| AD NUMBER |
| --- |
| AD334110 |
| CLASSIFICATION CHANGES |
| TO: unclassified |
| FROM: confidential |
| LIMITATION CHANGES |
| TO:<br>Approved for public release, distribution unlimited |
| FROM:<br>Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 16 NOV 1962. Other requests shall be referred to Naval Propellant Plant, Indian Head, MD. |
| AUTHORITY |
| NOL ltr dtd 3 Apr 1975; NOL ltr dtd 3 Apr 1975 |

# APPLICATION OF A RADIO-TRACER METHOD TO THE DECOMPOSITION MECHANISM OF POLYURETHANE PROPELLANT SYSTEMS (U)

U.S. NAVAL PROPELLANT PLANT INDIAN HEAD MARYLAND

*Published by the*
*Technical Information Department*
*(102/62/548)*

CONFIDENTIAL

RESEARCH AND DEVELOPMENT DEPARTMENT

NavWeps Report 8021
Technical Report 121

16 November 1962

# APPLICATION OF A RADIO-TRACER METHOD TO THE DECOMPOSITION MECHANISM OF POLYURETHANE PROPELLANT SYSTEMS(U)

By

P. E. Wilkniss
D. Levine

U. S. NAVAL PROPELLANT PLANT
Indian Head, Maryland

O. A. WESCHE
Captain, USNavy
Commanding Officer

JOE L. BROWNING
Technical Director

CONFIDENTIAL

## FOREWORD

The Naval Propellant Plant has been conducting research investigations for the past several years to improve methods of predicting the useful life of solid propellants. The experiments described in this report indicate that the radioactive tracer technique provides a convenient tool for following the degradation of polyurethane propellants. The data are as of 1 October 1962 and are subject to modification or withdrawal.

The names of manufacturers are given to identify types of material and equipment and do not constitute an endorsement of the products.

F. E. Brinckman
Head, Analytical
Chemistry Division

Approved by:

Bodo Bartocha
Associate Director
for Research

Released by:

J. E. Wilson
Director, Research and
Development Department

## CONTENTS



## FIGURES

Abstract Confidential

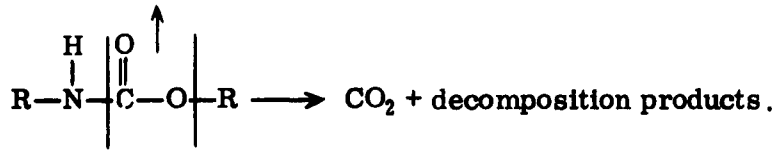
ABSTRACT

A new technique employing radio-tracer $C^{14}$ has been used for following the thermal degradation of a polyurethane propellant. The described tracer method is thought to be an effective tool to investigate the influence of such parameters as moisture, pressure, other ingredients of the propellant, etc., on the rate of carbon dioxide evolution and, therefore, the rate of binder breakdown. Extrapolation of the data obtained indicates that the half life of the propellant is 6.7 years.

# APPLICATION OF A RADIO-TRACER METHOD TO THE DECOMPOSITION MECHANISM OF POLYURETHANE PROPELLANT SYSTEMS(U)

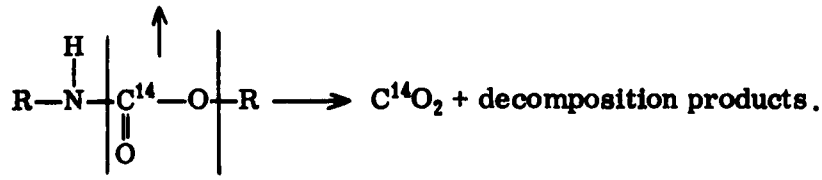
Several techniques have been employed for following the decomposition of polyurethane propellants in order to predict their safe, useful lives. Among the techniques used are stress relaxation measurements,[1,2] swelling measurements,[1] nuclear magnetic resonance measurements,[3] and extraction procedures.[4,5]

One paper[6] reports the evolution of gases consisting chiefly of carbon dioxide and hydrogen during thermal decomposition of a polyurethane propellant. It is believed that the urethane linkage of the propellant binder is one source for the $CO_2$ being evolved, according to




The purpose of the work described in this paper is (1) to determine unequivocally whether or not the urethane linkage is mechanistically involved in storage decomposition of this selected propellant, and (2) to evaluate a sensitive method for determining the rates of such decomposition. Furthermore, it was planned to investigate the rate of $CO_2$ evolution which is a measure of the rate of decomposition of urethane linkages; and therefore, also, a measure of decomposition of the propellant binder.

The approach in this problem involves using a radio-tracer method; i.e., labeling the carbon atom of the urethane linkage with radioactive $C^{14}$,




It is obvious that if the urethane linkage breaks, $C^{14}O_2$ should be evolved which can be easily detected by its radioactivity. This, in turn, is a demonstration for the decomposition of the urethane linkage.

As an example of a polyurethane propellant, the formulation of the Aerojet-General Polaris urethane propellant (ANP 2639 AF) was used. The basic ingredients of this propellant are ammonium perchlorate, 60%; aluminum, 15%; and a polyurethane binder, 24%.

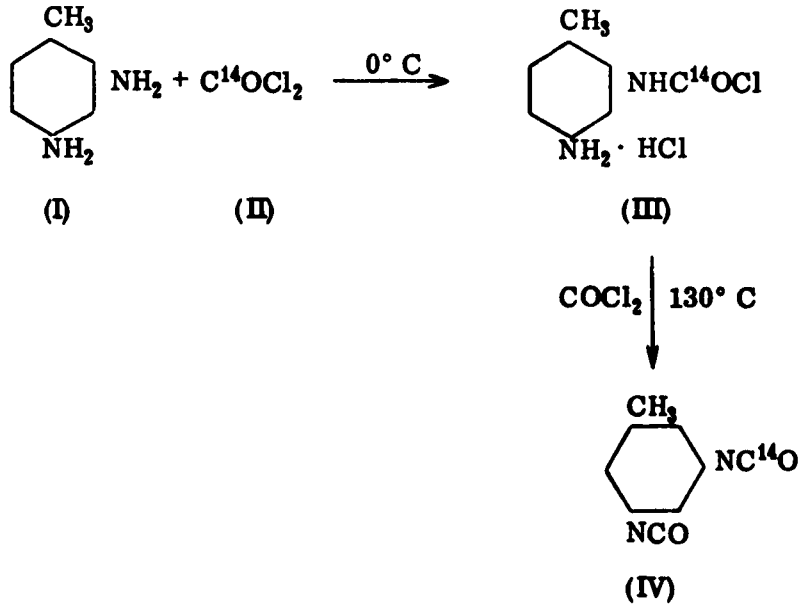
The binder itself consists of a three-dimensional network, made up of a 2,4-toluenediisocyanate (TDI)-polypropylene glycol (PPG) chain, crosslinked with monohydroxyethyl-tris-hydroxypropyl N,N,N',N'-ethylenediamine (MTDA).

