 10,000 hours, and samples indicate that it still is in serviceable condition.

In addition, the anti-oxidants themselves do not sublime out of the oil in service such as occurs with conventional anti-oxidants used at elevated temperatures.

Fully inhibited against foaming and air entrainment.

Other Features

Helps to resist formation of coke and varnish deposits to assure equipment protection, to reduce system cleaning and to lower filter and oil replacement frequency

Fully inhibited against harmful rusting and foaming to help assure continued protection of equipment

Has high "interfacial tension," which means that it separates quickly from water, thus protecting circulating systems against harmful contamination

Applications

Ideal Plus Oil is being used in a number of the 7000 Series of Gas Turbines manufactured by General Electric.

This product also can be used in various other kinds of equipment where premium performance is required: Such equipment includes:

Oil flooded rotary air compressors;

Machines or machine components having oil impregnated bearings;

And in applications requiring outstanding resistance to oxidation at high temperatures (up to 400° F.).

The Ideal Plus Oil is recommended for applications experiencing foaming and air entrainment that is using an oil containing a silicone foam inhibitor. To reduce this problem and to obtain maximum performance, the oil containing a silicone foam inhibitor should be drained and replaced with a fresh charge of Ideal Plus Oil.

(Continued)

Ideal Plus Oil
Typical Properties

	ASTM Test Method	Ideal Plus Oil
Gravity, °API	D 287	32.0
Flash Point, °F	D 92	430
Viscosity, SUS at 100 °F SUS at 210 °F Kinematic at 100 °F, cSt Kinematic at 210 °F, cSt	 D 2161 D 445 	 162 44.7 34.6 5.62
Viscosity Index	D 2270	110
Color	D 1500	L1.5
Pour Point, °F	D 97	−25
Neutralization No.	D 974	0.1
Corrosion	D 130	1A
Carbon Residue, %	D 524	0.04
Rust Test, Procedure B, 24 hrs.	D.665	No Rust
Foam Test, ml uence I Sequence II Sequence III	D 892	 10/0 20/0 10/0
Oxidation Stability Hrs. to 2.0 Acid No.	D 943	 10,000
Corrosion and Oxidation Test FTM 791b-5308.6 72 hrs./347 °F Vis Change, 100 °F., SUS, % Increase Acid No. Increase	 — 	 3.0 +0.2

STANDARD HANDBOOK OF LUBRICATION ENGINEERING

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JOHN BOYD, *Technical Consultant*
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Chapter 44

NUCLEAR POWER PLANTS

By E. R. BOOSER

Materials and Processes Laboratory
Large Steam Turbine-Generator Dept.
General Electric Co.

The growing application of nuclear power plants for generation of electricity and for ship propulsion has created a number of new types of lubrication problems. First, radiation effects must be considered in applying lubricants to many plant components. Second, a combination of radiation with an unusual environment must be considered for devices operating in the water, liquid metal, hot gas, or other fluids used to carry heat out from the reactor. Finally, consideration must be given to improve reliability because of reduced accessibility to lubricants and lubricated equipment in locations where a failure could lead to serious consequences.

This chapter will outline some applications problems and experiences in nuclear plants. In considering any specific lubrication design or application problem, principles given in preceding sections of this Handbook should be considered. Established lubricants and lubricant technology will, for instance, serve most needs of turbines, generators, motors, hoists, and other plant accessories. Basic lubrication principles will also serve as useful guides for control-rod drives, for bearings operating in water or liquid metals, and for other unusual conditions peculiar to atomic plants.

In the following review, consideration is first given to the effect of radiation on oils and greases. This is followed by a general consideration of lubrication problems in nuclear power plants. Finally, guides are given for water and liquid-metal lubrication.

EFFECT OF RADIATION ON LUBRICANTS

Radiation damage to petroleum oils and greases in a nuclear plant results primarily from ionization as a secondary effect from bombardment of lubricant molecules by fast neutrons, slow (or thermal) neutrons, and gamma rays emanating either directly or indirectly from the nuclear reactor.[1] Fast neutrons cause damage primarily by colliding with hydrogen atoms in the lubricant molecules and ejecting hydrogen nuclei as recoil protons. The ejected protons then interact with orbital electrons to produce molecular excitation and ionization. Gamma radiation excites and causes ejection of orbital electrons with resulting ionization of the lubricant molecule. Damage by thermal neutrons results primarily from the capture of these neutrons by the nuclei of hydrogen atoms with subsequent emission of high-energy gamma radiation. Neutron radiation exists primarily in and immediately adjacent to the nuclear reactor itself. Gamma rays may also be encountered from the coolant fluids, after their activation in the reactor, as they pass through the external flow system.

Since the mechanism is somewhat similar in all cases, the degree of damage suffered by a lubricant depends primarily on the total quantity of radioactive energy absorbed —whether it be from neutron bombardment or from gamma radiation.[1] The common energy unit for expressing absorbed dosage, the *rad*, is equal to 100 ergs absorbed per gram of material. One rad for oil is approximately equal to one roentgen, the roentgen being commonly used in health physics as a measure of ionizing gamma radiation. Radiation doses can be approximately converted to rads of energy absorption for different types of lubricating oils by use of the factors in Table 1.[1] For example, the

Table 1. Energy Absorption by Oils for Various Types of Radiation
(*From ref. 1*)

Oil type	Dosage equivalent to 1 rad			
	Thermal neutrons, neutrons/sq cm	Fast neutrons,* neutrons/sq cm	Gamma energy	
			Photons/sq cm†	Roentgens
Petroleum	2.63×10^{10}	2.10×10^{8}	1.95×10^{9}	1.03
Diester	2.92×10^{10}	2.49×10^{8}	2.01×10^{9}	1.05
Dimethyl silicone	4.25×10^{10}	3.72×10^{8}	1.78×10^{9}	0.93
Alkylbenzene	5.60×10^{10}	2.36×10^{8}	1.98×10^{9}	1.04
Polyglycol	5.25×10^{10}	3.92×10^{8}	2.09×10^{9}	1.10

* Fast neutrons ≥ 1.0 mev.
† Gamma photons, average energy = 1.0 mev.

rads absorbed by a petroleum oil in a radiation field of 10^{10} thermal neutrons/sq cm/sec, 10^{9} fast neutrons/sq cm/sec, and 50 r/sec of gamma radiation would be estimated as follows:

$$\frac{10^{10}\text{ th. n./sq cm/sec}}{2.63 \times 10^{10}} = 0.4 \text{ rad/sec}$$

$$\frac{10^{9}\text{ f.n./sq cm/sec}}{2.10 \times 10^{8}} = 4.8 \text{ rads/sec}$$

$$\frac{50\text{ r}}{1.03} = \underline{48.5 \text{ rads/sec}}$$

$$\text{Total} = 53.7 \text{ rads/sec}$$

If 10^{8} rads were the limiting radiation dose for the oil, its life would be

$$\frac{10^{8}\text{ rads}}{53.7\text{ rads/sec}} = 1.86 \times 10^{6}\text{ sec}$$

or about 520 hr.

For other types of materials than those indicated in Table 1 or for more exact estimation of the dose to be expected from a particular source, reference should be made to more detailed nuclear data. The overall deterioration rate of a lubricant will be determined not only by the radiation level but also by the temperature, availability of oxygen, contamination, presence of catalytic metal surfaces, moisture, and other service factors.

Oil. Damage of oil by radiation results primarily from cross linking and polymerization as aftereffects of ionization. In the presence of oxygen and high tempera-

...ey pass through the external flow

...cases the degree of damage suffered
quantity of radioactive energy absorbed
from gamma radiation.[a] The common
...rad is equal to 100 ergs absorbed per
...ately equal to one roentgen, the roent-
a measure of ionizing gamma radiation
...rted to rads of energy absorption for
factors in Table 1.[a] For example, the

...or Various Types of Radiation
...1)

...ge equivalent to 1 rad

...et one[a] one ...cm	Gamma energy	
	Photons sq cm†	Roentgens
× 10⁹	1 95 × 10⁹	1 03
× 10⁹	2 01 × 10⁹	1 05
× 10⁹	1 76 × 10⁹	0 93
× 10⁹	1 95 × 10⁹	1 04
× 10⁹	2 09 × 10⁹	1 10

...eld of 10^{11} thermal neutrons sq cm/sec,
gamma radiation would be estimated

rad/sec

4.8 rads/sec

48.5 rads/sec

53.7 rads/sec

the oil, its life would be

× 10⁹ sec

...icated in Table 1 or for more exact
...articular source, reference should be
...rall deterioration rate of a lubricant
level but also by the temperature,
of catalytic metal surfaces, moisture,

...arily from cross linking and polymeri-
...esence of oxygen and high tempera-

tures, oxidation reactions may also be involved. With dosages below about 1×10^{8} rads the damage to an oil will generally be minor. With larger amounts of radiation, however, viscosity increases approximately logarithmically as further irradiation gives increasing molecular size. This characteristic is shown for a number of industrial petroleum oils in Fig. 1.[a]

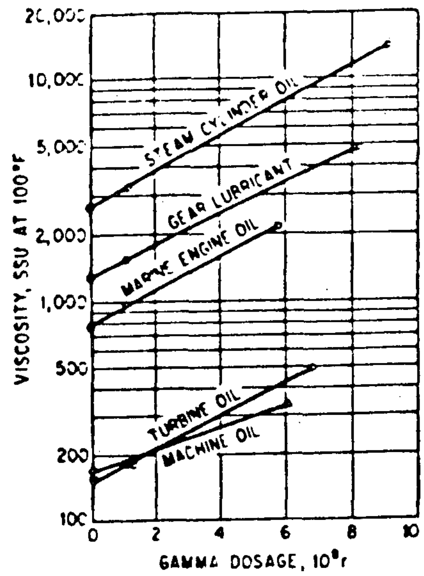

FIG. 1. Viscosity change of industrial petroleum oils with irradiation.[a]

For many lubricant applications, a dose which gives a 25 per cent increase in 100 F viscosity can be taken as a *tolerance limit*. Lower radiation absorptions will seldom change the lubricant sufficiently to interfere with its performance. Greater dosage will result in more rapid thickening, sludging, and operating trouble. Table 2

Table 2. Radiation Tolerance Limit for Several Oil Types
(References given in parentheses)

Oil	*Tolerance limit, 10⁸ rads for 25% increase in 100 F viscosity*
Petroleum:	
SAE 10 automotive (1)	1.8
SAE 20 automotive (1)	0.4–2.4
Light turbine oil (3)	1.5
Machine oil (3)	2.5
Marine engine oil (3)	1.0
Steam cylinder oil (3)	1.8
Synthetic:	
Diester MIL-L-6085 (4)	1.1
Polypropene oxide (1)	1.0
Alkylbenzene (1)	5
Methyl silicone (1)	<1.0
Methyl phenyl silicone (2)	1
Tetraaryl silicate (1)	0.6
Dichlorobiphenyl (1)	3

gives approximate tolerance limits for several types of oil from literature data. These values may vary considerably with the base stocks and additives used. Since aromatic oils have the greatest radiation stability, even the degree of refining can have a pronounced influence.[9]

The effect of radiation on the physical properties, oxidation resistance, foam characteristics, and wear resistance of a conventional 150-SSU turbine oil is indicated in Table 3.[5] At radiation dosages of both 0.9×10^8 and 2.7×10^8 rads there was a decided drop in oxidation stability along with an increased susceptibility to foaming. The rust inhibitor also appears susceptible to damage by radiation, but addition of fresh rust inhibitor to the irradiated oil restores its rust-prevention properties. In this study, a number of turbine-oil formulations evolved about 0.05 ml of hydrogen gas per gram of oil per 10^6 rads of radiation.

Grease. Conventional greases consisting of petroleum oils thickened with sodium, lithium, calcium, or other soaps have relatively poor radiation stability. At radiation doses ranging from about 10^7 to 10^8 rads, significant breakdown of the soap gel

Table 3. Effect of Radiation on Conventional Petroleum Turbine Oil
(From ref. 5)

	Radiation dosage, 10^6 rads				
	0	9	45	90	270
Viscosity, SSU:					
At 100 F	152.4	155.1	162.8	174.5	224
At 210 F	43.8	44.1	44.6	45.5	49.2
Viscosity index	108	110	110	109	112
Gravity, °API	31.5	31.5	31.3	31.4	30.7
Color, ASTM	1.0	1.0	1.25	1.25	2.5
Flash point, OC, F	430	410	405	415	295
Fire point, OC, F	485	470	475	485	475
Pour point, F	0	0	0	10	10
Neutralization No., mg of KOH/g	0.09	0.04	0.03	0.01	0.01

structure can be expected. With this breakdown there is an increased softening of the grease to the point where it may become fluid. At even higher dosages, the polymerizing effect of radiation on the oil used in the grease will eventually result in an overall hardening effect. Some greases using radiation-resistant oils with thickeners such as copper phthalocyanine, a sodium amate, calcium complex soap, an indanthrene dye, or clay particles appear capable of withstanding doses of 10^9 rads while still maintaining satisfactory consistency for lubrication purposes.[6-8]

Synthetic Lubricants. Many synthetic oils are somewhat more unstable under radiation conditions than are petroleum oils. This is surprising in view of the excellent thermal and oxidation stability exhibited by methyl silicones, diesters, silicates, and some other synthetic fluids. The tolerance limits for several synthetics and petroleum oils are compared in Table 2. Petroleum oils are seen generally to have a higher tolerance limit than synthetics.

An exception is the high order of stability possible with synthetic oils consisting of aromatic hydrocarbons. Alkyl benzene fluids have been used, for instance, to produce oils with improved radiation resistance.[10] The stability of silicones also increases with increasing proportion of aromatic structure.[9] With aromatics the absorbed energy apparently goes to a large extent into harmless resonant energy in the aromatic ring structure. This reduces the degree of damaging ionization and free radical formation which occurs on a much more general basis with the chainlike structures in paraffinic oils or in the saturated ring structure of naphthenic oils.

l types of oil from literature data ase stocks and additives used Since ; even the degree of refining can have

properties. oxidation resistance, foam entional 150-SSU turbine oil is indicated 9×10^6 and 2.7×10^9 rads there was a an increased susceptibility to foaming o damage by radiation, but addition of ores its rust-prevention properties In ions evolved about 0.05 ml of hydrogen

of petroleum oils thickened with sodium, y poor radiation stability. At radiation significant breakdown of the soap gel

entional Petroleum Turbine Oil
5)

	Radiation dosage, 10⁶ rads			
	9	45	90	270
	155 1	162 8	174 5	224
	44 1	44 6	45 5	49 2
	110	110	109	112
	31 5	31 3	31 4	30 7
	1 0	1 25	1 25	2 6
	410	405	415	295
	470	475	485	475
	0	0	10	10
9	0 04	0 03	0 01	0 01

there is an increased softening of fluid At even higher dosages, the ed in the grease will eventually result es using radiation-resistant oils with sodium amate, calcium complex soap, capable of withstanding doses of 10⁹ nsistency for lubrication purposes ils are somewhat more unstable under This is surprising in view of the excel. by methyl silicones, diesters, silicates, nce limits for several synthetics and oleum oils are seen generally to have a

possible with synthetic oils consisting ds have been used, for instance, to ice [10] The stability of silicones also tic structure.[4] With aromatics the ent into harmless resonant energy in e degree of damaging ionization and more general basis with the chainlike d ring structure of naphthenic oils.

