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PRODUCTION AND IDENTIFICATION  
OF  
HELIUM DIFLUORIDE

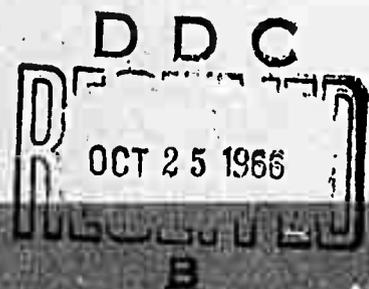
Final Summary Report  
to  
Office of Naval Research

ARPA Order 615  
Program Code 5910

AN-1530

October 1966

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**AEROJET-GENERAL NUCLEONICS**  
SAN RAMON, CALIFORNIA

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PRODUCTION AND IDENTIFICATION OF HELIUM DIFLUORIDE

Final Summary Report

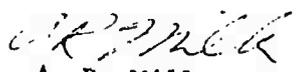
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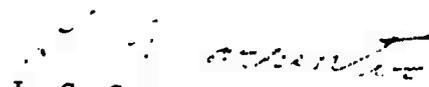
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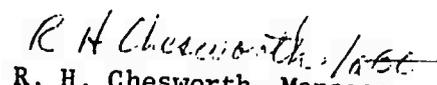
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PRODUCTION AND IDENTIFICATION OF  
HELIUM DIFLUORIDE: FINAL REPORT\*

SYNOPSIS

An 18-month program to produce and identify the helium difluoride molecule is summarized in this final report. Nine tritiated samples were produced during the program; new IR absorption peaks found in two samples suggest that tritium decay is producing observable changes. It appears too soon to assign these new peaks to helium-compound formation. Experiments during the program indicated it is possible to detect helium-containing compounds in samples containing as little as one-half curie of tritium. This work was performed under Contract Nonr-4795(00), ARPA Order 615, Program Code 5910, with the Office of Naval Research.

The beta decay of tritium in a bifluoride-containing specimen was followed by infrared spectrophotometry for evidence of the conversion of  $F-T-F^-$  ions into  $F-He-F$  molecules. Difficulties in producing suitable samples consumed so much time that the period available for observation proved too brief to support any valid conclusions; however, AGN will continue observations of the samples under a company-funded program.

The first phase of the program was initially divided into the study of the growth of suitable single crystals and the production of composite pressed disks. Both  $NaHF_2$  and  $KHF_2$  were originally considered, but  $NaHF_2$  was chosen because water-free  $NaF$ , the starting material, can be readily obtained. On the other hand, water-free  $KF$  is not commercially available and is difficult to handle without moisture pick-up from the atmosphere.

It was experimentally determined that the optimum method of producing samples was to mix a small amount of polycrystalline  $NaHF_2$  with  $KBr$ , and cold-press the mixture into transparent pellets. The nine tritiated samples produced under this contract were fully encased to prevent the escape of radioactive material.

It is expected that definitive results will be obtained in six to eight months.

\*Published by Aerojet-General Nucleonics

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PRODUCTION AND IDENTIFICATION OF HELIUM DIFLUORIDE:  
FINAL REPORT

I. INTRODUCTION

The purpose of this program was to produce and identify the helium difluoride molecule; this final report summarizes activities of Aerojet-General Nucleonics under Contract Nonr-4795(00) with the Office of Naval Research from 1 December 1964 through 31 August 1966.

The beta decay of tritium in a bifluoride-containing specimen was followed by infrared spectrophotometry for evidence of the conversion of  $F-T-F^-$  ions into  $F-He-F$  molecules. New peaks found in two of the tritiated samples produced during this program suggest that tritium decay is producing observable changes. Difficulties in producing suitable samples consumed so much time that the period available for observation proved too brief to support any valid conclusions; however, AGN will continue observations of the samples under a company-funded program.

The original goal of this program was to fabricate an IR-transparent sample capable of producing a detectable quantity of  $HeF_2$  in several months. The program was based on an article by Pimentel and Spratley, and one by Pimentel, Spratley and Miller. Pimentel and Spratley (Ref. 1) suggested that the helium difluoride molecule might prove to be stable and they defined expected infrared absorption frequencies by analogy with the isoëlectronic  $HF_2^-$  ion and xenon-fluorine compounds.

Pimentel, Spratley and Miller (Ref. 2) suggested that the beta decay of a tritium atom, held in an appropriate solid lattice, should provide ideal conditions for the formation of  $HeF_2$ . The lattice used in this study contained sodium bifluoride, a material having distinct  $F-H-F^-$  ions in which the hydrogen atom is strongly held between the two fluorine atoms. The recoil energy of tritium is so low (an average of 24 kcal/mole) relative to the H-F bond

strength (100 kcal/mole) that the  $^3\text{He}$  daughter should not be displaced from the position of the parent  $^3\text{H}$  atom. Tritium decay in the  $\text{TF}_2^-$  ion, then, should convert it to  $\text{HeF}_2$ .