The results obtained by employing this propellant system to study the decomposition of its urethane binder linkage by the radio-tracer method are described in the following sections.

## EXPERIMENTAL

### Preparation of Toluenediisocyanate Labeled with $C^{14}$

In order to prepare a propellant which is labeled with $C^{14}$ at the urethane linkage of its binder, TDI labeled in one or both of its isocyanate groups is needed. Because it appears very difficult to label both isocyanate groups in a well defined way, TDI labeled in only one isocyanate group was prepared. The method reported by Siefken[7] for the preparation of isocyanates in general was employed. This method and the apparatus used were modified to meet the special requirements in synthesizing the desired labeled compound. The preparation of the labeled TDI is a two-step reaction as follows:



Toluenediamine (TDA, I) dissolved in methylene chloride is reacted at 0° C with labeled phosgene[1] which is also dissolved in methylene chloride. The intermediate compound (III) precipitates and is completely freed of methylene chloride and excess phosgene by evacuation.

In the second reaction step, compound III is suspended in high-boiling Aroclor 1248[2] and is reacted with unlabeled phosgene at 130° C until a clear solution is obtained. Finally, the labeled TDI is recovered from this solution by vacuum distillation. The apparatus shown in Figure 1 was used in this procedure.

Two batches of radioactive TDI were prepared by the following procedure:

For batch no. 1, 3.66 g of TDA (recrystallized from benzene) dissolved in 45 ml methylene chloride was reacted with 2.7 ml liquid phosgene carrier plus 0.1 millicurie of $C^{14}$-phosgene (specific activity 1.52 millicuries per millimol) dissolved in 15 ml methylene chloride. The intermediate salt precipitate was freed from phosgene and methylene chloride, suspended in Aroclor, and reacted with phosgene gas until a clear solution was obtained. The TDI was recovered by vacuum distillation and analyzed for purity by reacting a sample with di-n-butylamine, and titrating the excess amine with hydrochloric acid.[(8)]

Batch no. 2 was prepared in the same way as batch no. 1 except 0.5 millicurie (specific activity 1.52 millicuries per millimol) radioactive phosgene was used.

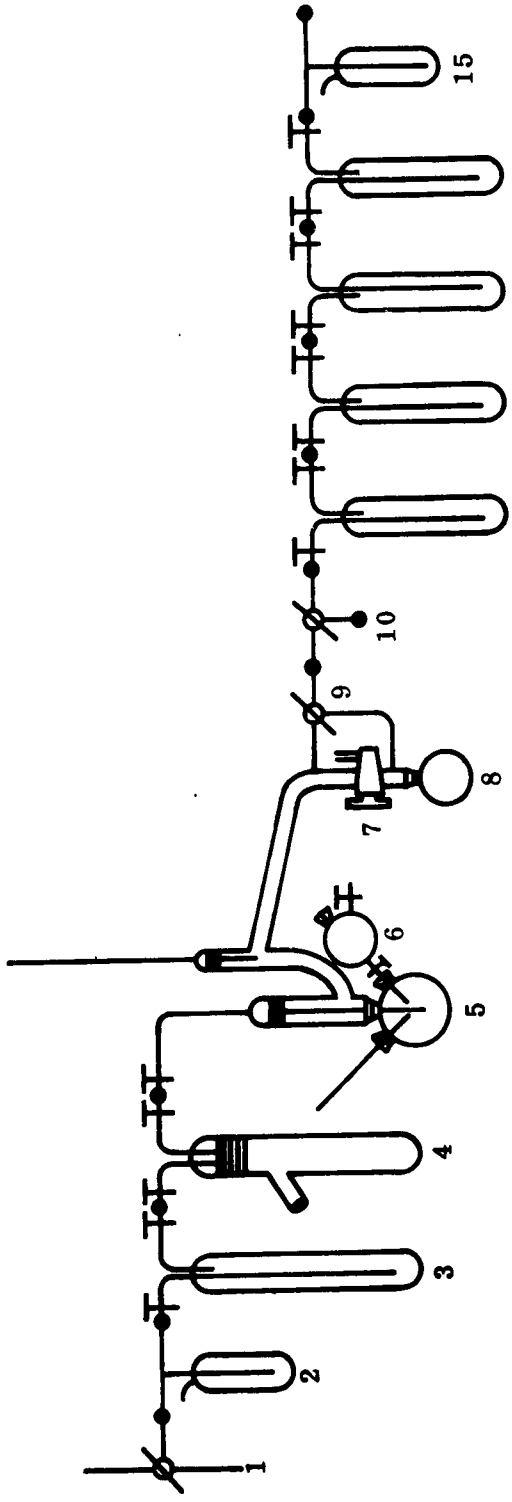
Data of batch no. 1 and batch no. 2 are given below:

| | Batch no. 1 | Batch no. 2 |
|---|---|---|
| Yield: | 3.0 g TDI (57% of the theory) | 3.0 g TDI (57% of the theory) |
| Boiling point: | 90° C/2 mm Hg | 90° C/2 mm Hg |
| Melting point: | 21.3° - 21.6° C | 20.8° - 21.3° C |
| Purity: | 94.7% | 97.8% (after two distillations) |
| Specific activity: | 14.8 microcuries/gram TDI | 51.0 microcuries/gram TDI |
| Total activity: | 44.4 microcuries (44% of applied amount) | 153 microcuries (30% of applied amount) |

In order to obtain a purer product, 4 ml of inactive TDI (purity 99%) was added to the 3 g of labeled TDI (Batch no. 2) and the mixture distilled again. Results were as follows:

| | |
|---|---|
| Yield: | 5.74 g TDI |
| Boiling point: | 90° C/2 mm Hg |
| Melting point: | 20.8° - 21.5° C |
| Purity: | 98.6% |
| Specific activity: | 21.0 microcuries/gram |

[1]Obtained from Nichem Company.
[2]Obtained from Monsanto Chemical Company.