LUBRICATION PROBLEMS IN NUCLEAR POWER PLANTS

Nuclear power plants all have several common characteristics an atomic reactor where splitting of large atoms such as uranium-235 produces heat, a fluid circulating through the reactor to carry away the heat, and a steam turbine-generator for converting the heat to electricity The systems differ greatly in design details of the reactor and in the fluid system used for removing its heat

The principal components in some typical nuclear power plants are indicated in the schematic diagrams of Fig. 2. Radiation levels for plant components are given in Table 4 [11] In general, the lubrication problems may be divided into two classifications, first, those in the very high level of radiation within and immediately adjacent to the nuclear reactor itself and, second, those at the much lower radiation levels in pumps, turbine, generator, etc, more remote from the reactor and outside the primary shielding Lubrication within the nuclear reactor must generally be handled with water, liquid metal, or dry sliding because of the destructive effect of the extremely high level of radiation on any normal oils and greases In other locations having lower levels of radioactivity, many bearing and lubrication requirements are identical or very similar to those in conventional equipment in use in fossil-fuel-powered generating stations. Although individual equipment conditions will have to be considered separately in almost every case, the following will indicate some general considerations with each type of plant.

Table 4. Typical Radiation Levels in Nuclear Plants
(From ref 11)

	Lubricant dosage level, rads/hr			
Type of plant	Boiling water	Pressurized water	CO_2 cooled	Liquid metal
Turbine	0.1–0.3	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$
Coolant circulating pumps or compressors	10^2–10^3	10^2–10^3	10	10^4–10^6
Remote fuel-handling devices	0–10^5	0–10^5	0–10^5	
Control-rod drives	0.1–10^3	10–10^3	0.1–10	

Pressurized Water Reactor. Most nuclear power plants in operation in the United States use water to remove heat from the reactor. In the pressurized water (PWR) system, water carrying heat away from the reactor is maintained at a high pressure of approximately 2,000 psi. This pressurized, heated water leaving the reactor then goes to a heat exchanger where steam is generated in a secondary circuit. The steam then passes to a steam turbine-generator for producing electricity.

In these PWR systems, water is used for bearings and sliding parts of operating components in the primary water circuit. Water is called on to lubricate sleeve and thrust bearings in water-circulating pump motors, drives for the control rods used to regulate the power level of the reactor, and some sliding parts within the reactor itself. A review of some considerations involved in water lubrication is given later in this chapter.

Table 4 indicates that radiation levels for other components of a pressurized water system are so low that conventional petroleum lubricants can be used. Thus, the steam turbine-generator, condensate pumps, and related equipment can use conventional petroleum oils. Hoists and other devices used in refueling the reactor and in handling used fuel rods will vary greatly in the amount of radiation to which they are exposed. The drive portions of such devices are generally protected from radiation by a height of water which extends 20 ft or more above the top of the reactor during refueling operations Consequently, normal petroleum lubricants are usually used with no difficulty.

MATERIAL AGING AND RADIATION EFFECTS LIBRARY DATA ENTRY FORMAT

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DOCUMENT TITLE: LUBRICATION FUNDAMENTALS

AUTHOR: J. GEORGE WILLS

SOURCE: MOBIL OIL CORP

DOCUMENT NUMBER: N/A

THIS DOCUMENT CONTAINS ARRHENIUS AND RADIATION AGING INFORMATION PERTAINING TO THE FOLLOWING:

MATERIAL CLASSIFICATION: LUBRICANTS

SUBJECT: RADIATION EFFECTS

COMMERCIAL NAME	GENERIC NAME
NOT STATED	LUBRICANTS
NOT STATED	GREASES

Lubrication Fundamentals

J. GEORGE WILLS
Mobil Oil Corporation

MARCEL DEKKER, INC.
New York and Basel

Lubrication Fundamentals

J. GEORGE WILLS

About the book . . .

...LUBRICATION FUNDAMENTALS is a basic textbook and practical engineering reference work for all those concerned with the operation and maintenance of machines. This book bridges the gap between the highly technical literature and the operating and maintenance manuals by presenting a comprehensive and detailed account of the entire technology of lubrication. The book contains discussions of the basic products, the machine elements that require lubrication, the methods of application, the specific machinery lubricated, the handling and storing of lubricants, and the conservation of lubricants. Every chapter also discusses the need for lubrication, the factors affecting lubrication, and lubricant selection. There is a chapter on the new field of synthetic lubricants as well.

LUBRICATION FUNDAMENTALS is profusely illustrated with over 300 diagrams, graphs, tables, and pictures, many of which are in two colors. This book will be of great assistance to those who need to understand the technology of lubrication and to those who need to make use of it, including engineering students, machine designers, lubrication engineers, machinery operators, plant maintenance personnel, purchasing managers, and machinery and lubricants marketers.

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11

Nuclear Power Plants

POWER REACTORS

Basically, all nuclear power reactors are similar. They differ in function, makeup, and operating characteristics from research or testing reactors or from production reactors, such as those at Hanford, Washington, which are used to manufacture plutonium. The power reactor, whose main function is to furnish energy, consists broadly of a core containing nuclear fuel, a moderator (although this is eliminated in fast reactors), a cooling or heat transfer system, a control system, and shielding. In practice, although they are basically similar, it is possible to design an almost endless number of different reactor types by using various combinations of fuel, coolant, and moderator. Table 11.1 lists the main elements involved in the design of a reactor. Under each design element is listed the basic variations possible for fuel, fertile material, moderator, coolant, neutron energy level, and geometry. Multiplying all these variables, we find that there are at least 1200 combinations from which to choose.

It would seem that such variety could lead to confusion, but in actuality certain combinations are ruled out because of the availability of some of the

Table 11-1 Reactor Component Variables

Fuel	Fertile Material	Moderator	Coolant	Neutron Energy	Geometry
Natural uranium	Th-232	Light water	Gas (CO_2, He)	Fast	Heterogeneous
U-235	U-238	Heavy water	Light water	Intermediate	Homogeneous
U-233		Graphite	Heavy water	Thermal	
Pu-239		Terphenyl	Liquid metal		
		None	Hydrocarbons		

components or the economics. for example, many areas must use natural uranium, for they lack the capability of enrichment. This rules out certain types of reactors, such as the fast flux. Also, natural uranium puts a limitation on the type of moderator, critical size, and power level, and although heavy water is a good moderator, especially for naturally fueled reactors or low enrichment, its cost has mitigated against its widespread use. Helium as a coolant for gas cooled reactors has found limited use because it is found in sufficient quantities only on the North American continent.

For these reasons various countries throughout the world have pursued a particular course of design that depended on the availability of materials for construction and fuel; for example, most European nations have based their first generation designs on the use of natural uranium because of a lack of enrichment facilities. On the other hand, the United States, with its extensive system built for defense purposes, has concentrated its reactor designs on enriched fuel. The almost exclusive use of natural uranium in Europe however, is changing with the introduction of enrichment facilities.

In addition, the environmental conditions existing in certain areas dictate the use of nuclear energy as well as the particular reactor design. England, because of a critical shortage of fossil fuel, acted quickly to consider nuclear power and was the first country to develop electric energy from the fissioning process. The urgency of the situation made it necessary to use the simplest and most reliable reactor available at the early stages. Therefore, England developed the gas cooled, graphite moderated, natural uranium reactor to a high degree of usefulness and efficiency.

In the early 1950s, fossil fuels were relatively plentiful and cheap in the United States and to a large extent in Russia and, therefore, it was less urgent to develop nuclear power, which could not then compete with fossil fueled generation. As a consequence, the long term view was taken, and various reactor concepts were developed on which to base the most feasible and economical design for use in the future. The choice today in the United States is a light water cooled and moderated, enriched fuel reactor, although much attention is still being directed to the fast breeder and high temperature gas cooled converter type.

Basic Reactor Systems

Among the hundreds of combinations of fuel, coolant, moderator, etc. which have theoretical possibilities as reactor systems, eight basic types have been studied in the research stages and have resulted in the demonstration of commercial power reactors.

1. Pressurized water reactor
2. Boiling water reactor
3. Sodium graphite reactor
4. Fast breeder reactor
5. Homogeneous reactor
6. Organic cooled and moderated reactor
7. Gas cooled reactor
8. High temperature, gas cooled reactor

Pressurized Water Reactor Fission heat is removed from the reactor core by water pressurized at approximately 2000 psi to prevent boiling (Fig. 11-1). Steam is generated from a secondary coolant in the heat exchanger.

Major Characteristics

Light water is the cheapest coolant and moderator.

Water is a well documented heat transfer medium and the cooling system is relatively simple.

High pressure requires a costly reactor vessel and leakproof primary coolant system.

High pressure, high temperature water at rapid flow rates increases corrosion and erosion problems.

Steam is produced at relatively low temperatures and pressures (compared with fossil fueled boilers) and may require superheating to achieve high plant efficiencies.

Containment requirements are extensive because of possible high energy release in the event of primary coolant system failure.

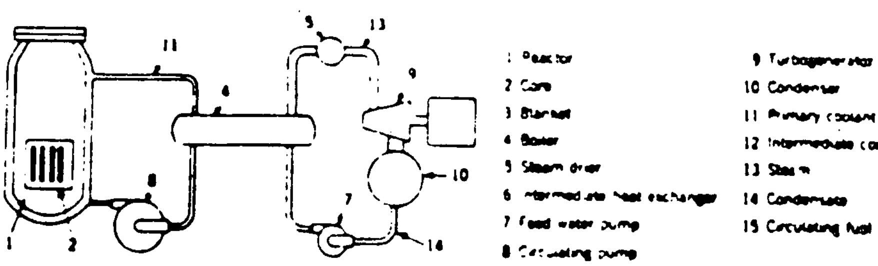
Boiling Water Fission heat is removed from the reactor by conversion of water to steam in the core (Fig. 11-2). It may be a single or dual cycle system.

Major Characteristics

Light water is the coolant, moderator, and heat exchange medium, as in a pressurized water reactor.

Reactor vessel pressure is less than the primary circuit of the pressurized reactor.

Fig. 11-1 Pressurized Water Reactor System The key applies to Figs. 11-1 through 11-7



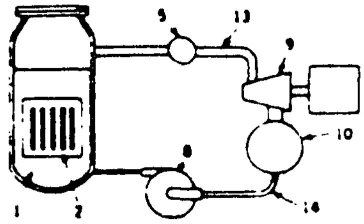


Fig. 11-2 Direct Cycle Boiling Water Reactor

Steam pressures and temperatures are similar to those of pressurized water.
Heat exchanges, pumps, and auxiliary equipment requirements are reduced or eliminated.
Has an inherent safety characteristic in that pow[illegible] causes a void formation, thus reducing the core power level.

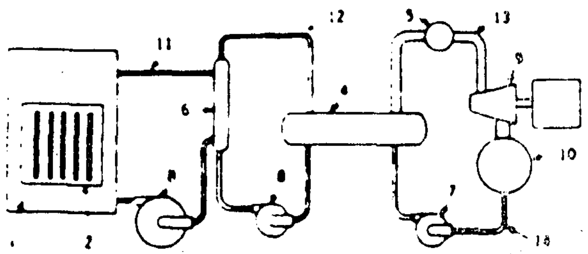
Sodium Graphite Molten sodium metal (Fig. 11-3) transfers high temperature heat from graphite moderated core to an intermediate exchanger. Intermediate sodium-potassium coolant transfers heat to the final water cooled, steam generation equipment.

Major Characteristics

The high boiling point of liquid metal eliminates pressure on the reactor and primary system.
Permits high reactor temperatures.
Steam generated at relatively high temperatures and pressures.
Corrosion problems are minimized.
Low coolant pressures reduce containment requirements.
Violent chemical reaction with water and high radioactivity of alkali metal requires a triple cycle coolant system with dual heat exchange equipment to minimize hazards.
Relatively complex core.

Fast Breeder Heat from fission by fast neutrons is transferred by sodium coolant (Fig. 11-4) through an intermediate sodium cycle to steam boilers as in the sodium graphite type. No moderator is used. Neutrons escaping from the core into a blanket breed fissionable Pu-239 from fertile U-238.

Fig. 11-3 Soldium Graphite Reactor System



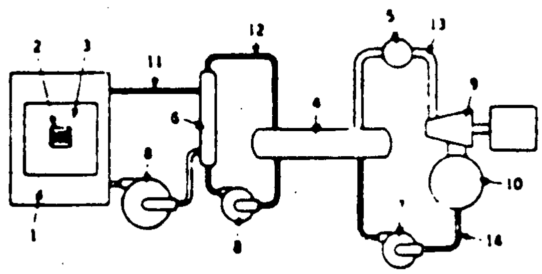


Fig. 11-4 Fast Breeder Reactor System

Major Characteristics

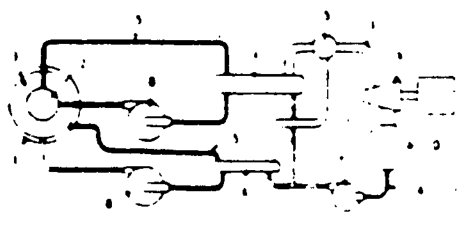
Reactor is designed to produce more fissionable material than is consumed.
Wide choice of structural materials as a result of low absorption of high energy neutrons.
Low neutron absorption by fission products permits high fuel burn up.
A small core with a minimum area intensifies heat transfer problems.
Core physics, including short neutron lifetime, makes control difficult.

Aqueous Homogeneous Heat formed in the core, which is a critical mass of solution or slurry of fuel and moderator, is carried by fuel solution to the heat exchangers to form steam (Fig. 11-5). Slow neutrons from the core breed fissionable U-233 from Th-232 in the blanket.

Major Characteristics

The system has a high degree of inherent stability; mechanical control rods are unnecessary.
Fuel element problems are eliminated. Continuous processing of irradiated fuel is possible to remove fission products and permit maximum burn up.
Fuel solution is highly radioactive and corrosive.
Core and blanket, including primary system, must be kept at high pressure to prevent boiling.
Precautions must be taken to avoid accumulation of critical mass outside the reactor vessel.

Fig. 11-5 Homogeneous Reactor System



Containment requirements are high, for radioactive material is circulated through the primary coolant and blanket loops.

Organic Moderated Heat is removed from the core by organic coolant at low or moderate pressure. Steam is generated in the boiler or heat exchanger (Fig. 11-6).

Major Characteristics

High pressure in reactor and primary circuit is avoided, although higher temperatures can be achieved than in a pressurized water reactor.
Organic coolant becomes only slightly radioactive and causes little corrosion.
Heat transfer characteristics good but lower than water.
Hydrocarbon coolant may deteriorate and cause fouling or scale formation on the fuel elements.

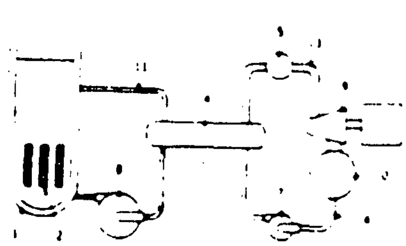
Gas Cooled Heat removed from the core by gas at moderate pressures is circulated through steam generating heat exchangers that produce low and high pressure steam. It utilizes carbon dioxide gas, graphite moderator, and natural uranium fuel.

Major Characteristics

Utilizes natural uranium fuel and relatively available materials and construction.
Permits low pressure coolant and relatively high reactor temperatures.
Containment requirements are moderate and corrosion problems minimal at low temperatures.
Reactor size is relatively large because of natural fuel and graphite moderator. Power density (kilowatt output per liter of core volume) is extremely low.
Poor heat transfer characteristics of gases require high pumping requirements.
Steam pressures and temperatures are low.
Carbon dioxide gas is relatively cheap, safe, and easy to handle.

High Temperature, Gas Cooled Heat from the reactor core is carried by inert helium to the heat exchanger for generation of steam or directly to a gas turbine; the gas returns to the reactor in a closed cycle (Fig. 11-7).

