Explosives and Pyrotechnic Propellants for Use in Long-Term Deep Space Missions

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Theme

FUTURE long-term deep space missions, such as the exploration of the outer planets, necessitate the spacecraft being exposed to deep space environments for periods of up to 10 yr. The explosive and propellant actuated devices on board used to perform mechanical functions must survive these exposures and exhibit a predictable performance. More specifically, the chemical components (i.e. the explosive and pyrotechnic propellant materials) in the devices must maintain their initial characteristics throughout the mission.

Under relatively high sterilization temperatures (e.g. two 64-hr cycles at 125°C) and on prolonged exposure to an outer space environment (e.g. 10 yr at 66°C under 10^{-6} torr) these chemical components could experience several physical changes.

To determine the survivability of materials to be used in long-term deep space missions, each item must be tested. Since heat sterilization is accomplished in a few days, laboratory tests duplicating the sterilization requirements may easily be performed.[1-6] However, since real-time aging and either performance testing of the devices or analytical (chemical) testing of the components to determine their survivability and reliability after several years' aging is not practicable, an accelerated aging technique must be used.

An accelerated aging procedure can only be meaningful when the critical degradation process occurring at the elevated test temperature is truly the same process which occurs at the actual storage temperature. The relationship between the rate of a degradation process and temperature may not be a single linear relationship but instead be two or even more linear relationships. It is, therefore, extremely important that the temperature chosen for the accelerated aging tests be within the temperature range applicable to the chemical reaction occurring in real-time aging.

Basically, the processes involved in aging can be described in terms of solid state kinetics, so it is possible to deduce a meaningful and correct aging from data on the parameters relating to the physicochemical properties of the materials such as thermal decomposition kinetics, sublimation kinetics, phase change characteristics, change of state phenomena, etc. These decomposition and sublimation kinetics, when available, can be used to predict material losses up to a 10-yr period under deep space environment exposures. When these kinetic data are not available, an analytical approach to determine these parameters can be used. Since explosive and propellant materials stored for years in a vacuum at some elevated temperature will experience degradation through sublimation and/or thermal decomposition, two parameters of major interest are the rates of these two processes.

By using data available in the literature and analytical expressions on explosive and pyrotechnic propellant materials, a selection of candidate materials most likely to survive sterilization and long-term deep space aging can be made. In this study the explosive components of the electroexplosive devices used in NASA, Army, Navy, and Air Force systems were identified, and categorized into primary explosives, secondary explosives, and propellant ingredients, and then, along with some available but as yet unused explosives, evaluated for qualification as candidates. The qualification of a material as a candidate for long-term deep space missions has been based upon its ability to survive the conditions stated earlier.

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Table 1 Primary explosives surveyed

Common name	Acronym	Chemical formula	Melting point, °C	End application or principal use[a]
Lead styphnate		$PbC_6H_3N_3O_9$	exp.	IN, S, D
Barium styphnate		$BaC_6H_3N_3O_9$		IN, S, D
Lead 4, 6 dinitroresorcinol(basic)	LDNR	$Pb_2C_6H_4N_2O_8$	213	D
Lead mononitroresorcinol	LMNR	$PbC_6H_3NO_4$		IN, S, D
1, 3, 5 tripicrylbenzene	TPB	$C_{24}H_9N_9O_{18}$	386	D
Potassium 4, 6-dinitrobenzofuroxan	KDNBF	$KC_6H_4N_4O_6$	exp. 210	S
Diazodinitrophenol	DDNP	$C_6H_2N_4O_5$	157	S
Black powder		74% KNO_3 10.4% S 15.6% C		IN, S, IG
Lead azide		$Pb(N_3)_2$	exp.	IN, D
Copper azide		$Cu(N_3)_2$	exp. 202	IN, IG

[a] IN = Initiator; IG = Igniter; S = Squib; D = Detonator.