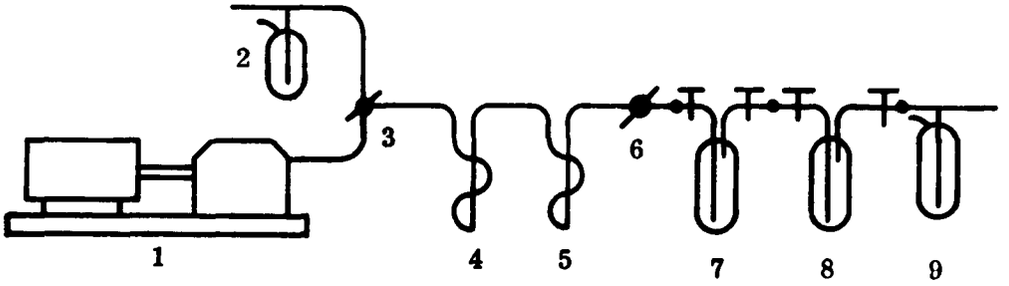

1. Three-way stopcock to admit either phosgene or nitrogen gas.
2. Stock valve.
3. Trap to condense unlabeled phosgene gas as a carrier.
4. Trap to open ampoule containing labeled phosgene (by means of steel ball and magnet) and to add non-radioactive phosgene carrier.
5. Pyrex flask (50-ml) in which a solution of phosgene in methylene chloride is prepared and reacted with TDI solution in methylene chloride admitted through dropping funnel (6).
6. Dropping funnel.
7. Two-way stopcock.
8. Receiving flask.
9. Three-way stopcock.
10. Three-way stopcock to attach several aniline water traps to react $C^{14}$ phosgene and convert it to diphenylurea.
11-14. Cooling traps to retain excess phosgene and methylene chloride evaporated from (5).
15. Stock valve.

FIGURE 1. APPARATUS FOR PREPARATION OF LABELED TOLUENE DIISOCYANATE

Specific activity of the TDI was determined in two ways. One was by preparing very thin counting samples of solid material obtained by reacting TDI with di-n-butylamine and evaporating the solvent. The other was by reacting TDI with $Ba(OH)_2$ solution and counting the resulting $BaCO_3$ in an "infinitely thick" layer. In both cases adequate samples of standardized $BaC^{14}O_3$ were used as standards. The results for the specific activity of TDI were in agreement within 20%.

## Mixing and Curing of Labeled Propellant

The Aerojet-General Polaris urethane propellant formulation ANP 2639 AF was used. The apparatus used for mixing the radioactive propellant is shown in Figure 2. The entire propellant mixing procedure was carried out under a pressure of 10 mm Hg. When material had to be added the mixer was flushed with prepurified nitrogen. Gases evolved on mixing, including $C^{14}O_2$, were caught in the cooling traps (liquid nitrogen) of the apparatus. All ingredients used were carefully dried. The operation was started by mixing a premix of PPG, MDTA, and lecithin for 10 minutes. Coarse and fine ammonium perchlorate (blended together) was added in three equal portions, the mixing time after each addition being 10 minutes. In the next step, a premix of aluminum, carbon black, copper chromite, and phenyl beta-naphthylamine was added in two equal portions; mixing time again was 10 minutes after introducing each portion. The TDI (labeled diluted with unlabeled) together with ferric acetyl acetonate were added; the total batch was mixed for 25 minutes. The mixture was cast in an aluminum cylinder and cured for 4 days at 43° C. Two batches of labeled propellant weighing 250 g each were prepared.




1. ARC-35-Z-blade mixer
2. Stock valve
3. Three-way stopcock
4-5. Cooling traps
6. Three-way stopcock
7-8. $Ba(OH)_2$ traps
9. Stock valve

**FIGURE 2. APPARATUS FOR MIXING OF LABELED PROPELLANT**

In the first batch, an activity of 44 microcuries of TDI was incorporated. During curing the temperature went out of control, up to at least 130° C. This is thought to be the reason the propellant did not cure completely. Therefore, this batch was used only for a qualitative study.

In the second batch, 34 microcuries of labeled TDI was included. After 4 days of curing, a good rubbery propellant was obtained.

## Counting of $C^{14}O_2$ Evolved from Propellant

Radioactive carbon dioxide was expected to be evolved on mixing (because of traces of moisture causing hydrolysis of the TDI) and on storage of the propellant as a result of decomposition of the urethane linkages.

### $C^{14}O_2$ Evolved on Mixing:

The $CO_2$ evolved on mixing was condensed with liquid nitrogen, reacted with $Ba(OH)_2$ solution to form $BaCO_3$, and finally the $BaCO_3$ counted with a Geiger-Mueller Counter after usual sample preparation (as an "infinitely thick" $BaCO_3$ layer).

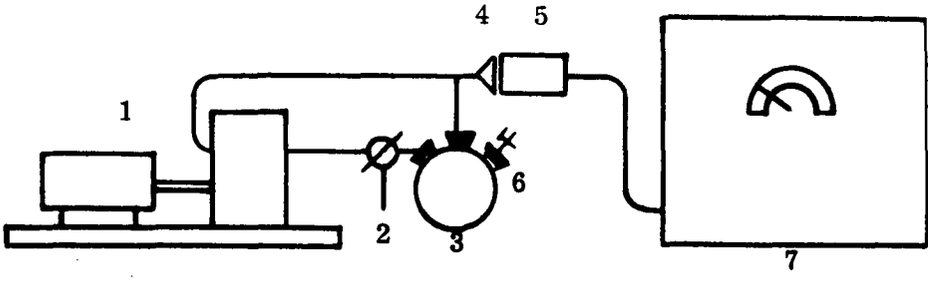
### $C^{14}O_2$ Evolved on Storage:

Continuously Working Counting System: The first approach was to use a continuously working counting system as shown in Figure 3 and similar to one described by Basolo.[9] The propellant sample is contained in flask 3. The gas over the propellant is circulated in a closed system by means of a pump (1). It passes a counting window (4) made of a very thin Mylar film, which allows the $C^{14}$ beta-radiation to penetrate into the Geiger-Mueller Counter (5) directly attached to the counting window. The counts are registered in the scaler (7). The stopcocks (2) and (6) serve to change the atmosphere in the closed system, if necessary.

The results obtained on testing this system showed that its counting efficiency is too low for the activities of the $CO_2$ evolved from the propellant sample. Therefore, a second technique of counting the activity was chosen.

Noncontinuous Counting System: This second method is based on a noncontinuous counting procedure. The propellant sample is stored in a 100-ml flask with an outlet closed by means of a three-way stopcock. Through this three-way stopcock, the flask containing the sample is first evacuated and then filled with inert gas containing a certain amount of inactive $CO_2$ (approximately 10 ml $CO_2$) which serves as carrier for the $CO_2$ evolved from the propellant

sample. In this way it is possible to sample even the very small amounts of $CO_2$ coming from the propellant because they mix with the added carrier.




1. Pump
2. Stopcock
3. Flask
4. Counting window
5. Geiger-Mueller counter
6. Stopcock
7. Scaler

FIGURE 3. COUNTING OF LABELED PROPELLANT

From time to time the storage flask is evacuated; all the $CO_2$ contained is trapped with liquid nitrogen and reacted with $Ba(OH)_2$ solution. The precipitated $BaCO_3$ is then prepared as usual for counting with a Geiger-Mueller Counter (as an "infinitely thick" layer). This method, as described, worked satisfactorily, the counting efficiency being high enough for the counted activities.