Fig. 11-6 Organic Cooled and Moderated Reactor



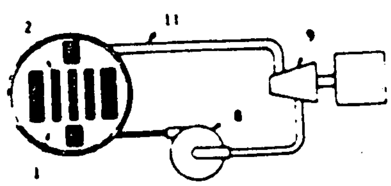


Fig. 11-7 High Temperature Gas Cooled Reactor

Major Characteristics

Good efficiency can be achieved in a dual cycle with a minimum gas temperature of 1400°F (760°C).

High fuel burn up is possible and conversion of fertile material permits lower fuel costs.

Minimum corrosion of fuel elements will be caused by inert gas.

High temperature coolant minimizes the disadvantages of poor heat transfer characteristic of the gases.

Possible contamination of turbine in a direct cycle caused by fuel element failure.

Fuel element design for long life is complicated by high temperatures.

The supply of helium worldwide is limited.

RADIATION EFFECTS ON PETROLEUM PRODUCTS

In general, radiation damage may be defined as any adverse change in the physical and chemical properties of a material as a result of exposure to radiation. Radiation damage is, of course, a relative term, for the changes in a material that may be adverse to one process or system may be advantageous to another. This is true of organic materials in particular; for example, the evolution of a gaseous hydrocarbon from a liquid organic material may result in an explosion hazard, an increase in liquid viscosity, or, on the other hand, a new method for synthesizing a hydrocarbon. Similarly, radiation of an organic fluid may result in unwanted growth in molecular size with consequent thickening or solidification of the liquid, or may present a feasible method of polymerization to form an elastomer or plastic. In the study of radiation damage, we are concerned mainly with the adverse or undesirable changes in the lubricants of a power reactor.

Broadly speaking, there are two mechanisms of radiolysis that must be considered in a study of the damage to organic fluids. One is the primary electronic excitation and ionization of organic molecules caused by beta particles, gamma rays, and fast neutrons. The other is the capture of thermal neutrons and some fast neutrons by nuclei that would cause changes in the nuclei and the generation of secondary radiation that would result in further damage.

Two methods are utilized to measure radiation energy. One measures the quantity of energy to which the material is exposed and is called the roentgen (R); the other is the amount of energy that the material absorbs and is called the rad. For gamma radiation, the exposure unit (the roentgen) is defined as the quantity of electromagnetic radiation that imparts 83.8 ergs of energy to 1 g of air.

The radiation dosage of a material is defined as an absorption of 100 ergs of energy from any type of radiation by 1 g of material. Actually, absorbed energy will vary with the type of radiation and the effect will depend on the material exposed. For gamma radiation, however, one rad absorbed is approximately equivalent to 1.2 R of radiation dosage. The rad is useful for comparing the equivalent energy of mixed radiation fluxes but does not distinguish between types.

From a radiation damage standpoint, 1 rad of *neutron flux* causes 10 times more biological damage to tissues than an equivalent absorbed energy of gamma rays. For petroleum products, however, the dosage, as measured by such effects as viscosity increase, is almost equivalent for the two types. This is discussed in more detail later in this capter.

The general levels of radiation dosage are as follows:

Dosage (roentgens)	Effect
200 – 800	Lethal to humans
< 5 million	Negligible to petroleum products
5 – 10 million	Damaging to petroleum products
> 10 million	Survived by only most resistant organic structures

Based on experimental work to date, the damage to petroleum products may be summarized in the list below. It must be appreciated, however, that the intensity of these effects or, in fact, the incidence of one or more of them will depend on the amount of absorbed energy, the exact composition of the specific petroleum material, and other environmental conditions such as temperature, pressure, and gaseous composition of the atmosphere.

The effects are as follows:

1. Liquid products (fuels and oils) darken and acquire an acrid oxidized odor.
2. Hydrogen content decreases and density increases.
3. Gases such as hydrogen and light hydrocarbons evolve.
4. Physical properties change, higher and lower molecular weight materials are formed, and olefin content increases.
5. Viscosity and viscosity index increase.
6. Polymerization to solid state can occur.

Mechanism of Radiation Damage

Organic compounds and covalent materials do not normally exist in an ionized state and therefore are highly susceptible to electronic excitation and ionization as the result of deposited energy. Covalent compounds, including the common gases, liquids, and organic materials consist of molecules that are formed by a group of atoms held together by shared electron bonding, which yields strong exchange forces. The molecules are bound together by relatively weak van der Waal forces.

Conversely, ionic compounds, such as inorganic materials, which include salts and oxides, are already ionized (metals may also be considered as being in an ionized state) and are not susceptible to ionization but are susceptible to further electronic excitation. Ionic compounds consist of highly electropositive and electronegative ions held together in a crystal lattice by electrostatic forces in accordance with Coulomb's law. There is no actual union of ions in the crystal to form molecules, although all crystals may be considered as being composed of large molecules of a size limited only by the capacity of the crystal to grow.

Therefore, the effect of radiation energy on nonionic compounds is to form ions, radicals, and excited species and thereby make the compounds more reactive with themselves or with the atmospheric environment. On the other hand, the effect of radiation on ionic compounds is to change the properties of the compound related to crystal structure. How each type of radiation affects organic materials is discussed below.

Fast Neutrons Most materials have a low capture cross section for fast neutrons and, therefore, these particles can deposit energy only by elastic and inelastic scattering. Indeed, one important use of organic materials is to moderate or deenergize fast neutrons to make them into thermal neutrons that can be captured in the fission process.

The main bulk of fast neutron deposited energy causes considerable damage to organic materials by exciting the molecule and causing ion formation. Some fast neutrons deposit energy by momentum losses which cause dislocation of atoms, commonly called Wigner type damage.

An appreciable fraction of the neutron's energy is transferred to each struck nucleus. The nucleus is ejected as a recoil ion and the neutron is scattered or reflected to continue striking other nuclei until it is degraded in energy to the thermal energy state. The recoil ion interacts with orbital electrons, thus producing molecular excitation and ionization and becoming neutralized. As recoil ions, they are above the thermal energy state.

Gamma Radiation Gamma rays react with matter either by photoelectric effect, Compton effect, or pair production. The precedence of a particular mechanism depends on the atomic number of the irradiated medium and the energy of the gamma radiation. For materials of low atomic number (<2?), such as hydrogen, and carbon, the photoelectric effect predominates at gamma energies below 0.1 MeV, the Compton effect from 0.1 to 10 MeV, and pair production above 10 MeV. For materials of high atomic number (>82), such as lead, the photoelectric effect from 1.0 to 4.0 MeV, and pair production above 4 MeV.

In accordance with current theory, the methods of energy transfer affect material as follows:

1. *Photoelectric effect.* Gamma energy interacts with the entire atom and transfers an entire photon of energy in one encounter. This energy is absorbed by a single electron which is usually in a K or L shell (Fig. 11.8). The electron ejects from the atom with an energy equal to the incident photon minus the binding energy of the electron of the atom.

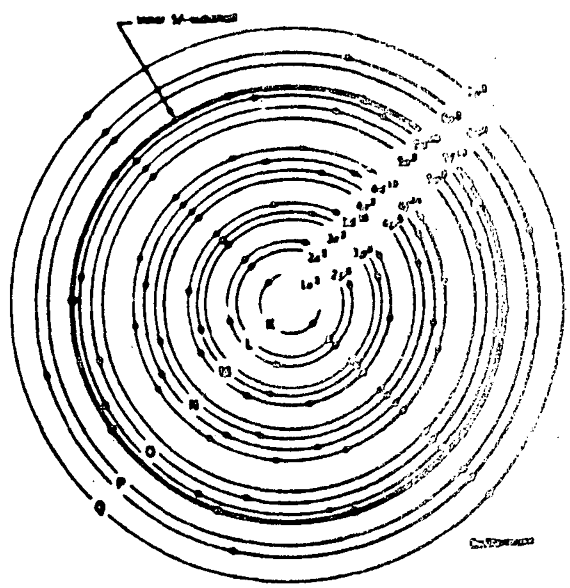


Fig. 11-8 Electron-Shell Structure

2. *Compton effect.* A gamma ray photon interacts with a single electron and loses a portion of its energy to the electron, which recoils at an angle to the incident gamma photon.
3. *Pair production.* The gamma energy is completely converted in the region of the nuclei's Coulomb field, the result is the formation of a positron-electron pair.

The ejected high energy electrons or electron-ion pairs in turn react with orbital electrons to cause electron excitation and ionization.

Thermal Neutrons Thermal neutrons are captured by nuclei, which in turn become radioactive and give off alpha particles, gamma radiation, beta particles, or protons. These reactions are symbolized as (n,α), (n,γ), (n,β) or (n,p),* respectively. Although thermal neutrons cause very little damage to organic materials, that which occurs is due to the secondary radiation that results predominately from the 2.2 MeV rays given off by the capture of thermal neutrons by hydrogen nuclei. For chloro-organics the (n,β) reaction is important because of high thermal neutron capture cross section of chlorine. Nitro-organics suffer radiation damage when thermal neutrons absorbed in the $N^{14}(n,p)C^{14}$ reaction cause ejected protons which ionize the media.

*These symbols indicate that a neutron is absorbed and alpha, gamma, beta, or proton radiation results.

Calculation of Energy Absorption and Radiation Damage

Energy deposition or absorption leading to radiation damage is described by using the units of the rad. This was accomplished by the International Commission on Radiological Units in 1953, which recommended that the absorbed dose of any ionizing radiation be defined as the amount of energy imparted to matter by ionizing particles per unit mass of irradiated material. The unit of absorbed dose is the rad which is equivalent to 100 ergs of absorbed energy per gram of material. It is often more convenient, however, to measure the absorption of ionizing energy from a radiating source by its effect on a quantity of air rather than the material being irradiated. Therefore a relationship between the rad is convenient, although not strictly accurate, 1 rad may be considered as equivalent to 1 eV. Because, as previously stated, the major energy transferred from source to medium results in electronic excitation and ionization, and organic materials may suffer such damage, methods for approximate calculation of the estimated damage from this energy absorption have been developed.

For example, the average energy required to sever a chemical bond is approximately 2 eV and the typical energy to cause ionization of a hydrocarbon is 10 eV. Therefore, it is reasonable that the MeV level energies available from average fast neutrons and gamma photons radiated from a reactor core are more than sufficient to cause (even by secondary processes) ionization and dissociation in a chemical compound.

The rate of reaction, which will be taken as the extent of radiation damage, is measured in the amount of material reacting for a given energy input. The term G has been assigned to the rate of reaction and is defined as the number of molecules reacting for each 100 eV of energy absorbed.

To particularize these general theories to nuclear power plant applications, several broad generalizations can be made regarding the effect of radiation on organic fluids. Two of the most striking effects of organic liquid irradiation are gas evolution and viscosity changes. The gas evolution is not dependent on the dosage rate but is rather a linear function of the applied energy dose. Similarly, viscosity is a function of dosage with a marked threshold of reaction. The viscosity gradually increases until a definite dose has been absorbed when there is an exponential increase in viscosity with small incremental additions of radiation energy.

Another general observation is that aromatic compounds behave differently than other organic compounds, especially the aliphatics. The theory frequently offered to explain this is that in an aliphatic substance the electrons paired to form the carbon-to-carbon or carbon-to-hydrogen bond have a different absorptive capacity for radiative energy than the bonds in an aromatic C – C or C – H linkage. It is theorized that energy absorbed in the aromatic ring structure is distributed over the entire structure rather than in any particular C – C or C – H bond.

Although the discussion to this point has been theoretical, with emphasis on the particular type of radiation, in practice the radiation from a reactor core is mixed. Therefore, to estimate the radiation stability we must calculate the contribution from each type of radiation. To do this a table of viscosity changes based on increasing radiation exposure has been developed experimentally for various standard organic liquids.* To use this information we furnish the following example.

*Experiments by Bolt and Carroll – California Research Corporation.

Hexadecane is exposed to a radiation flux consisting of

10^{10} thermal neutrons (cm^2) (sec)

10^9 fast neutrons/(cm^2) (sec)

10^{11} gamma photons/(cm^2) (sec)

How many hours of exposure will produce an increase in viscosity of 55 percent at 210°F (99°C)?

First determine the dosage in rad. Based on data developed in experiments by Bolt and Carroll of California Research Corporation, we find that hexadecane will absorb 1.0×10^9 rad when exposed to any one of the following fluxes:

Thermal neutrons 2.82×10^{19} th n/cm^2

Fast neutrons 1.95×10^{17} f n/cm^2

Gamma radiation 1.95×10^{19} γ/cm^2

Now the contribution of each component of that assumed radiation flux may be calculated as follows:

$$\text{Thermal neutron contribution} = \frac{10^{10}\ \text{th n/cm}^2 - \text{sec} \times 1.0 \times 10^9\ \text{rad}}{2.82 \times 10^{19}\ \text{th n/cm}^2} = 0.4\ \text{rad/sec}$$

$$\text{Fast neutron contribution} = \frac{10^9\ \text{f n/cm}^2 - \text{sec} \times 1.0 \times 10^9\ \text{rad}}{1.95 \times 10^{17}\ \text{f n/cm}^2} = 4.8\ \text{rad/sec}$$

$$\text{Gamma radiation contribution} = \frac{10^{11}\ \text{th n/cm}^2 - \text{sec} \times 1.0 \times 10^9\ \text{rad}}{1.95 \times 10^{19}\ \text{th n/cm}^2} = 0.4\ \text{rad/sec}$$

From these same experiments, a dose of 5.0×10^8 rad causes an increase at 210°F of 55% in the viscosity of hexadecane. Therefore, under the mixed flux being estimated hexadecane is stable to the radiation for the following period:

$$\frac{5.0 \times 10^8\ \text{rad}}{56.2\ \text{rad/sec}} = 8.9 \times 10^6\ \text{sec} = 2470\ \text{h}$$

Chemical Changes in Irradiated Materials

The physical and chemical properties of hydrocarbon fluids which make them important as lubricants change during irradiation to varying degrees based on their chemical composition and the presence of additives. These changes may be traced to alteration of the chemical structure of the materials. As discussed, nuclear radiation either directly, or by secondary radiation, deposits high level energy in the irradiated organic substance and causes ionization and molecular excitation. The ions and excited molecules rapidly react to form free radicals which further combine or condense (Fig. 11.9).

The changes in chemical structure may be measured by various classic methods. For example, it is possible to determine the approximate number of free radicals formed by the use of scavengers such as iodine. In addition gas

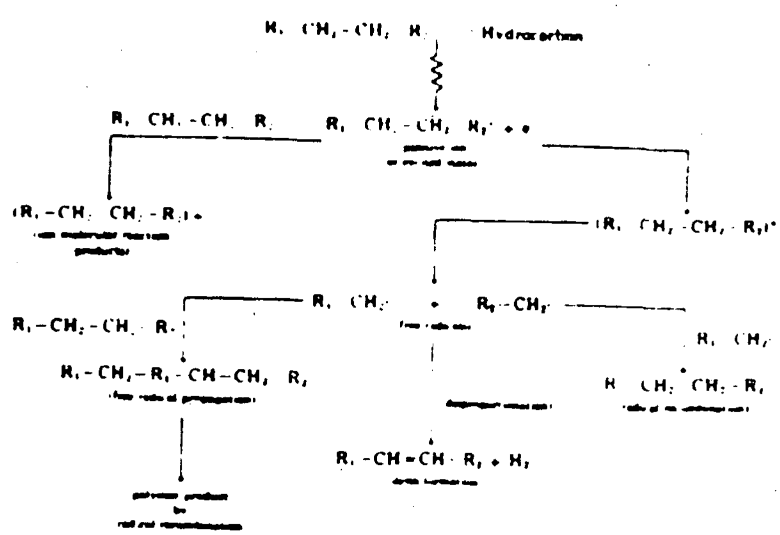


Fig. 11-9 Radiolysis Processes in Hydrocarbons

is evolved, either hydrogen or light petroleum fractions. Investigations have shown that both carbon-hydrogen and carbon-carbon bonds can be broken by radiolysis. The dissociated or ionized molecules can condense, rearrange, form olefins, or other products, depending on the environment. At temperatures below 400°F (204°C), temperature effects do not seem to be significant.