Table 2 Secondary explosives surveyed

Common name	Acronym	Chemical formula	Melting point °C	End application or principal use[a]
Azobis (2, 2′, 4, 4′, 6, 6′ hexanitrobiphenyl)		$C_{24}H_6N_{14}O_{24}$	>485	NA
Ammonium picrate	Expl D	$C_6H_6N_4O_7$	d. 265	
3, 3′ bis (methylnitramino) -2, 2′, 4, 4′, 6, 6′-hexanitrobiphenyl	Bitetryl	$C_{14}H_8N_{10}O_{16}$	218	
1, 3 diamino -2, 4, 6, trinitrobenzene	DATB	$C_6H_5N_5O_6$	290	
3, 3′ diamino -2, 2′, 4, 4′, 6, 6′ hexanitrobiphenyl	DIPAM	$C_{12}H_6N_8O_{12}$	304	MDF
1, 3 bis (2, 4, 6 trinitrophenylamino) -2, 4, 6-trinitrobenzene	Dipicryl DATB	$C_{18}H_7N_{11}O_{18}$	335	
N, N dipicrylpyromellitimide	DIPPI	$C_{22}H_6N_8O_{16}$	d. 370	
Dodecanitroquaterphenyl		$C_{24}H_6N_{12}O_{24}$	>400	NA
2, 2′, 4, 4′, 6, 6′ hexanitrodiphenylamine	Hexite	$C_{12}H_5N_7O_{12}$	243	
Cyclotetramethylenetetranitramine	HMX	$C_4H_8N_8O_8$	276	D
2, 2′, 4, 4′, 6, 6′ hexanitroazobenzene	HNAB	$C_{12}H_4N_8O_{12}$	221	
2, 2′, 4, 4′, 6, 6′ hexanitrobiphenyl	HNB	$C_{12}H_4N_6O_{12}$	241	NA
2, 2′, 4, 4′, 6, 6′ hexanitrodiphenylsulfone	HNDS	$C_{12}H_4N_6O_{14}S$	d. 345	
2, 2′, 4, 4′, 6, 6′ hexanitrooxanilide	HNO	$C_{14}H_6N_8O_{14}$	d. 302	
2, 2′, 4, 4′, 6, 6′ hexanitrostilbene	HNS	$C_{14}H_6N_6O_{12}$	316	MDF
Potassium hexanitrodiphenylamine		$C_{12}H_5N_7O_{12}K$		NA
Nitrocellulose		$C_6H_9O_4(ONO_2)$	d.	Propellant
Nitroglycerine		$C_3H_5N_3O_9$	13.2	Propellant
Nitroguanidine	NG	$CH_4N_4O_2$		
2, 2′, 2″, 4, 4′, 4″, 6, 6′ 6″ nonanitroterphenyl		$C_{18}H_5N_9O_{18}$	440	
2, 2′, 4, 4′, 4″, 6, 6′, 6″ octanitro-m-terphenyl		$C_{18}H_6N_8O_{16}$	>400	
2, 2′, 4, 4′, 6-pentanitrobenzophenone		$C_{13}H_5N_5O_{11}$	320	NA
Pentaerithrytol tetranitrate	PETN	$C_5H_8N_4O_{12}$	141	
Cyclotrimethylenetrinitramine	RDX	$C_3H_6N_6O_6$	204	MDF, D
Tetranitradibenzo- 1, 3a, 4, 6a tetraazapentalene	TACOT	$C_{12}H_4N_8O_8$	378	MDF, D
1, 3, 5 triamino-2, 4, 6 trinitrobenzene	TATB	$C_6H_6N_6O_6$	330	
2, 4, 6 trinitroaniline	TNA	$C_6H_4N_4O_6$	190	
Tetranitrocarbazole	TNC	$C_{12}H_5N_5O_8$	296	
1, 4, 5, 8 tetranitronaphthalene		$C_{12}H_4N_4O_8$	>400	
2, 2′, 4, 4′ tetranitrooaxnilide	TNO	$C_{14}H_8N_6O_{10}$	d. 313	
2, 4, 6 tripicryl-s-triazine		$C_{21}H_6N_{12}O_{18}$	352	NA
1, 3, 5-tris (methylnitramino)-2, 4, 6-trinitrobenzene	Tristetryl	$C_9H_9N_9O_{12}$	exp. 205	

[a] MDF = Mild detonating fuse; D = Detonator; IG = Igniter; NA = Not available.

Table 3 Pyrotechnic propellant ingredients surveyed

Common name	Chemical formula	Melting point °C	End application or principal use[a]
Aluminum	Al	660	S, IG, GG
Ammonium dichromate	$(NH_4)_2Cr_2O_7$	d. 170	IN, IG
Ammonium perchlorate	NH_4ClO_4	d. 300	IN, S, IG
Barium chromate	$BaCrO_4$		IN, S, IG
Barium nitrate	$Ba(NO_3)_2$	592	IN, S, IG
Barium peroxide	BaO_2	450	IN, IG
Boron	B	2300	S, IG, GG
Carbon	C	3500	IN, S
Cupric oxide	CuO	1326	IN, S
Diatomaceous Earth	84%–92% SiO_2	1600	S
Ferric oxide	Fe_2O_3	1565	IN
Lead chromate	$PbCrO_4$	844	IG
Lead peroxide	PbO_4	d. 290	IN
Lead thiocyanate	$Pb(SCN)_2$	d. 190	S, IG
Magnesium	Mg.	651	IG
Molybdenum trioxide	MoO_3	795	IG
Nickel	Ni	1455	IN, S
Potassium chlorate	$KClO_3$	356	S, IG
Potassium perchlorate	$KClO_4$	610	IN, S, IG, GG
Potassium nitrate	KNO_3	338	S, IG, GG
Silicon dioxide	SiO_2	1713	IN
Teflon	$[C_2F_4]_n$	d. 250	IG
Titanium	Ti	1725	IG
Titanium hydride	TiH_2	d. 400	IN, GG
Tungsten	W	3410	IG
Viton A		d. 200	IN, IG, GG
Viton B		d. 200	IN, IG, GG
Zirconium	Zr	1857	IN, S, IG