The activity of the $BaCO_3$ obtained from the samples was compared to standardized $BaC^{14}O_3$ for calculating the specific and absolute activity.

## RESULTS

### Qualitative Results

Evolution of $C^{14}O_2$ on Mixing:

The counting of the gases evolved on mixing after treating showed that the $BaCO_3$ obtained was radioactive. This indicates that TDI is decomposed on mixing. No quantitative investigation of this result has been done so far.

Evolution of $C^{14}O_2$ on Storage:

The $BaCO_3$ samples obtained from the propellant on storage were found to be radioactive. Because the carbon atom of the urethane linkage of the propellant is the only site labeled, this indicates that the urethane linkage is decomposed on storage of the propellant. It is therefore a source for the $CO_2$ evolved on storage as reported. (6)

Checking of Continuous Counting System:

The continuous counting system was checked with a specimen of the unsatisfactorily cured propellant (approximately 125 g of batch no. 1, containing 22 microcuries of $C^{14}$-labeled TDI). The entire propellant sample (a viscous slurry) was stored under air at 77° C. The results of this experiment are plotted in Figure 4. The counting rates obtained were rather low; and, because of this low counting efficiency, the system was not used for other experiments. Figure 4 also shows that evolution of $CO_2$ from the uncured propellant is rapid at the beginning, while it slows markedly to a steady rate after 3 days of storage.

## Quantitative Results

The noncontinuous counting procedure was used to investigate the $CO_2$ evolution rate from the radioactive propellant (batch no. 2).

The propellant (169.3 g), containing 23.1 microcuries of TDI was cut in rectangles (1/4 × 1/2 × 3/4 inch) and stored in three equal portions in 100-ml flasks. An inert atmosphere of 40 ml nitrogen and 10 ml carbon dioxide was used, thus maintaining a pressure of about 0.5 atm in the storage flasks. The storage temperature was maintained at 71° C. Figure 5 shows the results obtained.

As shown in Figure 5, the $CO_2$ evolution rate becomes steady at about the 50th day of storage. The flat point in the curve between the 33rd and 35th day is caused by a breakdown of the heating system. It was found that the heating system was not completely adjusted at the beginning, causing a temperature difference of 3° C between Samples 1 and 2 and a temperature difference of about 1° C between Samples 1 and 3. This is thought to be the cause of the different rates of $CO_2$ evolution among the three samples. The difference in the evolution rate disappeared after some time. From the 60th day on, the $CO_2$ is evolved at an activity rate of 0.75 count per minute per day per gram of propellant.

Further, the following calculations can be made: 34.2 microcuries of $C^{14}$ as labeled TDI was incorporated in the original 250-g propellant mix; 169.3 g of propellant, containing 23.1 microcuries of labeled TDI, was recovered for storage. Therefore, 1 gram of propellant contained 0.14 microcurie of $C^{14}$-TDI.

If the 75th day of storage is taken then there is an accumulated average (over all three samples) of 100 counts per minute per gram of propellant. This is a total activity of $4 \times 10^{-3}$ microcuries (converted from counts per minute to microcuries by means of $BaC^{14}O_3$ standard).