Because most petroleum lubricants are combinations of saturated and unsaturated aliphatics and aromatic compounds, the reactions of these principle hydrocarbon classes have been studied under the influence of ionizing radiation. These studies (Table 11-2) indicate, as would be suspected, that

Table 11-2 Summary of Radiation Changes in Organic Compounds

G-Values*	Saturated Hydrocarbons	Unsaturated Hydrocarbons	Aromatic Hydrocarbons
Polymerization	None*	10-10 000	None
Cross linking	1	5-14	< 1
H_2 evolution	2-6	<	0.04-0.4
CH_4 evolution	0.08-1	0.1-0.4	0.001-0.08
Destruction of irradiated material	4-9	5-2000	1

*G = molecules produced, destroyed, or reacted per 100 eV of energy absorbed

Source: From *Nuclear Engineering Handbook*, by H. Etherington © 1958 McGraw Hill Book Company, Inc., used by permission of McGraw-Hill Book Co., Inc.

Table 11-3 Radiation Sources for Research

Type	Power	Types of Radiation	Energy of Radiation	Application*	Remarks
Heavy-water tank reactor	1-5 MW	Neutrons (fast and thermal), secondary particles, and radiations	Thermal neutron flux $2-8 \times 10^{13}$ n/cm² sec Gamma flux 10^{8} R/hr	High flux, general research reactor, quite large, isotope production, large equipment physics experiments, medical research, loop experiments	Uses forced cooling. D_2O is expensive and requires special handling increasing cost over a comparable light-water-moderated reactor; reactor can be made critical with natural uranium, although enriched uranium is normally used; very high flux is obtained with a small critical mass; reactor can be pressurized; core can be made large, which allows more flexibility for experiments; core may be averaged to give a wide range of neutron spectrum from thermal to fast; somewhat safer than light-water-moderated reactor because of longer neutron lifetime
Aqueous homogeneous reactor	10W 5-500 W 50 kW	Neutrons (fast and thermal), secondary particles and radiations	Thermal neutron flux 2×10^{8} n/cm² sec Thermal neutron flux, 10^{10} n/cm² sec Thermal neutron flux 10^{12} n/cm² sec	Basic physics research, medical and biological research, radioisotope production, testing by the danger coefficient method, exponential experiments, study of effect of neutron and gamma radiation on chemical and biological materials, production of short-lived radioisotopes, educational training facility	Fuel can be added and maintained easily; no fuel element fabrication cost; corrosion and chemical problems increase with power level; limited space for high flux irradiation; large negative temperature coefficient is desirable safety feature; small critical mass required; difficult handling problems of radiolytic gases; can purify radiolytic gases to provide a relatively pure source of gamma emitters

Graphite (pile) reactor	3 - 30 MW	Neutrons (fast and thermal) secondary particles and radiations	Thermal neutron flux $1 - 5 \times 10^{12}$ n/cm² sec Gamma flux $10^6 - 10^8$ R/hr	Isotope production, large equipment physics experiments, medical research, loop experiments	Can be made critical with natural uranium, very large core with space for a number of sample irradiations, neutron flux per unit of power low, reactor is bulky and expensive, air cooling sufficient for all except very high powered ones, thermal to fast flux is high (approximately 100 to 1)
Swimming pool reactor	10 - 100 kW	Neutrons (fast and thermal) secondary particles and	Thermal neutron flux $10^{11} - 10^{13}$ n/cm² sec Gamma flux $10^6 - 10^7$ R/hr	Flexible source of radiation, used for shielding studies, irradiation, training and instruction purposes	Can operate at low power (up to 200 kW rather cheaply, relatively safe, requires demineralized water as shield, coolant, reflector, and moderator, large pool enables large objects to be irradiated, low-power reactors use natural circulation, higher power reactors (1 MW) require forced circulation cooling, 5 MW reactor requires special core encasement, ratio of thermal to fast neutrons is approximately 1 to 1
	1 - 5 MW		Thermal neutron flux $10^{13} - 5 \times 10^{13}$ n/cm² sec Gamma flux $10^6 - 10^8$ R/hr		
Subcritical assemblies*	3 W	Neutrons (fast and thermal) secondary particles and radiations	Thermal neutron flux 10^5 n/cm² sec	Introductory reactor theory training and studies	Minimum facility required with corresponding low cost, shielding problems small, requires special neutron source of Van de Graaff for operation
Zero power reactor*	0.1 - 10 W	Neutrons (fast and thermal) secondary particles and radiations	Thermal neutron flux 10^7 n/cm² sec Gamma flux 80 R/hr/w	Absorption properties of reactor materials, critical reactor source, physics and reactor theory training	Useful for reactor studies and training
Temperature controlled reactor*	1 kW	Neutrons (fast and thermal) secondary particles and radiations	Thermal neutron flux 10^{10} n/cm² sec	Production of short lived isotopes, physics experiments, radiation testing source for critical experiments	Minimum cost critical reactor capable of being installed in any location, minimum experience necessary for operation

Table 11-3 Radiation Sources for Research (Continued)

Type	Power	Types of Radiation	Energy of Radiation	Application[a]	Remarks
Argonaut reactor[c]	10 kW	Neutrons (fast and thermal), secondary particles and radiations	Thermal neutron flux 10^{11} n/cm² sec	Production of short-lived isotopes for medical use and research, reactor training	Low cost, good training reactor, minimum fa[illegible]ty cost
Light water high-flux tank reactor[c]	5–200 MW	Neutrons (fast and thermal), secondary particles and radiations	Thermal neutron flux 5×10^{13}–10^{14} n/cm² sec Gamma flux 10^{8}–10^{9} R/hr	Radiation effects on structural materials, in pile (loop) studies of fuel elements and other components	Higher power at a cheaper cost than for a comparable swimming pool reactor, uses simple forced cooling, pressurization can be used, ratio of thermal to fast neutrons is approximately 1 to 1, 20 MW and above are generally classified as material test reactors, their high flux levels permit studies of radiation damage for structural materials and for fuel element studies in a reasonable time
Van de Graaff machine	0.25 kW 0.5 kW 3.0 kW 50 μA beam 5 μA current	Electrons, positive ions, secondary particles, and gamma radiation	1 MeV 2 MeV 3 MeV 5 MeV 10 MeV	Polymerization reactions, food preservation and sterilization operations, basic research requiring relatively small quantities of other forms of radiations needed in teaching physics, biology, chemistry, etc., radiography	Versatile machines, can produce neutrons as secondary particles and gamma radiation as secondary radiation
Linear accelerator	4 kW 10 kW 18 kW 60 kW 400 kW	Electrons, secondary particles, and gamma radiation	6–10 MeV 24 MeV 10 MeV 10 MeV	Irradiation of plastics, polymerization, catalytic and other chemical reactions, basic and applied research, higher energy electrons, monoenergetic, sharply defined beams	Nearly monoenergetic beams

Resonant transformer	5 kW 10 kW 25 kW	Electrons	1 MeV 2 MeV 4 MeV	Irradiation of plastics, food sterilization, chemical reactions, such as polymerization	A relatively low-cost source of lower energy electrons with significant industrial applications
Cockcroft Walton generator	250 W 500 W	Positive ions	0 25 to 0 5 MeV 1 to 1 75 MeV	Nuclear reactions, chemical and biological irradiations and studies	A high intensity source (0 5 to 3 mA) of relatively low energy positive ions
Circular accelerators such as cyclotrons and betatrons	Very low	Electrons positive ions secondary particles and gamma radiation	Up to 30 beV	Basic particle physics studies	Principally used to produce high energy particles at low current density very expensive for general irradiation studies
Cobalt 60		Gamma[1]	1 17 and 1 33 MeV	Food and drug sterilization chemical reactions, medical research, hydrocarbon research, physics studies, chemical research, radiation damage studies	Useful for environmental irradiation studies, source can be contained in lead cask (small irradiation volume), water well (requires demineralized water), or in a hot cell
Fuel Elements (MTR)		Gamma	$10^{?}$ to $10^{?}$ R/hr equivalent to 5000 C of Cobalt-60	Food sterilization, hydrocarbon research	Wide range and energies, difficult to reproduce conditions of test high handling expenses limited availability
Other radioactive isotopes		Neutrons	Variable	Tracer studies (medicine agriculture, anthropology etc), basic physics density measurements reactor startup, chemical reactions (such as polymerization), radiography, food sterilization, ionization	A summary of applications and a bibliography is included in the report Isotopes -- an eight year summary of U S distribution and utilization available (price $2) from Superintendent of Documents U S Government Printing Office, Washington 25 D C Cost information on isotopes is available from ORNL and from private companies making isotopes available

[1]Light water tank reactor

[2]Because all reactors produce neutrons and gamma radiation to a greater or lesser extent the application of a particular reactor to given use is not sharply defined. The application column therefore lists only those areas to which the particular type of reactor is most suitable. With the exception of those programs that require very high neutron fluxes such as radiation damage studies most of the reactors are applicable to such areas as production of radioisotopes, fundamental investigations of radiation effects on chemical reactions or in genetic mutations, analytical use such as chemical activation analysis and neutron diffraction studies, medical therapy, as in neutron capture techniques, and training in reactor engineering and physics

Table 11-4 Characteristics of Stock Oils Used for Radiation Resistance Comparisons

Description	Sp gr 60/60°F	Color ASTM	Viscosity at 100°F		Viscosity at 210°F		Viscosity Index	% Wt Sulfur
			CS	SUS	CS	SUS		
A Mineral colza oil	0.838	½	4.21	39.81				0.1
B Empire pale oil	0.932	3	49.4	229.3	5.44	43.78	12	1.91
C 150-sec solvent naphthenic	0.884	2	34.6	181.9	5.04	42.47	67	0.44
D Light neutral turbine	0.872	1	32.2	151.1	5.3	43.31	107	1.14
E 150-sec light neutral low sulfur	0.863	1½	32.6	152.9	5.34	43.45	107	0.21
F Heavy neutral turbine	0.888	2	102	472.8	10.7	61.82	98	1.34
G Solvent bright stock	0.905	4½	540	2544.0	32.7	154.4	97	1.78
H "Aromatic extract"	0.913		62.3	289.1	7.02	47.18	68	2 approx

N-d-m Analysis

Viscosity Gravity Constant	%C	%C	%C	Molecular Weight	Refractive Index n 20°C
A 0.833	8.0	32.0	60.0	250 approx	1.4661
B 0.908	24.8	24.7	50.5	370	1.4866
C 0.860	11.7	26.3	62.1	330	1.5179
D 0.819	5.5	32.3	62.3	400	1.4800
E 0.815	6.2	25.4	68.4	410	1.4778
F 0.822	8.1	23.2	68.7	500	1.4878
G 0.818	7.9	22.9	68.2	670	1.4978
H 0.862	19.4	25 approx	55 approx	390	1.5085

unsaturated hydrocarbons are most reactive and aromatics the least affected. Saturated compounds fall somewhere between the two extremes. The results are expressed as G values; that is, the number of molecules [illegible] reacting or produced for each 100 eV of ionizing radiation. For example, at least 6 to 15 molecules of unsaturated hydrocarbons react for each 100 eV. In certain instances, high G values (up to 10 000) result for free radical polymerization.

Table 11-5 The Effect of Irradiation (with Air Access at 85° F) for Base Oils of Different Types

Oil	10⁸ Rads Dose				5 × 10⁸ Rads Dose			
	Color inc	Sp gr inc	% Viscosity inc 100°F	% Viscosity inc 210°F	Color inc	Sp gr inc	% Viscosity inc 100°F	% Viscosity inc 210°F
A					2½	0.008	60	
B	1½	Nil	13.1	9.5	2	0.002	[illegible]	46
C	1½	Nil	13.9	8.3	3½	0.004	49	38
D	2½	Nil	13.3	8.3	4	0.004	34	30
E	1	0.002	9.8	9.9	2½	0.009	106	64
F	2	0.001	14.[illegible]	10.3	6	0.002	94	50
G	½	Nil	17.7	1.0	3½	0.003	113	99
H					4		83	4[illegible]

whereas low G values (G = 6) are found for random crosslinking and very low values (G < 1) for methane formation.

Aromatic materials, with a G value for destruction of 1, are highest in radiation resistance. The principal reaction is crosslinking, from which very small amounts of gas evolve.

Additional studies were made on a range of petroleum oils representative of typical paraffinic, naphthenic, and aromatic materials varying in sulfur content. The physical and chemical characteristics of the base oils are listed in Table 11-4 and the effect of irradiation on these oils is given in Table 11-5. The viscosity was plotted against the aromatic and sulfur content (Fig. 11-10). These data show that as the aromatic content increases the viscosity increase is reduced in almost a linear relationship. The effect of sulfur content is similar but more marked. Further, it was noted that radiation damage appears greatest for oils with the highest molecular weights or the highest initial viscosity.

Because it was found that naturally occurring compounds improved the radiation stability of petroleum oils and that these compounds were usually removed by refining procedures, the effect of using synthetic aromatic and sulfur compounds as additives was studied. The results are shown in Table 11-6. From these studies it appears that a disulfide or an alkyl selenide, provides good radiation damage protection. The disulfides prevent polymerization by a mechanism termed free radical chain stoppers. The disulfides have an advantage also of being good EP and antiwear agents but do not prevent oxidation or olefin formation.

Fig. 11-10 Radiation Stability versus Sulfur and Aromatic Content

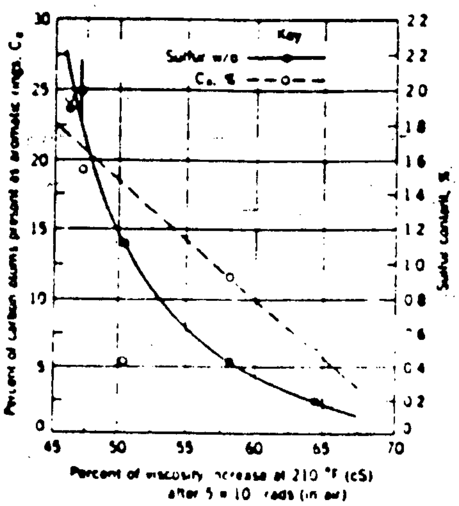


Table 11-6 The Effect of Aromatic Sulfur Compounds on the Radiation Stability of a Petroleum Oil (with Air Access, at 86°F)

Fluid	% Sulfur Added	5×10^8 Rads, % Viscosity increase, cSt: 100°F	5×10^8 Rads, % Viscosity increase, cSt: 210°F	10^9 Rads, % Viscosity increase, cSt: 100°F	10^9 Rads, % Viscosity increase, cSt: 210°F	Optical Densities* of IR Peaks: 10.34 (olefin)	Optical Densities* of IR Peaks: 5.84 (oxidation)
150-sec low sulfur light neutral (oil E, Table 28)		108	64	400	194	0.18	0.12
E + cyclic compound	0.7	117	66	256	135		
E + cyclic compound	2.3	100	58	280	141		
E + monosulfide	0.5	83	51	257	142	0.17	0.12
E + monosulfide	1.7	67	35	168	84		
E + disulfide A	0.9	82	38	137	78	0.18	0.13
E + disulfide B	0.8	59	37			0.17	0.12
E + selenide		74	41	216	119		

*Determined by differential infra-red analysis between unirradiated sample and sample irradiated to 10^9 rads

It is well known, however, that aromatic compounds possess good thermal and radiation stability and in the latter case protect less stable aliphatic molecules by the transfer of energy. These compounds are usually characterized by complex molecules which resonate between a number of possible electronic structures and, therefore, possess fairly stable excited energy states. In other words, when a paraffinic hydrocarbon absorbs energy, it is raised to an unstable state in which the energy is greater than the electronic forces that constitute the chemical bonds. The result is a bond fracture with residual free radicals. In an aromatic with an equivalent absorbed energy, the higher level is not sufficient to sever the greater electronic binding forces, and the energy is eventually liberated as heat or light. The radiation stability of aromatic petroleum extracts are, in decreasing order, polyglycols, paraffinic hydrocarbons, diesters, and silicones. The effect of aromatic compounds was studied both as antirad additives to mineral oils and as pure synthetic fluids. The results are given in Figs. 11-11 and 11-12. These data show the following relationships:

1. The aromatics with bridging methylene groups between the aromatic molecules are less efficient as protective agents than antirad additives with direct links between aromatic rings.
2. Long chain alkyl groups attached to the aromatic rings make them less protective agents, probably because of a difference in stability of the compound and lowering of the aromatic ring content.
3. Small amounts of a free radical inhibitor in addition to the aromatic additive substantially reduce the viscosity increase.
4. The protection afforded is not simply a direct function of aromatic content, in fact it would appear that 40 percent of added aromatic material

is a practical maximum. Beyond 40 percent it is preferable to use a pure aromatic of suitable physical characteristics.