[a] IN = Initiator; IG = Igniter; S = Squib; D = Detonator; GG = Gas generator.

Contents

Explosives and pyrotechnic propellant materials which will withstand heat sterilization cycling and 10-yr deep space aging, have been selected by means of a detailed literature survey, 110 reports, and an analytical evaluation of the physicochemical properties of the materials. The chemical components of the electroexplosive devices used in U.S. missiles and spacecraft were categorized into primary explosives, secondary explosives, and propellant ingredients (Tables 1–3). Kinetic data on parameters such as thermal decomposition and sublimation were obtained for these materials and used as a basis for the 10-yr life prediction.

Table 4 Qualified candidates

Secondary explosives	Pyrotechnic propellant ingredients		
	Inorganic	Metal	Organic
Diaminohexanitrobiphenyl (DIPAM)	Ammonium perchlorate	Aluminum	Teflon
Cyclotetramethylenetetra-nitramine (HMX)	Barium chromate	Boron	Viton A
Hexanitrostilbene (HNS)	Barium nitrate	Magnesium	Viton B
Tetranitrodibenzotetraaza-pentalene (TACOT)	Barium peroxide	Titanium	
Nonanitroterphenyl	Carbon	Tungsten	
Octanitroterphenyl	Cupric oxide	Zirconium	
Triaminotrinitrobenzene (TATB)	Diatomaceous Earth	Zirconium/Nickel Alloy	
Diaminotrinitrobenzene (DATB)	Ferric oxide		
	Lead chromate		
	Lead peroxide		
	Molybdenum trioxide		
	Potassium chlorate		
	Potassium perchlorate		
	Potassium nitrate		
	Silicon dioxide		
	Titanium hydride		

Table 5 Conditionally qualified candidates[a]

Primary explosives	Secondary explosives
Barium styphnate	Azobishexanitrobiphenyl
Lead dinitroresorcinol, basic (LDNR, basic)	Ammonium picrate (Explosive D)
Lead mononitroresorcinol (LMNR)	Bis(methylnitramino)hexanitrobiphenyl (Bitetryl)
Lead styphnate	Bis(trinitrophenylamino)trinitrobenzene (Dipicryl DATB)
1, 3, 5 tripicrylbenzene (TPB)	Dipicrylpyromellitimide (DIPPI)
Potassium 4, 6 dinitrobenzofuroxan (KDNBF)	Dodecanitroquaterphenyl
	Hexanitroazabenzene (HNAB)
	Hexanitrobiphenyl (HNB)
	Hexanitrodiphenylamine (Hexite)
	Hexanitrodiphenylsulfone (HNDS)
	Hexanitrooxanilide (HNO)
	Potassium hexanitrodiphenylamine
	Nitroguanidine (NG)
	Pentanitrobenzo phenone
	Tetranitronaphthalene
	Tetranitrocarbazole (TNC)
	Tetranitrooxanilide (TNO)
	Tripicryl-s-triazine
	Tris (methylnitramino) trinitrobenzene (Tristetryl)

[a] Indeterminate without further data or testing.

Many explosive and pyrotechnic propellant materials are available which appear to be capable of surviving heat sterilization and 10-yr deep space flight times without deterioration. When data on the parameters relating to the physicochemical properties of these materials such as thermal decomposition kinetics, sublimation kinetics, change of state phenomena, etc. are available, the chemical and thermal stability of these materials under the specified environments have been determined. Unfortunately, data of this type are available for only a small number of explosive materials and therefore only a few secondary explosives and propellant ingredients can be definitely qualified as candidate materials (Table 4) capable of withstanding the specified environments. The limited amount of relevant data that are available on a larger number of primary and secondary explosives is sufficient to qualify these materials conditionally (Table 5). Further data and/or testing are required for definite qualification.

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