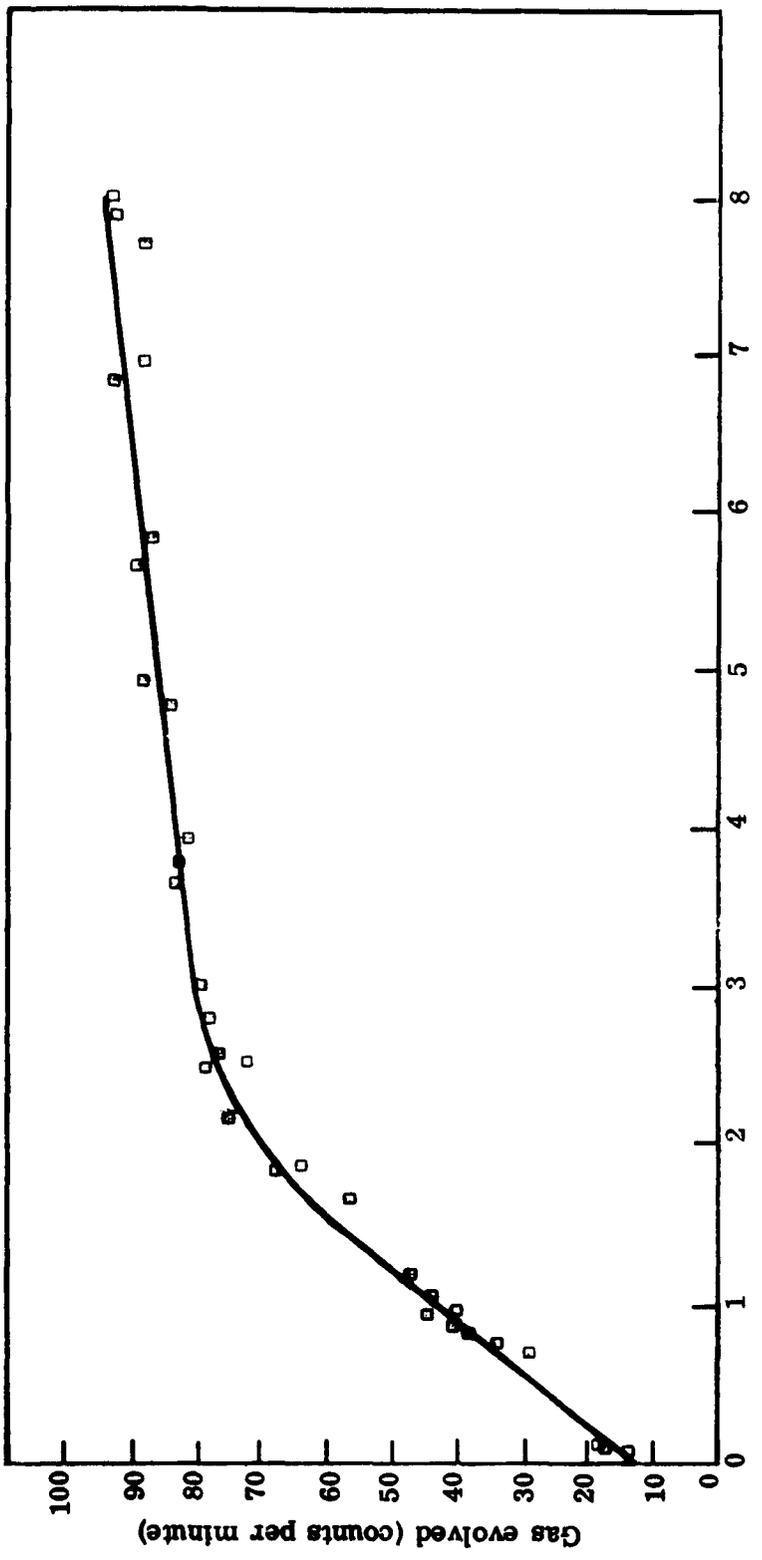



FIGURE 4. $CO_2$ EVOLUTION FROM A-1 POLARIS PROPELLANT

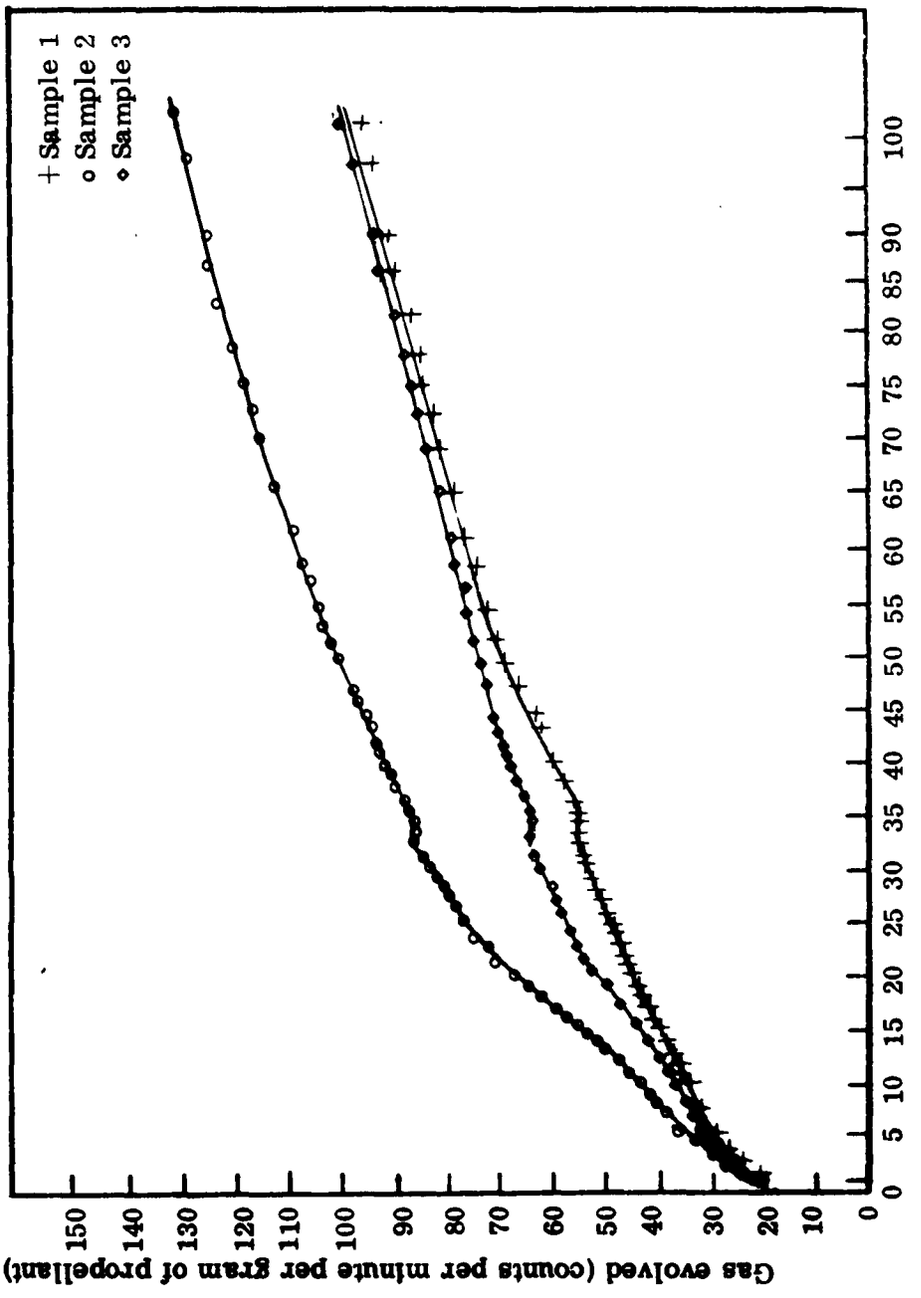



FIGURE 5. EVOLUTION OF RADIOACTIVE $CO_2$

As indicated above, at the beginning of storage each gram of propellant contained $1.4 \times 10^{-1}$ microcuries of $C^{14}$-TDI. Until the 75th day, $4 \times 10^{-3}$ microcuries or 2.86% of this initial activity evolved from the sample as $CO_2$. As every $C^{14}O_2$-molecule urethane linkage and as the other ($C^{12}$) urethane linkages behave the same way, this means also that 2.86% of all the urethane linkages of the binder have been cleaved. If it is now assumed that the $CO_2$ evolution rate remains constant at 0.75 count per minute per day per gram of propellant (from the 60th day), then the useful life or half life of the propellant can be roughly predicted.

A $C^{14}$ activity evolved at a rate of 0.75 count per minute per gram per day means $3 \times 10^{-5}$ microcuries per gram per day or 0.02% of the originally introduced activity. So if the rate stayed constant for the rest of the year, then the propellant binder would degrade 2.86% (first 75 days) plus 5.8% ($0.02 \times 290$) which would equal 8.66% in the first year. Assuming constant rate, the following years would bring 7.3% degradation of the binder. **Fifty percent of the binder would be decomposed after 6.7 years, thus the useful life or half life of the propellant is 6.7 years.**

## DISCUSSION

The experiments showed radioactive $CO_2$ is evolved on mixing, the only source of which is the labeled TDI. So far, no quantitative investigation has been made nor has the mechanism of the TDI decomposition been studied. It is believed, however, that the $CO_2$ evolution is from hydrolysis of the TDI caused by traces of moisture contained in the other propellant ingredients. It should be possible to investigate thoroughly the $CO_2$ evolution on mixing by this method.

This method should also be a valuable tool in investigating the $CO_2$ evolution on curing and furthering the optimal conditions of curing. Experiments have not yet been carried out.

It has been proven by the experiments performed in this study that cleavage of the urethane linkage of the propellant binder is one source for the $CO_2$ evolution observed on thermal decomposition of urethane propellants. The results do not at this point indicate whether this is the only source for $CO_2$ evolution; further experiments will be required to investigate this. The mechanism of the cleavage of the urethane linkage has not been determined yet. It is believed, however, that hydrolysis is not the only cause. The described tracer method is thought to be an effective tool to investigate the influence of such parameters as moisture, pressure, other ingredients of the propellant, etc., on the rate of $CO_2$ evolution and, therefore, rate of binder breakdown.