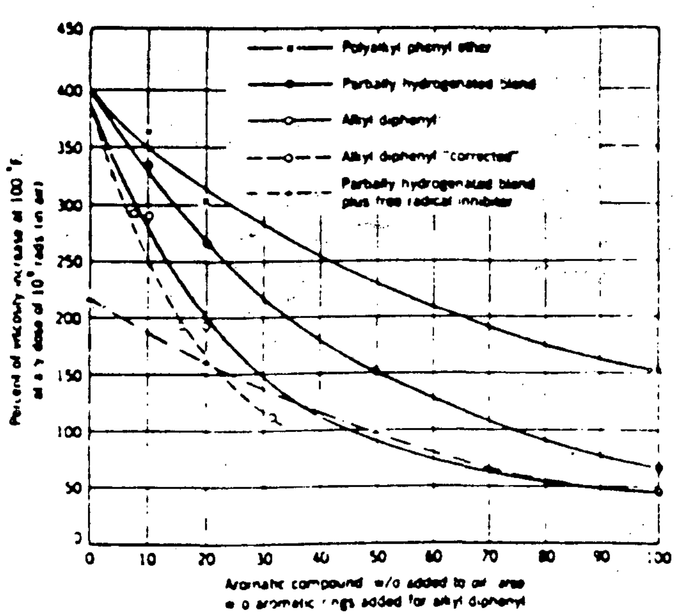
The study of aromatics showed that radiation stability is a function of the bond dissociation energy of the weakest carbon bond. These are plotted in Fig. 11-13.

Initially, in a study of the suitability of petroleum products for reactor lubrication, tests were conducted on conventional oils and hydraulic fluids by Carroll and Calish of the California Research Corporation. The samples were irradiated by using spent fuel elements from the Materials Testing Reactor in Arco, Idaho. This is essentially a gamma source. The petroleum products tested were four industrial oils, four base oils (pale, neutral, and white oils and bright stock), two gear lubricants, and an automatic transmission fluid. The test results (Figs. 11-14 to 11-17) were determined by changes in viscosity and VI after static irradiation up to 9×10^8 R.

Mobil investigations on turbine oils at similar doses are described in Fig. 11-18.

Most of these investigations show that high quality, mineral oil based lube oils can withstand irradiation up to 100 Mrad and that synthetic fluid lubricants are available with radiation stability above 100 Mrad.

Fig. 11-11 Radiation Protection of Synthetic Aromatic Additives



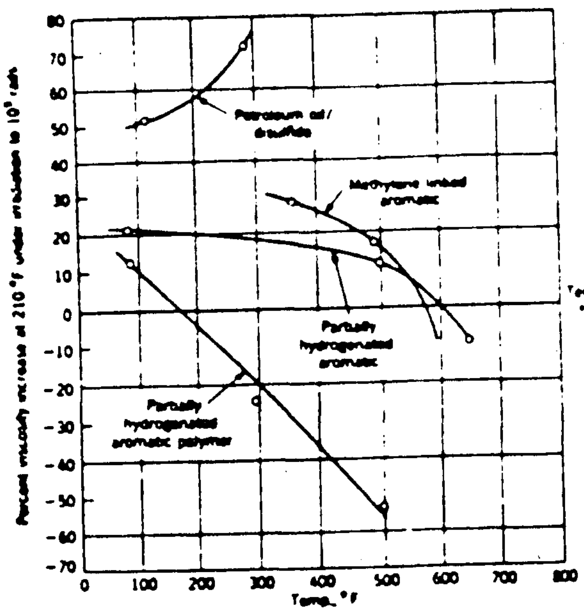


Fig. 11-12 Radiation Stability versus Temperature

A study of the changes in properties and performance of conventional lube oils after irradiation shows the following:

1. Conventional antioxidant additives of the phenolic or amine type confer little radiation stability to base oils and are preferentially destroyed between 10^8 and 5×10^8 rad.
2. Didodecyl selenide, which is known to be an effective antioxidant, also has radiation protective properties. The oxidation stability is effective after an irradiation of 10^8 rad.
3. Diester base oils, phosphate esters (wear additives), and halogenated EP agents produce acids at a low radiation dose.
4. Polymers such as polybutenes and polymethacrylates cleave readily and thus lose their effect as VI improvers.
5. Silicone antifoam agents are destroyed at low radiation dose.
6. In most cases, the presence of air, compared with an inert atmosphere, increases radiation damage by a factor of 1.6 to 2.3 times, as indicated by viscosity increase.

In summary, high quality, conventional lubricating oils are suitable for doses up to 10^8 rad. Further radiation resistance can be formulated into a good quality petroleum oil by the use of antirads such as radical scavengers (antirad A) or aromatic structures (antirad C). These formulated oils will pro-

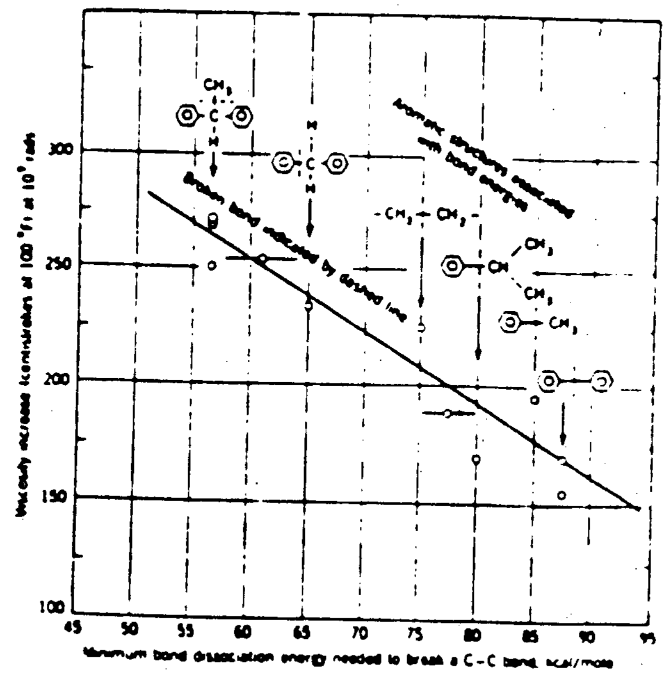
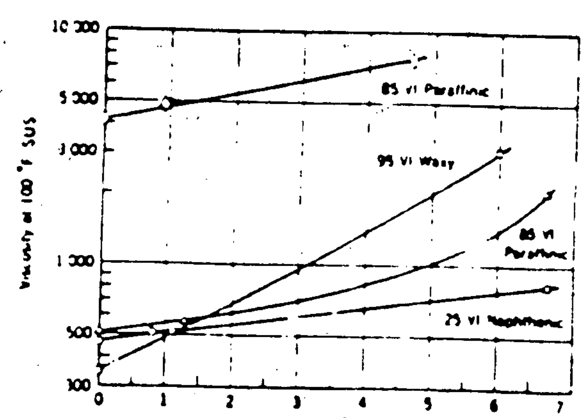


Fig. 11-13 Radiation Stability versus Bond Dissociation Energy

Fig. 11-14 Irradiation of Conventional Base Oils



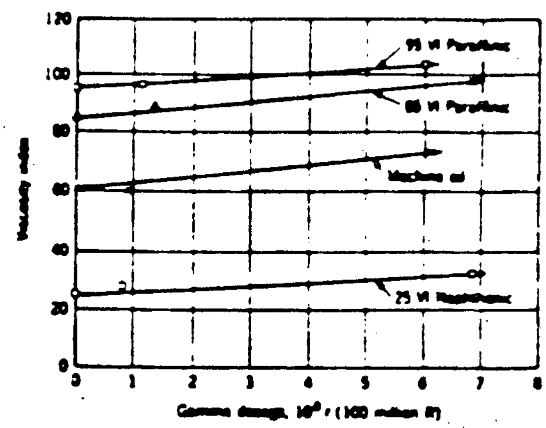
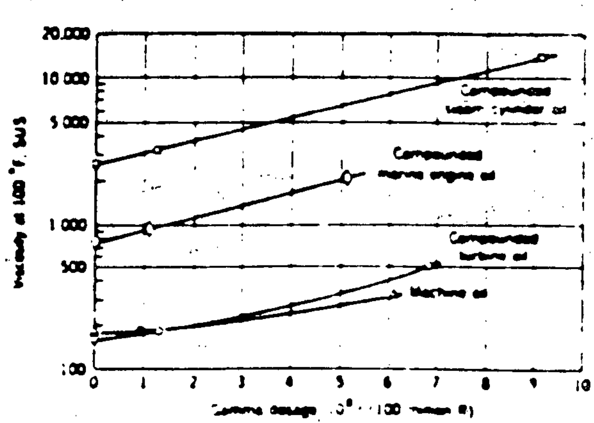


Fig. 11-15 Effect of Irradiation on VI

Fig. 11-16 Irradiation of Conventional Industrial Oils



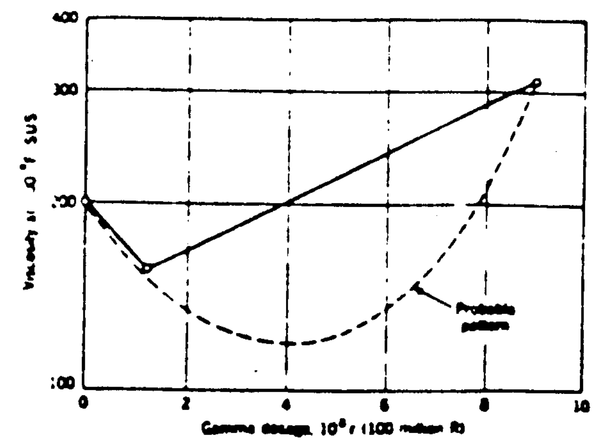
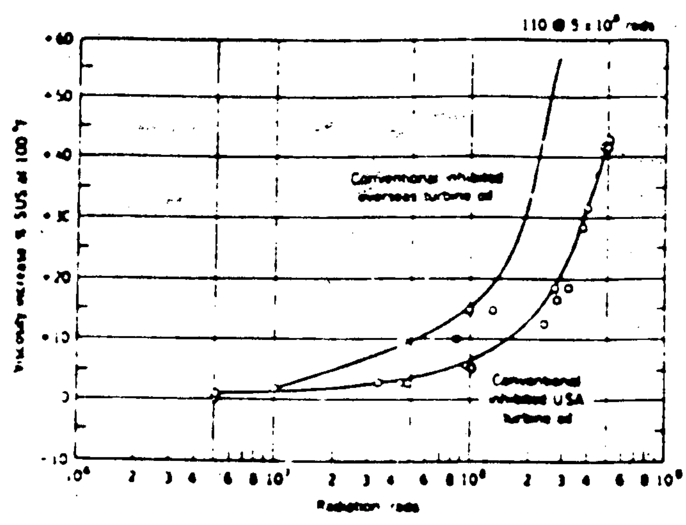


Fig. 11-17 Irradiation of VI Improved ATF

Fig. 11-18 Effect of Radiation on Turbine Oils



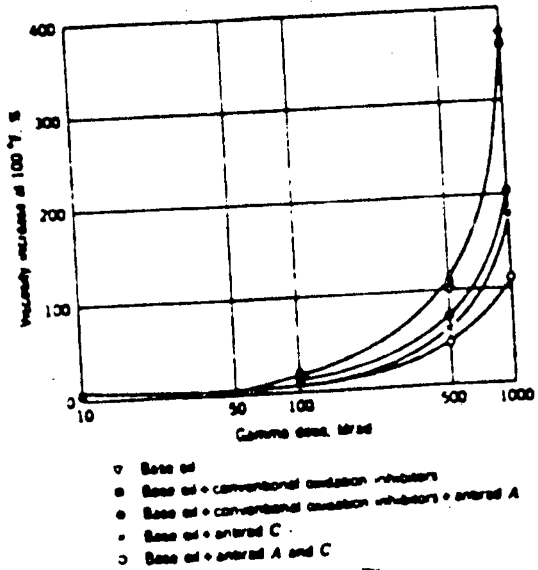
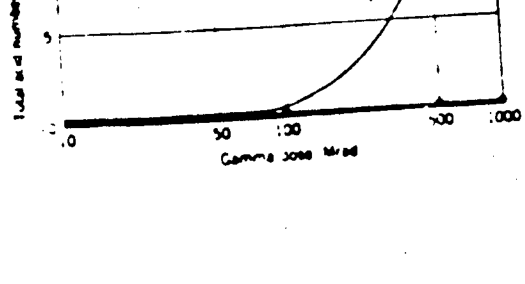


Fig. 11-19 Effect of Antirads on Viscosity

tect up to 10^9 rad, as shown in Figs. 11-19 and 11-20. Above these doses and at high temperatures, synthetic type lubricants that use partly hydrogenated aromatics blended with aromatic polymers are required. The effect of temperature at high radiation dose (10^9 rad) has been studied under a nitrogen atmosphere for these synthetic fluids (Fig. 11-12).

Fig. 11-20 Effect of Antirads on Oxidation



[illegible] in Comparison with Mineral Oils, Shell Four-Ball [illegible]

Fluid	Scar Diameter (mm) 100-kg Load for 10 Min	40-kg Load for 10 Min	Viscosity at 100°F, cSt
Methylene/ethylene linked aromatic	...	Seized after 35 sec	28.1
Ethylene linked aromatic	0.37	0.32	108
Partly hydrogenated blend A	0.30	0.32	34.5
A + polymer	0.34	...	251
A + disulfide (0.5 sulfur)	0.16	0.07	31.1
150-sec light neutral turbine oil	...	0.23	32.6
Five-ring polyphenyl ether	0.38	0.08	355

If, however, materials are to be satisfactory as lubricants, they must not only have good thermal and irradiation stability but their wear characteristics must be satisfactory. Such wear tests have been made by a Shell Four-Ball machine at two different loads and are given in Table 11-7. Table 11-8 lists a number of new generation synthetic and mineral oil blends and pure synthetic lubricants and potential applications.

Grease irradiation The damage caused by high energy radiation on greases is a dual effect. First, the radiation attacks the thickening structure and causes separation and fluidity. Following this, continued irradiation causes polymerization of the base oil to the original thickened condition and finally solidification. The precise pattern of change is dependent on the type of thickener, the gel structure, and the radiation stability of the thickener and base oil.