The beta particle ejected during decay was not expected to interfere with the IR spectrum since it should come to rest far enough from the parent to eliminate interaction with any helium-fluorine molecule that might form. Furthermore, the ionic bifluoride lattice consists of alternating regions of plus and minus charges which should not be greatly affected by the presence of an additional electron. Regardless of that, it is possible for the beta particle to become trapped in the lattice, forming a defect, such as an F center, that interferes with light. Fortunately, electron defects generally are active in the visible and ultraviolet region (Ref. 3) and so should not appear in the IR spectrum.

The program as scoped fell into two phases: the production of an appropriate solid lattice containing a tritium atom; and observation of beta decay for formation of  $\text{HeF}_2$ . It was originally thought that it would be necessary to incorporate 25 curies of tritium into the sample (sufficient to produce ten micromoles of helium in 76 days) if the lower limit of detectability was one micromole as suggested by Pimentel. Experiments performed during this program indicated that much smaller quantities can be detected, however, so that it is possible to detect helium-containing compounds in samples containing as little as one-half curie of tritium.

A tritiated  $\text{NaHF}_2$  lattice, observed with an IR spectrophotometer over a period of several months, was expected to show new absorption peaks growing at a rate corresponding to the decay of tritium. The new peak will grow at a linear rate of 0.1% per week for the first few months; the rate is linear because the time from synthesis is much less than the half-life of tritium.

The infrared-active absorption frequencies expected for  $\text{TF}_2^-$  and  $^3\text{HeF}_2$ , calculated from the data of Pimentel and Spratley (Ref. 1), on the basis of the measured peaks for  $^1\text{HF}_2^-$  are shown in Table 1.

Table 1

THE VIBRATIONAL POTENTIAL FUNCTION AND INFRARED-ACTIVE  
 FREQUENCIES OF  ${}^1\text{HF}_2^-$  (EXPERIMENT), AND  $\text{TF}_2^-$  AND  ${}^3\text{HeF}_2$  (PREDICTED)

	Bond Length $\text{\AA}$	Force Constant*			Frequency, $\text{cm}^{-1}$	
		$f_r$	$f_{rr}$	$f_\alpha$	$\nu_2$	$\nu_3$
${}^1\text{HF}_2^-$	1.13	2.31	1.72	0.28	1230	1425
$\text{TF}_2^-$	1.13	2.31	1.72	0.28	730	846
${}^3\text{HeF}_2$	1.08	3.47	0.35	0.28	763	1942

\* $f_r$  is the bond-stretching force constant (in millidynes/ $\text{\AA}$ );  $f_{rr}$  is the bond-stretching interaction force constant (in millidynes/ $\text{\AA}$ );  $f_\alpha$  is the angle bending force constant (in millidyne- $\text{\AA}$ /radian).

$\nu_2$  is the asymmetric-stretching frequency;  $\nu_3$  is the bending frequency.

The IR beam in the Perkin Elmer Model 21 is 3 by 10 mm, consequently the sample dimensions along the beam path, necessary to incorporate 25 curies of tritium, was set by the concentration of tritium. For example, a fully tritiated  $\text{NaHF}_2$  sample must be 0.85 mm in the beam direction; a sample containing 1% fully tritiated  $\text{NaHF}_2$  in an alkali halide diluent must be 85 mm long. The advantage of a short, fully tritiated  $\text{NaHF}_2$  lattice is offset by the difficulty of producing a single crystal, polycrystalline  $\text{NaHF}_2$  scatters too much of the IR. On the other hand, a small concentration of  $\text{NaHF}_2$  dispersed in an alkali halide matrix requires a rather long sample that absorbs too much of the IR beam. A third technique, suspension of the tritiated material in a liquid, was found to be unsuitable after a brief investigation. The first phase of the program therefore was initially divided into the study of the growth of suitable single crystals and the production of composite pressed disks. The major part of this program was consumed in developing techniques for producing an acceptable sample.

Both  $\text{NaHF}_2$  and  $\text{KHF}_2$  were originally considered, but  $\text{NaHF}_2$  was chosen because water-free  $\text{NaF}$ , the starting material, can be readily obtained. On the other hand, water-free  $\text{KF}$  is not commercially available (although it could have been made from the elements if necessary) and is difficult to handle without moisture pick-up from the atmosphere.

Although the IR spectrum of  $\text{NaHF}_2$  single crystals apparently has not been published, it was expected to resemble the spectrum of  $\text{KHF}_2$  (Ref. 4) since the F-H-F distance is the same for both lattices (Ref. 5), and it is the IR absorption of the  $\text{F-H-F}^-$  ion that was of interest to this program. The F-D-F distance is the same as the F-H-F distance (Ref. 6) suggesting that the F-T-F distance is also the same. In addition, the IR spectra for pressed halide disks containing  $\text{NaHF}_2$  and  $\text{KHF}_2$  are identical (Ref. 7).

On the other hand,  $\text{NaHF}_2$  has a different primitive unit cell than  $\text{KHF}_2$  (Ref. 8) and the IR spectra of the two bifluorides in mixed crystals of KBr shown an additional peak for  $\text{NaHF}_2$  (Ref. 7). The spectra are also different (Ref. 7) in a Nujol mull. Consequently, several experiments were performed to obtain the IR spectra of  $\text{NaHF}_2$  in a perfluorokerosene mull and in a composite KBr pressed disk.