Furthermore, the method is thought to be of special value in predicting the stability and useful lifetime of a polyurethane propellant in advance. As the sensitivity of the method can be increased by a factor of $10^4$ (by using a one hundred times higher $C^{14}$ activity and gas counting of the $C^{14}O_2$, which gives another factor of approximately $10^2$), it should be possible to investigate the stability of polyurethane propellant binders at room temperature, a more realistic situation than the high temperature-accelerated cycle.

An additional advantage of the method is that only small amounts of propellant are required for surveillance. Additional experiments are required to determine broader applicability of the method.

## REFERENCES

(1) J. G. Tuono and W. M. Vogel. "Two Apparatuses for Investigating Elastomers - 1. Relaxameter; 2. Vapor Pressure Apparatus." Bulletin of the 18th Meeting of the Joint Army-Navy-Air Force on Physical Properties of Solid Propellants. June 1959. SPIA/PP12. CONFIDENTIAL.

(2) J. G. Tuono and W. M. Vogel. "Studies on the Thermal Degradation of Polaris Binders ANP 2639 and ANP 2655." Bulletin of the Fourth Meeting of the Joint Army-Navy-Air Force Solid Propellant Surveillance Panel. pp. 71-83. December 10, 1959. CONFIDENTIAL.

(3) D. Levine, et al. "Polymer Degradation Studies of the Polyurethane Propellants." Bulletin of the 17th Meeting of the Joint Army-Navy-Air Force Panel on Analytical Chemistry of Solid Propellants. pp. 75-83. October 3, 4,5, 1961. CONFIDENTIAL.

(4) U. S. Naval Propellant Plant. THE STORAGE DEGRADATION OF POLARIS PROPELLANT. By C. Boyars, et al. Technical Memorandum Report 153. 29 September 1958. CONFIDENTIAL.

(5) U. S. Naval Propellant Plant. THE STORAGE DEGRADATION OF POLARIS PROPELLANT II (U). By J. G. Tuono and W. M. Vogel. Technical Memorandum Report 176. 12 February 1960. CONFIDENTIAL.

(6) U. S. Naval Propellant Plant. INVESTIGATIONS ON THE EVOLUTION OF GASES FROM AEROJET POLARIS PROPELLANTS DURING STORAGE. By W. M. Vogel and W. K. A. Gallant. Technical Memorandum Report 187. June 1961. CONFIDENTIAL.

(7) W. Siefken. "Mono- and Polyisocyanate." Ann. 562:75 (1949).

(8) Ibid. Ann. 562:99 (1949).

(9) F. Basolo and A. Wojcicki. "Metal Carbonyls. I. Carbon Monoxide Exchange with Nickel Tetracarbonyl and Dicobalt Octacarbonyl." J. Am. Chem. Soc. 83:520 (1961).

## DISTRIBUTION LIST

| Addressee | No. of copies |
|---|---|
| Naval Propellant Plant<br>(Archives Copy) | 1 |
| U. S. Department of the Interior<br>Bureau of Mines<br>4800 Forbes Avenue<br>Pittsburgh 13, Pennsylvania<br>Attn: M. M. Dolinar, Reports Librarian<br>Explosives Research Lab. | 1 |
| Nat'l Aeronautics & Space Administration<br>Washington 25, D. C.<br>Attn: Office of Technical Information &<br>Educational Programs, Code ETL | 1 |
| Scientific and Tech. Information Facility<br>P.O. Box 5700<br>Bethesda, Maryland<br>Attn: NASA Representative | 2 |
| Nat'l Aeronautics & Space Administration<br>Lewis Research Center<br>21000 Brookpark Road<br>Cleveland 35, Ohio<br>Attn: Library | 1 |
| Nat'l Aeronautics & Space Administration<br>Langley Research Center<br>Langley Air Force Base<br>Virginia<br>Attn: Library | 1 |
| Nat'l Aeronautics & Space Administration<br>Goddard Space Flight Center<br>Greenbelt, Maryland<br>Attn: Library | 1 |
| Nat'l Aeronautics & Space Administration<br>George C. Marshall Space Flight Center<br>Huntsville, Alabama<br>Attn: Library | 1 |

Nat'l Aeronautics & Space Administration
Manned Spacecraft Center
P. O. Box 1537
Houston 1, Texas
Attn: Library — 1

Rocket Research Laboratories
Air Force Systems Command
Edwards, California
Attn: DGS — 1

Air Proving Ground Center
Eglin Air Force Base
Florida
Attn: PGAPI — 1

Space Systems Division
Air Force Systems Command
P. O. Box 262, Air Force Unit Post Office
Los Angeles 45, California
Attn: TDC — 1

Armed Services Tech. Info. Agency
Arlington Hall Station
Arlington 12, Virginia — 10

Rocket Research Laboratories
Air Force Systems Command
Edwards, California
Attn: DGPS — 1

Aeronautical Systems Division
Wright-Patterson Air Force Base, Ohio
Attn: ASRCEM-1 — 1

Commander
Air Force Missile Development Center
Holloman Air Force Base
New Mexico
Attn: MDGRTL Technical Library — 1

Bureau of Naval Weapons
Department of the Navy
Washington 25, D. C.
Attn: DLI-3 — 2

Bureau of Naval Weapons
Department of the Navy
Washington 25, D. C.
Attn: RMMP-11 — 2

Bureau of Naval Weapons
Department of the Navy
Washington 25, D. C.
Attn: RMMP-331 — 1

Commander
U. S. Naval Weapons Laboratory
Dahlgren, Virginia
Attn: Technical Library — 1

Commander
U. S. Naval Ordnance Laboratory
White Oak
Silver Spring, Maryland
Attn: Library — 2

Commander
U. S. Naval Ordnance Test Station
China Lake, California
Attn: Technical Library Branch — 3

Director
U. S. Naval Research Laboratory
Washington 20, D. C.
Attn: Chemistry Division, Code 6130
R. R. Miller — 1

Department of the Navy
Office of Naval Research
Washington 25, D. C.
Attn: Code 429 — 1

E.I. duPont deNemours and Company
Eastern Laboratory
Gibbstown, New Jersey
Attn: Mrs. Alice R. Steward — 1

Ethyl Corporation
Research Laboratories
1600 West Eight Mile Road
Ferndale, Michigan
Attn: E. B. Rifkin, Assistant Director
Chemical Research — 1

The Dow Chemical Company
Security Section
Box 31
Midland, Michigan
Attn: Dr. R. S. Karpiuk, 1710 Building — 1