In general, greases have been evaluated for radiation damage by determining the worked penetration, following irradiation, and comparing it with the original value. These irradiation evaluations are usually of the static type; but, as mentioned previously, dynamic testing during irradiation has yielded markedly different results. Typical greases that have organic soap components of alkali or alkaline earth metals, although resistant to high amounts of radiation, break down at total doses of approximately 10^8 rad. Micrographs of the soap structure showed a drastic change in the normal fiber structure of the gelling agent. On the other hand, greases made with nonsoap thickeners, such as carbon black, were less affected. Micrographs of a carbon black grease showed the same structure (agglomeration of carbon particles dispersed throughout the oil phase) both before and after irradiation.

The stabilization of the thickening structure under irradiation solves the problem of softening or bleeding of the base oil but will not solve the eventual solidification of the grease. This is a function of the base oil, and the solutions discussed under lubrication oils (use of antirad additives or synthetic organics as base fluids) are valid.

The mechanism of change for three greases is shown in Fig. 11-21. In one case the grease had an unstable thickener and progressively softened to

Table 11-6 Radiation-Resistant Fluids, and Potential Applications

Application	Fluid Type	Initial Viscosity, cSt at 100°F	Flash Point, COC°F	Boiling Range, °F at 760 mm	% Viscosity Increase (100°F, cSt) at 10[illegible] Rads: In Air	% Viscosity Increase (100°F, cSt) at 10[illegible] Rads: In Inert Atmosphere
Hydraulic fluid/spindle lubricant	Synthetic aromatic A	13.8	305	480/745	45	25
	Synthetic aromatic B	34.5	345	645/745	70	45
Bearing lubricant	Oil/synthetic aromatic	25	345	...	152	80 approx
moderate stability	Synthetic aromatic B	34.5	345	645/745	70	45
high stability	Synthetic aromatic/polymer	74.5	345	645/800	20 approx	58
Gear lubricant	Oil/synthetic aromatic/disulfide	24	345		130 approx	70 approx
moderate stability	Aromatic/disulfide	31	345	645/745	54	29
high stability	Aromatic/polymer/disulfide	72	345	645/800	15 approx	40 approx
Heat transfer	Kerosine aromatics	2.9	115	320/745	100	60 approx
low temperature						
intermediate temperature	Synthetic aromatic A	13.8	305	400/745	45	25
high temperature	Synthetic aromatic C	38.3	340	630/745	65	40 approx

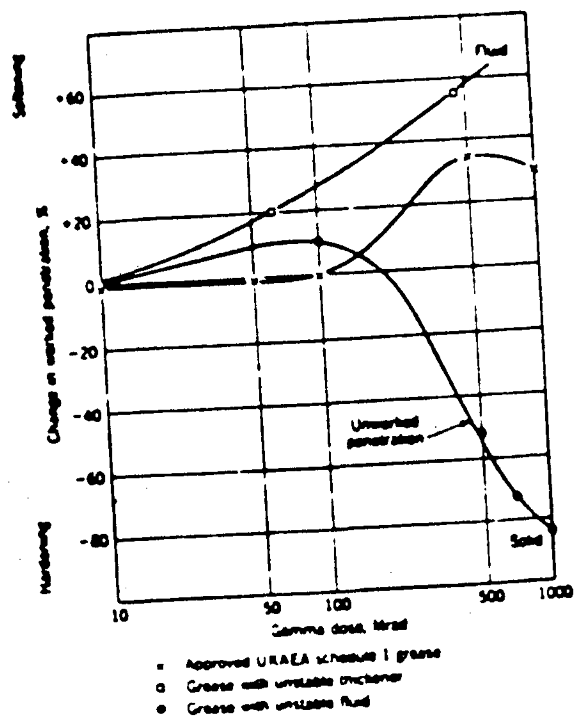


Fig. 11-21 Effect of Radiation on Greases

fluidity. Although such a grease might protect the bearing, the problem of leakage would be great, and incompatibility with reactor components would be an added problem. The second grease gradually decreased in penetration (solidified) after an initial increase or softening. Such a grease would cause failure in the lubricated mechanism. The third grease showed good stability with a slight softening up to 10^9 rad.

Radiation Stability of Thickeners The selection of the thickener or solid phase of a grease designed for nuclear applications requires consideration of compatibility as well as resistance to radiation, high temperature, mechanical shear, and atmosphere.

Certain elements are unsuitable, for their presence within or close to the reactor core would seriously affect the neutron economy, or react with the fuel element cladding to cause destruction of the canning and release of fission products. Accordingly the UKAEA has restricted lubricant composition (Table 11-9).

Effect of atmosphere can be illustrated by air, which has a serious oxidizing effect, especially when coupled with radiation. Conventional antioxi-

Table 11-9 Elements on Which Restrictions Are Placed For Radiation-Resistant Lubricants Used in United Kingdom-Type Reactors Employing Magnox Fuel Cans

None allowed	Mercury
0.1% allowed	Barium, bismuth, cadmium, gallium, indium, lead, lithium, sodium, thallium, tin, zinc
1% allowed	Aluminum, antimony, calcium, cerium, copper, nickel, silver, strontium, praseodymium.

Note: In certain instances the above limits can be exceeded, where it can be shown that the metals are present in a stable compounded form and that practical compatibility tests are satisfied.

dants are destroyed as noted above. Some of the organic modified thickeners have an antioxidant effect and perform a dual function. Hot pressurized carbon dioxide can cause rapid degeneration of conventional soap thickened greases, presumably by carbonate formation.

In a selection of the thickener, the compatibility of thickener and base fluid is of paramount importance, for even an exceptionally radiation resistant thickener, when in combination with certain base fluids, may at best yield weak gels that soften easily; for example, a satisfactory grease structure is extremely difficult to obtain by using an Indanthrene pigment with a paraffinic bright stock.

Various nonsoap thickeners that form good grease structure with both mineral oil and synthetic fluid bases are available. These thickeners may be grouped as follows:

1. *Modified clays and silicas.* Typical of the modified clays are Bentone 34 and Baragel, which are formed by a cation exchange reaction between a montmorillonite clay and a quatenary ammonium salt. This reaction produces a hydrocarbon layer on the surface of the clay which makes it oleophilic. Finely divided silicas may be treated with silicone to render them hydrophobic, or, as with Estersil, the silica may be esterified with n-butyl alcohol.
2. *Dye pigments.* Organic toners or dye pigments are utilized as grease thickeners (e.g., Idanthrene).
3. *Organic thickeners.* Typical of this type are the substituted aryl ureas characterized by the diamide carbonyl linkage which may be formed in situ by the reaction of diisocyanate with an aryl amine.

The behavior of these thickeners, when used in conjunction with a synthetic fluid, is shown in Fig. 11-22.

As with fluid lubricants, antirads may be added to the grease to increase its radiation stability. The effect of free radical scavengers and aromatic energy absorbers on a modified clay, synthetic fluid grease is shown in Fig. 11-23.

The comparison of radiation resistant greases with conventional soap type, mineral oil greases is shown in Figs. 11-24 and 11-25. The radiation stability of the fluids extracted from these greases is shown in Fig. 11-26.

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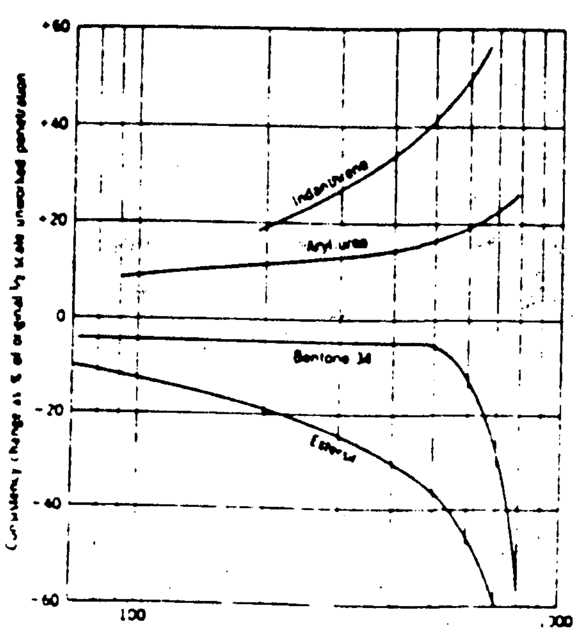
LUBRICATION RECOMMENDATIONS

The advent of nuclear energy has added a new dimension to the requirements of lubricants and other petroleum products in industrial applications. Equipment in the nuclear industry — research and power reactors; fuel processing machinery; conveyors, manipulators, and cranes in irradiation facilities; viewing windows and shield doors in hot cells; and heat exchange units — all require oils, greases, and organic fluids to perform conventional and special functions in radiation atmospheres.

Nowhere are the operating conditions of radiation, temperature, and atmosphere more demanding than in the power reactor field. At the outset, equipment was designed to operate without conventional petroleum lubricants because little was known of the behavior of petroleum products under irradiation and the exact severity of the application was overestimated. This placed a design and economic burden on nuclear power generation. As experience was gained in the operation of these plants, the original position was reconsidered. First, specific operating parameters of radiation flux, temperature and so on, were obtained, which realistically established the requirements; second, research in the radiation resistance of petroleum

Fig. 11-22 Effect of Thickener on Grease Polymerization



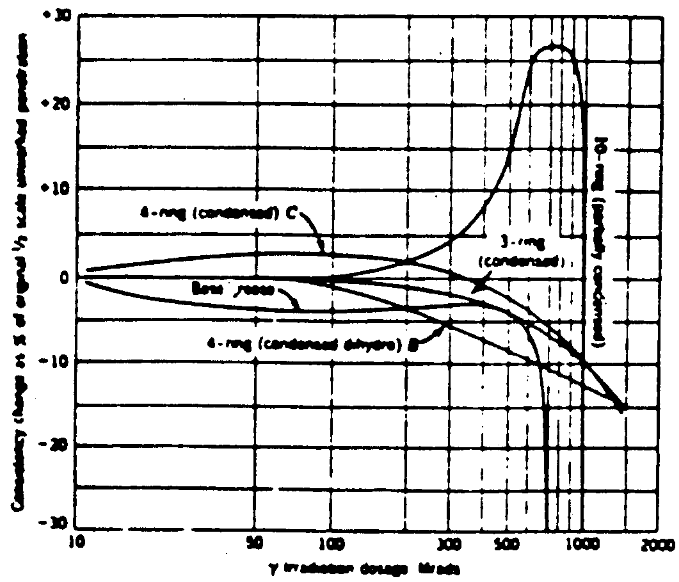
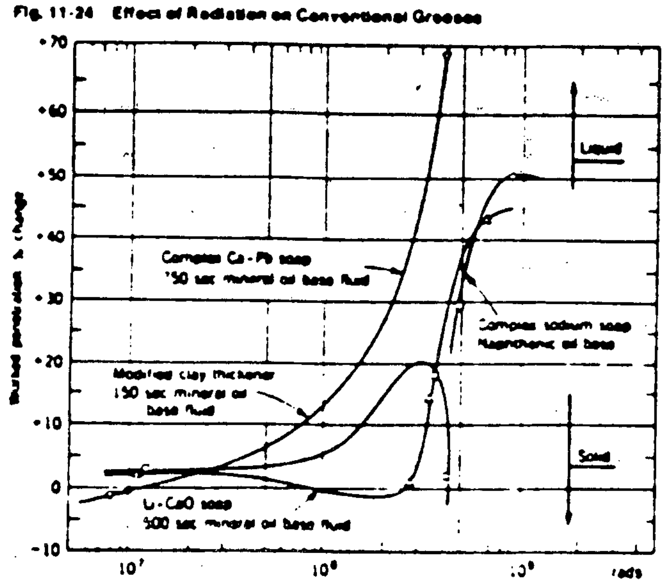


Fig. 11-23 Effect of Antirads on Grease Stability

Fig. 11-24 Effect of Radiation on Conventional Greases



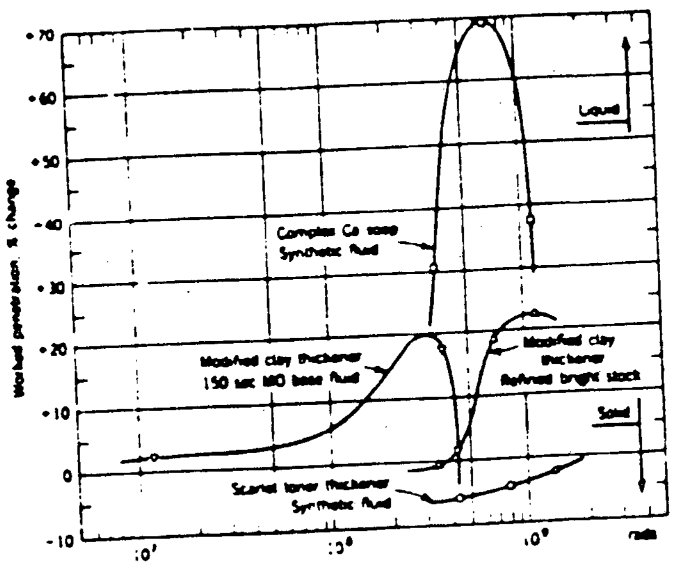
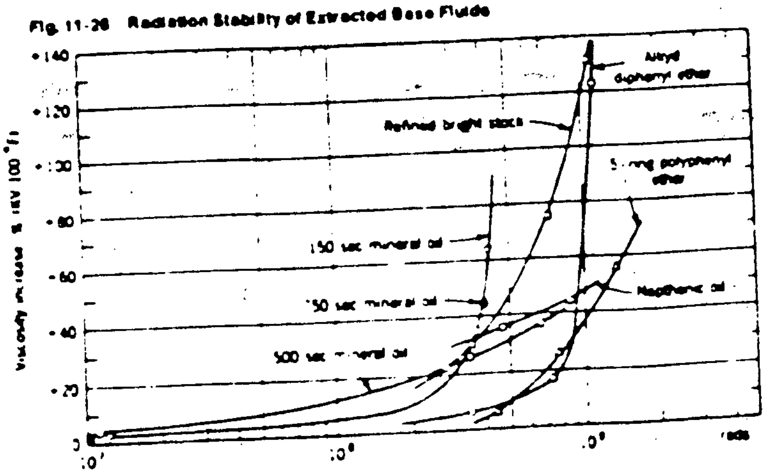


Fig. 11-25 Stability of Radiation Resistant Greases

Fig. 11-26 Radiation Stability of Extracted Base Fluids



materials showed that conventional lubricants could withstand doses up to 10^7 to 10^8 rad and that new petroleum lubricants could be developed to withstand more than 10^9 rad. As a consequence of this increase in knowledge and experience, nuclear power station owners and operators requested that whenever possible, proved engineering designs employing conventional petroleum greases and lubricating fluids should be adopted. This has lead to an increase, in new generation plants, of the use of petroleum lubricants.

Because the nuclear power industry is still in a developing stage, in which patterns of design and operating conditions are changing, most equipment is unique, and each plant requires separate consideration before proper lubricants and lubrication schedules can be established. Little repetitiveness exists in equipment or operating conditions, and, therefore, the best that can be accomplished in this chapter on lubrication recommendations is to furnish the background experience and establish the guide lines so that lubricating engineers can, after a survey of specific conditions, recommend the best lubricants for a particular application.

General Requirements

All lubricating engineers are familiar with the effect of the environmental factors of speed, load, temperature, and time on the life of gears and bearings, and on the physical and chemical properties of oils and greases exposed to these environmental conditions.

In conventional applications, the effects of speed, load, and temperature are evaluated in making recommendations. Selecting the correct lubricant and service interval is determined by evaluating the lubricant's anticipated performance under the most critical of these conditions: for example, speed may be the determining factor with antifriction bearings and the proper grease must resist excessive softening for the service period. In high loading, extreme pressure properties may be the determining consideration. In most cases, however, temperature is the most critical factor. Operating severity may be measured by the degree of heat, or the temperature, and the extent of exposure, or the time interval. The additional environmental factor of radiation in nuclear applications affects lubricants in much the same manner as heat. Both are modes of energy and, as we have seen in a

Table 11-10 Nuclear Reactor Systems Estimated Dose to Components — Rads per Year*

Component	Pressurized-Water Reactor	Boiling-Water Reactor	Organic-Moderated Reactor	Liquid Metal-Cooled Reactor	Gas-Cooled Reactor
Control rod mechanisms	10^8–10^9	10^8 max	10^8–10^9	[illegible]–10^8	10^4–[illegible]
Fuel-handling devices	10^6–10^7			[illegible]–10^8	[illegible]
Primary coolant pumps	10^6–10^7	10^6–10^7	[illegible]	Negligible	10^4 max
Auxiliary pumps	10^4–3 × 10^6	10^4–3 × 10^6	[illegible]	[illegible]–10^8	10^4 max
Auxiliary motors, etc.	10^6–3 × 10^7	10^6–[illegible]			10^4 max
Turbogenerator and auxiliaries	Negligible to 10	400 - 800	Negligible to 25	Negligible to 25	Negligible to 5 × [illegible]

*The rad, a unit of dose, is the absorption of 100 ergs of radiation energy per gram of material.

Table 11-11 Typical Operating Conditions in Components of CO_2 Cooled, Graphite Moderated Reactors

Component	Operating temperature, °C	Radiation dose (rad/yr)	Compatibility Requirements: With CO_2	Compatibility Requirements: With Reactor Materials	Volatility Requirements	Operating Atmosphere	Pressure of Operating Atmosphere (lb/in²)	Lubricant
CO_2 gas circulators								
bearings	80 max	10^3 max	Yes	Yes	Yes	CO_2 and air	Nil - slight	Oil
seals	30 - 140 or higher	10^4 max	Yes	Yes	Yes	CO_2	Slight	Oil
CO_2 gas valves								
gears, bearings and hydraulics	70 - 150 or higher	10^4 max	No	No	No	Air	Nil - slight	Oil or grease
Control rod mechanisms								
gears and bearings	70 - 150	10^3 - 5 × 10^8	Yes	Yes	Yes	CO_2	150 - 300	Grease, also oil for sintered bearings
Fuelling machines								
bearings and gears	100 - 400	10^3 - 3 × 10^9	Yes	Yes	Yes	CO_2 and air	Partial vacuum up to 150 - 300	Grease
hydraulic mechanisms	100 max	10^4 max	No	No	No	Air	Nil - slight	Oil
cooling fan bearings	100 max	10^3 max	Yes	Perhaps	Perhaps	CO_2 and air	150 - 300	Grease or oil
Ancillary machines								
service machines (when separate from fuelling machine), gears, and bearings	70 - 100	10^6 max under normal conditions	Yes	Yes	Yes	CO_2	Partial vacuum up to 150 - 300	Grease
Charge chute machines (when separate from fuelling machine), gears and bearings	100 - 400	10^6 - 10^8	Yes	Yes	Yes	CO_2	Nil up to 150 - 300	Grease
Reactor observation equipment (when separate from fuelling machine)	100 max	Dependent on use but could be high	Yes	Yes	Yes	CO_2 and air	Nil up to 150 - 300	Grease
Spent fuel element conveyor systems Chains and bearings	100 max	2 × 10^8 max under normal conditions	No	Yes	No	Air	Nil	Grease

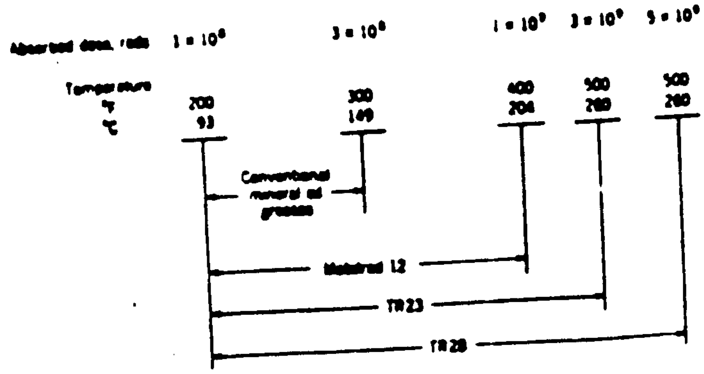


Fig. 11-27 Mobil's Radiation Resistant Greases

previous section, lubricants, like all organic materials, undergo major structural changes when certain thresholds of absorbed energy are reached. We know that petroleum products undergo thermal cracking and polymerization at certain temperatures and, likewise, that cleavage and cross-linking occur at certain radiation dosage thresholds.

In nuclear applications, radiation energy is expressed as the flux or dose rate. The particular types of radiation and the units have already been discussed. It is sufficient to state here that this dose rate applied over a specified interval will yield the absorbed dose for an exposed material. If, for example, a grease can absorb a dose of 5×10^9 rad before suffering physical or chemical changes that will render it useless as a lubricant, this grease can be used for 5000 days if the dose is absorbed at a rate of 1 Mrad a day or for only five days if the dose is 1000 Mrad a day.

Selection of Lubricants

Much has been published and extensive studies have been made that lead to the recommendation of correct lubricants. In the final analysis, however, the selection of the proper lubricant and its application to any particular equipment must be made by a lubrication engineer for each specific instance, based on the operating conditions and the type of bearing, gear, cylinder, etc., requiring lubrication. Nowhere is this more pertinent than in the lubrication of nuclear power plants. Because of the newness of the field, the uniqueness of the designs and the severity of operating conditions of temperature, radiation, and operating atmospheres, each plant is markedly different from every other. Therefore the experience of the lubricating engineer is important, and blanket recommendations serve only as guidelines to these engineers. Mobil engineers for more than 100 years have devoted their efforts to the study of lubrication requirements in thousands of plants all over the world, to the development of lubricants to meet these requirements, and to the perfection of application methods. The accumulated experience with all kinds of machinery has been helpful in numerous plants in the solution of lubrication problems and, in many cases, in the elimination of mechanical problems as well.

In selecting lubricants for a nuclear plant, the engineer should be consulted in the design phase, be cognizant of development work at equipment manufacturers, and participate in practical evaluation of prototype units under the operating conditions. In surveying the plant requirements, particular attention must be paid to the radiation flux profile which has been calculated for the various parts of the plant and compared with actual surveys during operation of similar plants. Extreme conservatism has been the rule in estimations of nuclear plant requirements, often to the detriment of practical solutions.

In estimating the radiation flux to which a lubricant will be exposed, benefit must be taken for the shielding effect of the equipment components which will attenuate the flux estimated for the surroundings. Estimated averages for the general flux levels in various nuclear power plants are shown in Table 11-10; more detailed estimates of a gas cooled, graphite moderated reactor plant of the British type are shown in Table 11-11.

The ability of Mobil lubricants to withstand radiation is shown in the graph plotted (Fig. 11-18) for two turbine oils statically irradiated and in the chart (Fig. 11-27) which shows the ranges for available greases.

GREASES

Commercial Equivalents of TVA Grades

	Turbine Bearing Grease	General Purpose Greases		
	TVA-UW-3 (NLGI-1 water washout resistant)	TVA-GP-0 (NLGI-1)	TVA-GP-1 (NLGI-2)	TVA-GPM-2 (NLGI2 + 3%) (Molybdenum Disulfide)
AMOCO	Amolith 1 EP	Amolith 1 EP	Amolith 2 EP	Molylith 2
ARCO	Litholine H EP-1	Litholine H EP-1	Litholine H EP-2	EP Moly 2
CHEVRON	Duralith EP-1	Duralith EP-1	Duralith EP-2	Moly Grease No. 2
CITGO	HEP-1	HEP-1	HEP-2	
EXXON	Lidok EP-1	Lidok EP-1	Lidok EP-2	Beacon Q2
GULF	Gulfcrown EP-1	Gulfcrown EP-1	Gulfcrown EP-2	Gulftex Moly
MOBIL	Mobilux EP-1	Mobilux EP-0	Mobilux EP-2	Mobilgrease Special
SHELL	Alvania EP-1	Alvania EP-1	Alvania EP-2	
TEXACO	Multifax EP-1	Multifax EP-1	Multifax MP-2	Molytex EP-2
UNION 76	Unoba EP-1	Unoba EP-1	Unoba EP-2	Unoba Moly HD Special No. 2

TVA APPLICATIONS: UW-3 - Wicket gate top and bottom bearings and operating mechanisms.

GP-0, 1 & 2 - Year round lubrication of industrial ball, roller and plain bearings, and automatic lubrication. These are lithium soap based greases and MUST NOT BE MIXED WITH GREASES CONTAINING OTHER BASE FILLERS such as polyurea, aluminum complex, sodium, calcium, etc.

These greases must pass the TVA Comparative Performance Tests for purchasing as described in pages 9-20 of Specification 18.00? (Proposed Revision To 12-23-70 Issue). CONSULT TVA LUBRICATION ENGINEERS BEFORE SUBSTITUTING FOR GREASES APPROVED AND FURNISHED ON IQT CONTRACTS.

2. Turbine Bearing Grease

*2.1 TVA Code - TVA-UW-3

This grease is to be Shell Alvania No. EP-1 a NLGI No. 1, extreme pressure lithium base grease. This grease is used on wicket gate top and bottom bearings and operating mechanism. Wicket gate bearings are subject to water washout.

Specifications:

Viscosity range SSU at 100°F		918
Viscosity range SSU at 210°F		80
Penetration at 77°F -	worked	320
	unworked	328
Dropping point at degrees F		390

3. General or Multipurpose Grease

Lubricant shall be an industrial, general-purpose, lithium-soap grease capable of satisfactory year-round lubrication of industrial ball, roller, and plain bearings and automatic lubrication. The grease shall pass the Comparative Performance Tests for purchasing GP-1 grease.

*3.1 TVA Code - TVA-GP-1

This grease shall be NLGI Grade 2. This consistency must meet TVA requirements when tested under the Comparative Performance Tests outlined in pages 9-20 in this specification.

*3.2 TVA Code - TVA-GP-0

This grease shall be NLGI Grade 1. This consistency must meet TVA requirements when tested under the Comparative Performance Tests outlined in pages 9-20 in this specification.

3.3 TVA Code - TVA-GPM-2

Lubricant shall be a general-purpose, NLGI Grade 2, lithium-soap grease containing at least 3% Molybdenum disulfide (MoS_2) additive by weight, and shall be capable of satisfactory year-round lubrication of automobile and truck chassis. Grease offered must be a standard product commercially available to fleet operators. NOTE: TVA does not approve any grease containing molybdenum disulfide (MoS_2) for use at TVA nuclear plants, as this type grease has been determined to be detrimental to stainless-steel by acting as a catalyst in promoting stress cracking in the metal.

*Revised October 1, 1983

COMPARATIVE PERFORMANCE TESTS FOR PURCHASING GP-1 GREASE

The system of comparative performance consists of ten separate tests on each sample. Rating tables have been prepared for the numerical evaluation of the experimental results. These tests are conducted in accordance with ASTM standards or other appropriate procedures. The grease is assigned a performance rating for a particular test procedure by choosing the correct range in which the experimental test results belong as listed on the appropriate rating table. Opposite this range is found a machine rating varying from 1 to 16. This number represents the performance rating of the grease for that particular test. The tables are arranged in such a manner that as experimental results become poorer, the assigned rating becomes higher. Also, certain of the tests are covered by limiting requirements as seen in footnotes of the rating table concerned. A rating of 16 does not necessarily mean that a grease has failed a particular test unless that test is covered by requirements which are not met. In order for a grease to pass this system of testing, it must not fail any of the individual tests nor may it have an "overall rating" exceeding 70* points. The "overall rating" is the sum of the machine ratings assigned for the 10 tests. In the event that a grease fails any individual test, it will not be given a rating for that test but simply marked "failed". Consequently, that grease will not receive an overall rating, but will again be marked "failed".

The tests used in the system are:

1. The Grease Worker: The shearing action in the test apparatus stimulates the working of the grease in service. Shear or mechanical stability of grease is its ability to withstand repeated working with a minimum change in its structure or consistency. The grease is placed in a cylindrical container and worked by forcing a preformed disk or worker through it. The consistency is measured by a standard penetrometer at 60 strokes and repeated after 10,000 strokes. The numerical evaluation is calculated from the difference in the two measurements.

Experimental Results[1/]	Machine Rating
1.8 or less	1
1.9 to 2.5	2
2.6 to 3.8	3
3.9 to 5.0	4
5.1 to 7.5	5
7.6	6
7.7 to 8.1	7
8.2 to 11.2	8
11.3 to 15.0	9

1/ Percentage change (either increase or decrease) from 60 to 10,000 strokes. Increase in penetration shall not exceed 15 percent; decrease shall not exceed 10 percent.

2. Shell Roller Test: The test produces a numerical evaluation of the change in consistency caused by the kneading or working action of the roller. This test is a measurement of the mechanical stability of the grease. It simulates conditions encountered by roller bearing greases in actual operation. The sample is placed in a heavy steel cylinder 8 inches long and 4 inches in diameter. A weighted roller 7 inches long by 2-3/8 inches in diameter is inserted and the cylinder closed and placed in a machine that rolls it. The difference in penetration measurements before and after four hours of rolling determines the percent change in consistency.

Experimental Results[1/]	Machine Rating
0	1
0.1 to 2.5	2
2.6 to 4.7	3
4.8 to 8.3	4
8.4 to 9.0	5
9.1 to 14.0	6
14.1 to 17.5	7
17.6 to 23.0	8
23.1 to 28.0	9
28.1 to 34.8	10
34.9 to 38.9	11
39.0 to 50.0	12

1/ Percentage change (either increase or decrease) between penetration measurements before and after the test. Increase in penetration shall not exceed 50 percent; decrease shall not exceed 10 percent.

3. Dropping Point: The dropping point is a qualitative indication of the heat resistance of grease on applications where a semisolid lubricant is required. It is that temperature at which grease passes from a semisolid to a liquid state: Grease is applied to the walls of a small metal cup having a hole in the bottom. The cup is supported in a special glass test tube and the assembly is slowly heated in an oil bath in a glass beaker so that the cup may be observed. Suitable thermometers are inserted in the test tube and in the oil bath. The temperature at which the first drop of grease falls from the cup is the dropping point.

Experimental Results	Machine Rating
Greater than 550°F	2
550.0 F to 509.0°F	4
508.9 F to 435.8°F	5
435.7 F to 396.0°F	6
395.9 F to 392.0°F	7
391.9 F to 384.0°F	8
383.9 F to 378.5°F	9
378.4 F to 369.0°F	10
368.9 F to 364.0°F	11
363.9 F to 357.0°F	12
356.9 F to 350.0°F	13

Shall be 350°F or greater

4. Bleeding and Evaporation: Bleed rate is a measurement of the tendency of oil to separate from a grease and is proportional to the amount of lubricant bled into the bearing. A wide variety of these tests are used throughout the grease industry, but none are known to be completely reliable. This is due largely to the lack of an established correlation between the results of laboratory and field tests. The test selected for this system is similar to Federal Test Method Standard No. 791a, Method 321.2 with modifications. The sample is placed in a wire gauze filter cone which is then suspended in a glass beaker and heated in an oven to 212°F and held for 50 hours. The bleeding is calculated from the weight increase of the beaker due to the oil dripping from the grease, and the evaporation is calculated from the weight loss of the whole apparatus.