Minnesota Mining and Manufacturing Co.
900 Bush Avenue
St. Paul 6, Minnesota
Attn: J. D. Ross
VIA: H. C. Zeman
Security Administrator — 2

Esso Research and Engineering Co.
Chemicals Research Division
P.O. Box 51
Linden, New Jersey
Attn: Dr. J. P. Longwell
VIA: Chief, New York Ordnance District
U. S. Army
770 Broadway
New York 3, New York
Attn: Facilities and Resources Branch — 1

American Cyanamid Company
1937 W. Main Street
Stamford, Connecticut
Attn: Dr. A. L. Peiker — 1

Hercules Powder Company
Bacchus Works
Magna, Utah
Attn: Librarian — 1

Hercules Powder Company
910 Market Street
Wilmington 99, Delaware
Attn: Technical Information Division
Research Center
Dr. Herman Skolnik 1

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena 3, California
Attn: I. E. Newlan
Chief, Reports Group 1

The Martin Company
Baltimore 3, Maryland
Attn: T. W. Woodard 1

Midwest Research Institute
425 Volker Boulevard
Kansas City 10, Missouri
Attn: Librarian 1

Forrestal Research Center
Princeton University
Princeton, New Jersey
Attn: Librarian 1

Purdue University
Department of Chemistry
Lafayette, Indiana
Attn: Dr. Henry Feuer 1

Rohm and Haas Company
Redstone Arsenal Research Division
Huntsville, Alabama
Attn: Librarian 1

Solid Propellant Information Agency
Applied Physics Laboratory
The Johns Hopkins University
Silver Spring, Maryland 3

Thiokol Chemical Corporation
Redstone Division
Huntsville, Alabama
Attn: Technical Director — 2

Thiokol Chemical Corporation
Elkton Division
Elkton, Maryland
Attn: Librarian — 1

Olin Mathieson Chemical Corporation
Marion, Illinois
Attn: Research Library
Box 508 — 1

Reaction Motors Division
Thiokol Chemical Corporation
Denville, New Jersey
Attn: Librarian — 1

Rocketdyne, A Division of
North American Aviation, Inc.
Solid Propulsion Operations
P.O. Box 548, McGregor, Texas
Attn: Library — 1

B.F. Goodrich Aerospace & Defense
Products
P.O. Box 157, Rialto, California
Attn: Mr. A. B. Japs, Tech. Manager
Rocket Motor Development — 1

American Machine and Foundry Co.
Mechanics Research Department
7501 North Natchez Avenue
Niles 48, Illinois
Attn: Phil Rosenberg — 1

Southwest Research Institute
Department of Structural Research
8500 Culebra Road
San Antonio 6, Texas
Attn: Dr. Robert C. DeHart, Director — 1

| | |
|---|---|
| Rocketdyne<br>6633 Canoga Avenue<br>Canoga Park, California<br>Attn: Library, Dept. 596-306 | 3 |
| Lockheed Propulsion Co.<br>P.O. Box 111<br>Redlands, California<br>Attn: Miss Belle Berlad, Librarian | 3 |
| Aerojet-General Corporation<br>P.O. Box 1947<br>Sacramento, California<br>Attn: Technical Information Office | 3 |
| Thiokol Chemical Corporation<br>Wasatch Division<br>P.O. Box 524<br>Brigham City, Utah<br>Attn: Library Section | 2 |
| Olin Mathieson Chemical Corporation<br>Research Library 1-K-3<br>275 Winchester Avenue<br>New Haven, Connecticut<br>Attn: Mail Control Room<br>Miss Laura M. Kajuti | 3 |
| Shell Development Company<br>4560 Horton Street<br>Emeryville 8, California | 1 |
| Ethyl Corporation<br>P.O. Box 3091, Istrouma Branch<br>Baton Rouge, Louisiana | 1 |
| Peninsular Chemical Research, Inc.<br>1103-5 N. W. 5th Avenue<br>P.O. Box 3597, University Station<br>Gainesville, Florida | 1 |

Commanding Officer
Office of Naval Research
1030 E. Green Street
Pasadena 1, California 1

Director
Special Projects Office
Department of the Navy
Washington 25, D. C. 1

U. S. Naval Ordnance Laboratory
Corona, California
Attn: P. J. Slota, Jr. 1

Bureau of Naval Weapons
Department of the Navy
Washington 25, D. C.
Attn: RRRE-6 1

Aerojet-General Corporation
P. O. Box 296
Azusa, California
Attn: Librarian 2

Hercules Powder Company
Allegany Ballistics Laboratory
P.O. Box 210
Cumberland, Maryland
Attn: Library 2

Armour Research Foundation
of Illinois Institute of Technology
Technology Center
Chicago 16, Illinois
Attn: Fluid Dynamics and Propulsion
Research, Department D 1

Atlantic Research Corporation
Shirley Highway and Edsall Road
Alexandria, Virginia 2

Monsanto Research Corporation
Boston Laboratories
Everett 49, Massachusetts
Attn: Library 1

Allied Chemical Corporation
General Chemical Division
Research Laboratory, P.O. Box 405
Morristown, New Jersey
Attn: L.J. Wiltrakis, Security Officer 1

National Cash Register Co.
Dayton 9, Ohio
Attn: Mr. B. Treadwell 1

Callery Chemical Company
Research and Development
Callery, Pennsylvania
Attn: Document Control 1

Pennsalt Chemicals Corporation
Box 4388
Philadelphia 18, Pennsylvania
Attn: Dr. G. Barth-Wehrenalp 1

Space Technology Laboratory, Inc.
5730 Arbor-Vitae Street
Los Angeles 45, California
Attn: Mr. Robert C. Anderson 1

Aeroprojects, Inc.
310 East Rosedale Avenue
West Chester, Pennsylvania
Attn: C. D. McKinney 1

United Technology Corp.
P. O. Box 358
Sunnyvale, California
Attn: Librarian 1

Aerojet-General Corporation
11711 South Woodruff Avenue
Downey, California
Attn: Florence Walsh, Librarian 1

| | |
|---|---|
| Aerospace Corporation<br>P. O. Box 95085<br>Los Angeles 45, California<br>Attn: Library-Documents | 2 |
| Thiokol Chemical Corporation<br>Rocket Operations Center<br>P. O. Box 1640<br>Ogden, Utah<br>Attn: Librarian | 1 |
| Bureau of Naval Weapons<br>Department of the Navy<br>Washington 25, D. C.<br>Attn: NPP Representative<br>Room 3002 | 1 |
| Director<br>Advanced Research Projects Agency<br>The Pentagon, Room 3D159<br>Washington 25, D. C.<br>Attn: Advanced Propellant<br>Chemistry Office | 1 |
| Bureau of Naval Weapons<br>Department of the Navy<br>Washington 25, D. C.<br>Attn: CS | 1 |
| Rocket Power, Inc.<br>3016 Foothill Blvd.<br>Pasadena, California | 1 |
| Amcel Propulsion Company<br>Box 3049<br>Asheville, N. C. | 1 |
| Superintendent<br>U. S. Naval Weapons Plant (Code 752)<br>Washington 25, D. C. | 1 |
| **Quality Assurance Department, NPP** | 1 |
| **Production Department, NPP** | 1 |
| **Safety Department, NPP** | 1 |
| **Research and Development Department, NPP** | 20 |
| **Technical Library, NPP** | 2 |
| **NPP Files** | 5 |