Experimental Results % Bleeding 1/	Bleeding Rating	Experimental Results % Evaporation 2/	Evaporation Rating
0.8 or less	1	0	1-1/2
0.9 to 1.7	2	0.1 to 0.2	3
1.8 to 2.1	3	0.3 to 0.9	4
2.2 to 2.4	4	1.0	5-1/2
2.5 to 2.7	5	1.1 to 1.2	7
2.8 to 3.7	6	1.3 to 1.4	8
3.8	7	1.5	9
3.9 to 5.5	8	1.6 to 1.9	10
5.6 to 5.7	9	2.0 to 2.7	11
5.8 to 7.3	10	2.8 to 3.3	12-1/2
7.4 to 8.0	11	3.4 to 5.9	14
8.1 to 8.7	12	6.0 to 6.6	15
8.8 to 9.2	13	6.7 or more	16
9.3 to 10.0	14		
10.1 to 10.9	15		
11.0 or over	16		

1/ Percent bleeding 50 hours at 100°C.
2/ Percent evaporation 50 hours at 100°C.

Sum of Ratings[3/]	Machine Rating
3.5 or less	1
3.6 to 14.5	2
14.6 to 15.0	3-1/2
15.1 to 15.5	5
15.6 to 16.0	6-1/2
16.1 to 16.5	8
16.6 to 17.0	9-1/2
17.1 to 18.0	11
18.1 to 19.5	12-1/2
19.6 to 20.0	14
20.1 to 24.0	15
24.1 or over	16

3/ Represents the total of the bleeding ratings (column 2) and the evaporation ratings (column 4).

5. Wheel Bearing: This test is a service evaluation of ball and roller bearing greases. It simulates conditions of these lubricants in actual operation. It measures the leakage of a lubricant from the hub and shows the tendency of the grease to form varnish-like deposits on the bearing. The bearings and hub of an ordinary automobile front axle are packed with a known weight of grease. The assembly is rotated at 600 rpm and a temperature of 220°F for 6 hours. The leakage is measured in the hub cap and a collector ring, the bearings are inspected for deposits, and the appearance of the grease on the bearings and in the hub is noted.

Wheel Bearings (660 rpm)

Experimental Results	Machine Rating
Pass A	4
Pass B	10.0
Fail	

The rating of the performance of a lubricant on this test is the judgement of the operator.

Must pass.

6. Rust Preventive Test: The ability of a grease to prevent rust or corrosion is very important, particularly when the equipment is on standby. The test for Rust Preventive Properties of Lubricating Greases, ASTM Designation D1743, determines the ability of the grease to prevent rust. A properly cleaned and greased roller bearing is subjected to humid atmosphere for 14 days. At this time the grease is removed and the bearing inspected for rust spots. The grease is rated on the number of rust spots visible to the naked eye.

Experimental Results[1/]	Machine Rating
0	1
1	3
2	6.5
3 or more	Fail

1/ Number of rust spots just visible to naked eye. Must not exceed two.

7. Shell Four Ball Test: There are several tests that may be performed on the Four Ball machine. Of these, four have been selected for use in arriving at a rating for this part of the system: Weld Point, Extreme Pressure Value, 2-1/2 Second Seizure Delay, and Percent Ideal E.P. The tests are used to evaluate the extreme pressure characteristics or load carrying capacity of a lubricant.

A system of four steel balls in the form of a tetrahedron is used. Three of the balls are securely locked in a ball pot and covered with the lubricant. The fourth ball is placed in a check and rotated at 1,800 rpm. The ball pot rests on a lever by means of which loads are applied to the system of balls. The pot is prevented from rotating by a calibrated arm assembly which, through linkage and springs, records on sensitized paper the torque or friction and seizures which may occur during a run. A series of 10-second runs is made at preselected loads, and runs at successively higher loads are made until welding of the four balls occurs. During the test procedure circular scars or wear spots are worn on the three stationary balls. Measurements are made of these scars and averaged for each run. From these scar diameters the extreme pressure value and the percent ideal E.P. are calculated.

a. The Weld Point is that point at which the loading is sufficient to cause immediate seizure and welding of the four balls occurs. It is expressed in terms of kilograms of applied load.

b. The Extreme Pressure Value, or load carrying capacity of the lubricant, is calculated by averaging the "corrected loads" when the test is completed. The "Corrected load" for any given applied load is calculated by dividing the average scar diameter (x) into the product of the Hertzian diameter (DH), for that load, and the applied load. The "corrected load" is, therefore, the ratio of the Hertzian diameter and the actual scar diameter times the load applied to obtain that diameter. The Hertzian diameter is the contact area of the spherical surfaces or the static indentation caused by deformation of the balls under load at the start of the test. It may be calculated from the formula:

DH = 0.0873 times the cube root of P
P = Applied Kilogram load

Therefore, corrected load = $\frac{LDH}{x}$

L = Load
DH = Hertzian diameter
x = Average scar diameter

and Extreme Pressure Value = $\frac{\text{Sum of the corrected loads}}{\text{Number of progressive runs}}$

c. 2-1/2 Second Seizure Delay is that point at which the applied load is sufficient to cause seizure to occur 2-1/2 seconds after the start of a run. Points of seizure are automatically recorded on the sensitized graph paper by the machine. They are recognizable by the rapid rise in the curve, and the points at which they occur can be read in seconds from the scale on the chart. If the applied load in kilograms is plotted against the seconds seizure delay on ordinary graph paper, a smooth curve should be obtained. From this curve the load at 2-1/2 seconds can be read.

d. The Percent Ideal E.P. is the ratio of the experimental E.P. value to the E.P. value of the perfect lubricant. The latter would be the calculated E.P. value, assuming the actual scar diameter and the Hertzian diameter to be equal; in which case, the applied load and the correct load would become the same, giving a value of 100 percent.

1% Ideal E.P. = $\frac{\text{Sum of the corrected loads}}{\text{Sum of the applied loads}}$

The sum of the ratings given the results of each of the four tests determines the rating for the Four Ball part of the system of rating.

Weld

Experimental Results	Weld Rating
200 kg or above	2
178	5-1/2
177 to 141	9
126	12-1/2
112	15-1/2

E.P.

Experimental Results	E.P. Rating
30 or above	1-1/2
29 to 26	4
25	6
24 to 23	7-1/2
22	9
21	11-1/2
20	14-1/2
19 or lower	16

2-1/2" S.D.

Experimental Results	2-1/2" S.D. Rating
80 kg or above	1
79 to 68	2
67 to 62	3
61 to 60	4
59 to 55	5
54 to 47	6
46 to 43	7
42 to 40	8-1/2
39	10-1/2
38 to 35	12
34 to 31	13
30 to 28	14
27 to 26	15
25 or less	16

% Ideal E.P.

Experimental Results	% Ideal E.P. Rating
50 or above	1
49.9 to 48.1	2
48.0 to 47.8	3
47.7 to 45.7	4
45.6 to 45.2	5
45.1 to 44.2	6
44.1 to 40.5	7
40.4 to 39.4	8
39.3 to 38.5	9-1/2
38.4 to 35.1	11-1/2
35.0 to 34.8	13
34.7 or under	14
	15
	16

Sum of Ratings[1/]	Machine Rating
14.0 or under	1
14.1 to 17.0	2
17.1 to 23.0	3
23.1 to 24.0	4
24.1 to 26.0	5
26.1 to 29.0	6
29.1 to 29.5	7
29.6 to 36.0	8
36.1 to 36.5	9
36.6 to 37.5	10
37.6 to 43.0	11-1/2
43.1 to 45.0	13-1/2
45.1 to 46.5	15
46.6 or over	16

1/ Represents the summation of the four individual ratings.

8. Water Resistance: This test is a method for determining the water washout characteristics of lubricating greases from a bearing under prescribed laboratory conditions. A blank run is made by packing a fixed amount of grease in a tared ball bearing and rotating at 600 rpm without water and at room temperature. After one hour the loss in weight of the bearing and grease is measured. The test is repeated with water controlled at 150°F impinging on the bearing plate at the rate of 5 milliliters per second. After one hour the bearing is removed and dried in an oven and the weight loss again measured. The loss due to the action of water is the numerical difference between the test conducted using water and the test conducted without water (blank).

Experimental Results for Blank 1/	Blank Rating
27.8 2/ or under	1-1/2
27.9 to 29.9	3
30.0 to 37.2	4
37.3 to 38.3	5
38.4 to 39.0	6
39.1 to 39.3	7
39.4 to 42.5	8
42.6 to 43.9	9
44.0	10
44.1 to 44.5	11
44.6 to 44.9	12
45.0 to 45.3	13
45.4 to 61.5	14
61.6 to 63.6	15
63.6 or over	16

1/ Blank is conducted by rotating the bearing containing grease sample without water.

2/ Percentage loss of grease from bearing.

% Water Loss 3/ (Due to Action of Water)	% Loss Rating (Due to Action of Water)
0	3
0.1 to 4.9	6
5.0 to 5.5	7
5.6 to 9.6	8
9.7 to 16.2	9
16.3 to 16.5	10
16.6 to 17.9	11
18.0 to 18.9	12
19.0 to 20.7	13
20.8 to 43.5	14
43.6 to 56.0	15
56.1 or over	16

3/ Represents the numerical difference between the test conducted using water and the test conducted without water (blank). (When the blank reading is the greater of the two readings, the percent less due to water is assumed to be 0. Since the figure 0 percent means that the grease is 100 percent insoluble, it represents the best possible condition attainable.)

Sum of Ratings[4/]	Machine Rating
9.0 or less	1
9.1 to 10.5	2
10.6 to 11.0	3
11.1 to 12.0	4
12.1 to 13.0	5
13.1 to 13.5	6
13.6 to 17.0	7-1/2
17.1 to 18.0	9
18.1 to 19.0	11
19.1 to 20.0	13
20.1 to 24.0	14
24.1 or more	16

4/ The summation of the blank rating and percent loss rating.

9. Norma Hoffman Oxidation Test: This test is a method for determining the resistance of lubricating grease to oxidation under static conditions. It is conducted in an oxygen bomb--ASTM D-942--equipped with a pressure gauge. Each of five dishes in the bomb is filled with four grams of grease. The bomb is charged with 100 pounds per square inch of oxygen and after a 24-hour leakproof test is placed in an oil bath controlled at 210°F, adjusting the pressure to 110 pounds per square inch. Results are reported as pounds per square inch gauge pressure drop after 100 hours. Longer tests are sometimes desirable.

Experimental Results	Machine Rating
2.3[1/] or less	1
2.4 to 4.0	2
4.1 to 4.3	3-1/2
4.4 to 5.0	5
5.1 to 6.0	6
6.1 to 6.3	7
6.4 to 6.7	8
6.8 to 7.1	9
7.2 to 7.3	10
7.4 to 8.0	11
8.1 to 10.0	12

1/ Pounds pressure drop at 210°F in 100 hours must not exceed 10 pounds.

10. High Temperature Beater Test: This test is to evaluate the change from drum consistency to residual consistency through solvent loss, oxidation and deterioration of fiber structure of the grease. The consistency of a 1-pound sample of grease is measured by means of the penetrometer. A ball bearing is packed with a portion of the sample and is placed in an operating chamber constructed in such a manner that the outer race of the bearing is held stationary while the inner race is left free to rotate. The remainder of the sample is placed in the chamber over the bearing. The bearing is rotated by means of a shaft secured to the inner race and attached to a drill press. Provisions are made for controlling the temperature of the grease in the chamber. The test is conducted at 4,775 rpm for 6 hours with the temperature being controlled at 320°F.

The condition of the grease is noted and recorded after three hours of the test has been completed. The condition is recorded as one of the following consistency states:

a. Softens but retains grease consistency.
b. Softens to semiliquid state.
c. Almost liquid.
d. Entirely liquid.

A rating is given for the state of the grease at this point.

After the test has been completed and the grease cooled to 77°F, the condition is again noted and recorded. The consistency at this time is again measured by means of the penetrometer. The grease is given a second rating according to the difference between the initial and final measurements as well as the appearance.

The condition of the grease at the end of six hours may fall into one of the following categories:

1. Slight hardening or softening (0-50 points on the penetrometer).
2. Intermediate hardening or softening (51-100 points).
3. Excessive hardening or softening (100 points or over).

Other conditions of the grease such as grease becomes spongy, excessive separation of oil from soap, or forming hard crust on the bearing and components of the operating chamber are taken into consideration in rating the grease at the end of the test.

A. Condition of Grease During Test

Experimental Results	Machine Rating
Retains normal grease consistency	3-1/2
Semiliquid	8
Almost liquid	11
Thinned to liquid	15

B. Condition of Grease After Test 1/

Experimental Results 2/	Machine Rating
Slight hardening or softening of test sample (0-50 points 3/)	3
Intermediate hardening or softening of sample (50-100 points)	7-1/2
Excessive hardening or softening of sample (100 points or over)	13

1/ Results recorded after sample has cooled to room temperature (77-80 F).

2/ In the event that any grease hardens to such an extent that it becomes rubbery or gummy, then it will not pass this test.

3/ Measured by the standard ASTM penetrometer. (Difference in penetrometer readings taken before and after test.)

Attachment to NCR WBNNEB8401

Westinghouse Tag Number	TVA ID Number	Function
1,2-PT-405	1,2-PT-68-68	Wide range RCS pressure
1,2-PT-406	1,2-PT-68-69	Wide range RCS pressure
1,2-PT-455	1,2-PT-68-340	Pressurizer pressure
1,2-PT-456	1,2-PT-68-334	Pressurizer pressure
1,2-PT-457	1,2-PT-68-323	Pressurizer pressure
1,2-PT-458	1,2-PT-68-322	Pressurizer pressure
1,2-LT-459	1,2-LT-68-339	Pressurizer level
1,2-LT-460	1,2-LT-68-335	Pressurizer level
1,2-LT-461	1,2-LT-68-320	Pressurizer level
1,2-LT-501	1,2-LT-3-43	Wide range SG level
1,2-LT-502	1,2-LT-3-56	Wide range SG level
1,2-LT-503	1,2-LT-3-98	Wide range SG level
1,2-LT-504	1,2-LT-3-111	Wide range SG level
1,2-LT-517	1,2-LT-3-42	Narrow range SG level
1,2-LT-518	1,2-LT-3-39	Narrow range SG level
1,2-LT-519	1,2-LT-3-38	Narrow range SG level
1,2-LT-527	1,2-LT-3-55	Narrow range SG level
1,2-LT-528	1,2-LT-3-52	Narrow range SG level
1,2-LT-529	1,2-LT-3-51	Narrow range SG level
1,2-LT-537	1,2-LT-3-97	Narrow range SG level
1,2-LT-538	1,2-LT-3-94	Narrow range SG level
1,2-LT-539	1,2-LT-3-93	Narrow range SG level
1,2-LT-547	1,2-LT-3-110	Narrow range SG level
1,2-LT-548	1,2-LT-3-107	Narrow range SG level
1,2-LT-549	1,2-LT-3-106	Narrow range SG level
1,2-FT-512	1,2-FT-1-3A	Steam flow
1,2-FT-513	1,2-FT-1-3B	Steam flow
1,2-FT-522	1,2-FT-1-10A	Steam flow
1,2-FT-523	1,2-FT-1-10B	Steam flow
1,2-FT-532	1,2-FT-1-21A	Steam flow
1,2-FT-533	1,2-FT-1-21B	Steam flow
1,2-FT-542	1,2-FT-1-28A	Steam flow
1,2-FT-543	1,2-FT-1-28B	Steam flow
1,2-PT-524	1,2-PT-1-9A	Steam pressure
1,2-PT-525	1,2-PT-1-9B	Steam pressure
1,2-PT-526	1,2-PT-1-12	Steam pressure
1,2-PT-534	1,2-PT-1-20A	Steam pressure
1,2-PT-535	1,2-PT-1-20B	Steam pressure
1,2-PT-536	1,2-PT-1-23	Steam pressure
1,2-LT-920	1,2-LT-63-180	Containment sump level
1,2-LT-921	1,2-LT-63-181	Containment sump level
1,2-LT-940	1,2-LT-63-182	Containment sump level
1,2-LT-941	1,2-LT-63-183	Containment sump level