| | |
|---|---|
| Commanding General<br>Aberdeen Proving Ground<br>Maryland<br>Attn: Ballistic Research Laboratories<br>ORDBG-BLI | 2 |
| Commanding General<br>USA Ordnance Arsenal, Frankford<br>Philadelphia 37, Pennsylvania<br>Attn: Propellant and Explosives<br>Section, 1331 | 1 |
| Commanding Officer<br>Picatinny Arsenal<br>Dover, New Jersey<br>Attn: Library | 2 |
| Commanding General<br>U. S. Army Ordnance Missile Command<br>Redstone Arsenal, Alabama<br>Attn: Technical Library | 5 |
| Commanding General<br>White Sands Missile Range<br>New Mexico<br>Attn: ORDBS-OM-TL | 3 |
| Commanding Officer<br>Radford Ordnance Plant<br>Radford, Virginia | 1 |
| Commanding General<br>Ordnance Ammunition Command<br>Joliet, Illinois<br>Attn: ORDLY-AREL, Engr. Library | 1 |
| Commanding Officer<br>Diamond Ordnance Fuze Laboratories<br>Washington 25, D. C.<br>Attn: ORDTL (012) | 1 |

| | | | |
|---|---|---|---|
| Naval Propellant Plant, Indian Head, Maryland (NavWeps Report 8021) APPLICATION OF A RADIO-TRACER METHOD TO THE DE-COMPOSITION MECHANISM OF POLYURETHANE PROPELLANT SYSTEMS (U). (TR 121) 16 November 1961. 13 pp. CONFIDENTIAL (SCP-4) A new technique employing radio tracer $C^{14}$ has been used for following the thermal degradation of a polyurethane propellant. The described (over) | CONFIDENTIAL (SCP-4) 1. Radio-tracer method 2. Polyurethane propellants - Surveillance 3. Polyurethane propellants - Life expectancy 4. Thermal degradation I. Wilkniss, P. E. II. Levine, D. CONFIDENTIAL (SCP-4) | Naval Propellant Plant, Indian Head, Maryland (NavWeps Report 8021) APPLICATION OF A RADIO-TRACER METHOD TO THE DE-COMPOSITION MECHANISM OF POLYURETHANE PROPELLANT SYSTEMS (U). (TR 121) 16 November 1961. 13 pp. CONFIDENTIAL (SCP-4) A new technique employing radio tracer $C^{14}$ has been used for following the thermal degradation of a polyurethane propellant. The described (over) | CONFIDENTIAL (SCP-4) 1. Radio-tracer method 2. Polyurethane propellants - Surveillance 3. Polyurethane propellants - Life expectancy 4. Thermal degradation I. Wilkniss, P. E. II. Levine, D. CONFIDENTIAL (SCP-4) |
| Naval Propellant Plant, Indian Head, Maryland (NavWeps Report 8021) APPLICATION OF A RADIO-TRACER METHOD TO THE DE-COMPOSITION MECHANISM OF POLYURETHANE PROPELLANT SYSTEMS (U). (TR 121) 16 November 1961. 13 pp. COFIDENTIAL (SCP-4) A new technique employing radio tracer $C^{14}$ has been used for following the thermal degradation of a polyurethane propellant. The described (over) | CONFIDENTIAL (SCP-4) 1. Radio-tracer method 2. Polyurethane propellants - Surveillance 3. Polyurethane propellants - Life expectancy 4. Thermal degradation I. Wilkniss, P. E. II. Levine, D. CONFIDENTIAL (SCP-4) | Naval Propellant Plant, Indian Head, Maryland (NavWeps Report 8021) APPLICATION OF A RADIO-TRACER METHOD TO THE DE-COMPOSITION MECHANISM OF POLYURETHANE PROPELLANT SYSTEMS (U). (TR 121) 16 November 1961. 13 pp. CONFIDENTIAL (SCP-4) A new technique employing radio tracer $C^{14}$ has been used for following the thermal degradation of a polyurethane propellant. The described (over) | CONFIDENTIAL (SCP-4) 1. Radio-tracer method 2. Polyurethane propellants - Surveillance 3. Polyurethane propellants - Life expectancy 4. Thermal degradation I. Wilkniss, P. E. II. Levine, D. CONFIDENTIAL (SCP-4) |

| | | | |
|---|---|---|---|
| tracer method is thought to be an effective tool to investigate the influence of such parameters as moisture, pressure, other ingredients of the propellant, etc., on the rate of carbon dioxide evolution and, therefore, the rate of binder breakdown. Extrapolation of the data obtained indicates that the half-life of the propellant is 6.7 years. | CONFIDENTIAL<br><br>When this card has served its purpose, it may be destroyed in accordance with OPNAV Inst. 5510. 17A.<br><br>CONFIDENTIAL | tracer method is thought to be an effective tool to investigate the influence of such parameters as moisture, pressure, other ingredients of the propellant, etc. on the rate of carbon dioxide evolution and, therefore, the rate of binder breakdown. Extrapolation of the data obtained indicates that the half-life of the propellant is 6.7 years. | CONFIDENTIAL<br><br>When this card has served its purpose, it may be destroyed in accordance with OPNAV Inst. 5510. 17A.<br><br>CONFIDENTIAL |
| tracer method is thought to be an effective tool to investigate the influence of such parameters as moisture, pressure, other ingredients of the propellant, etc., on the rate of carbon dioxide evolution and, therefore, the rate of binder breakdown. Extrapolation of the data obtained indicates that the half-life of the propellant is 6.7 years. | CONFIDENTIAL<br><br>When this card has served its purpose, it may be destroyed in accordance with OPNAV Inst. 5510. 17A.<br><br>CONFIDENTIAL | tracer method is thought to be an effective tool to investigate the influence of such parameters as moisture, pressure, other ingredients of the propellant, etc. on the rate of carbon dioxide evolution and, therefore, the rate of binder breakdown. Extrapolation of the data obtained indicates that the half-life of the propellant is 6.7 years. | CONFIDENTIAL<br><br>When this card has served its purpose, it may be destroyed in accordance with OPNAV Inst. 5510. 17A.<br><br>CONFIDENTIAL |