## II. REVIEW OF RESULTS

Nine tritiated samples containing quantities of tritium sufficient to indicate the formation of helium-compounds were produced under this contract. The samples were fully encased to prevent the escape of radioactive material, and thus can be safely handled or stored. Two of the samples (Pellet 5 and Pellet 8) will be stored in a dry ice chest to minimize possible decomposition of newly formed helium compounds.

Over the next 6 to 8 months, IR spectra will be obtained from these samples in a continuing effort to discern a helium compound. The examinations will be performed without additional cost to ONR; any encouraging results will be reported through the channels established for this contract.

### A. SUMMARY

The program as originally scoped fell into two logical phases: the production of the tritiated samples, and observation of these samples over several months to detect the formation of helium-containing compounds. After familiarization studies and screening tests, it was experimentally determined that the optimum method of producing samples was to mix a small amount of polycrystalline  $\text{NaHF}_2$  with  $\text{KBr}$ , and cold-press the mixture into transparent pellets. The optimum conditions for fabricating rectangular tritiated pellets were found to include:

- Use 1% tritiated  $\text{NaHF}_2$
- Mix the  $\text{NaHF}_2$  with the  $\text{KBr}$  for 5 minutes (when using less than 0.5g of material) in a mechanical mixer/grinder (Wig-L-Bug)

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- Evacuate the die for 5 minutes
- Apply pressure in the range between 9.7 and  $13 \times 10^4$  psi

It was originally considered that 25 curies of tritium would be required (in each sample) to be able to detect the formation of helium compounds, but experimental results showed that 0.5 curies of tritium were detectable in a reasonable length of time. The principal characteristics of the nine pellets produced under this program are summarized in Table 2.

Table 2

PRINCIPAL CHARACTERISTICS OF TRITIATED PELLETS

<u>Pellet No.</u>	<u>Tritium Content, curies</u>	<u>Infrared Transmission</u>
1	0.20	Very poor
2	0.20	(Contaminated with window cement)
3	7.14	Very poor
4	0.62	Fair
5	1.3	Good
6	1.6	Fair
7	0.1	Excellent
8	2.0	Good
9	3.0	Very poor

Although the observation time available during the course of this program proved too brief to permit firm conclusions as to the identity of the new peaks observed in two samples, the following results were obtained:

- The use of large single crystals for samples requires the handling of unacceptable quantities of tritium.
- A liquid-nitrogen-cooled  $TF_2$  film can be used with a low-temperature IR cell if the film is 0.1 mm thick.
- The pressed-pellet technique is the best approach to sample production.

- Helium compounds are detectable in 0.5-curie tritium samples.

## B. DISCUSSION

The original goal of this program was to form a tritium-containing sample capable of producing a detectable amount of  $\text{HeF}_2$  in a reasonable time. Professor Pimentel originally suggested that ten micromoles would be the minimum amount that would be detectable; however, this was apparently based upon his experience with IR absorption in general rather than with the  $\text{HF}_2^-$  system. Such an estimate leads to a tritium content of 25 curies.

Experiments performed during this program suggest that with the  $\text{HF}_2^-$  system only one-half to one curie of tritium will produce a detectable quantity of  $\text{HeF}_2$  in several months.

Samples 3 and 9 (which contain respectively 7.14 and 3.0 curies) do not have sufficient transmission for analysis. They were prepared as part of the experiment to observe any dramatic change. None was observed.

The absorption peak at  $960\text{ cm}^{-1}$  found in the 1.3-curie sample (Pellet 5) has been growing in an atypical fashion: although the area of the peak is increasing with time, the peak height is not. The peak seems to be growing sideways, i.e., the resolution is decreasing with time. The sample has been mounted in a permanent IR cell for convenience in observing changes in growth of this peak.

Nothing of interest has been detected from Pellet 4 and 6 (0.62 and 1.6 curies respectively) in 5 months; transmission is only fair, probably because they contain excess NaF and observation has been limited to major peaks.

The 2.0-curie sample (Pellet 8) has very good transmission and has shown a new peak at  $1010\text{ cm}^{-1}$  after 2 months; this peak appears to be growing, with respect to time, in the same manner as Pellet 5.

One interesting aspect found during this program is seen in the IR spectra of the tritiated samples: The bending and asymmetric-stretch frequencies for the  $\text{TF}_2^-$  ion agree with the predicted values in Table 1; this means that the force constants for the  $\text{TF}_2^-$  ion are the same as those for the  $^1\text{HF}_2^-$  ion.

New peaks have been observed in the 2.0- (Pellet 8) and 1.3-curie (Pellet 5) samples after several weeks that were not observed immediately after production; the peaks fall in the predicted region of 750 to 2000  $\text{cm}^{-1}$ . Two additional samples (Pellets 4 and 7), which also transmit in the region around 1000  $\text{cm}^{-1}$ , show nothing of interest, probably because of their lower tritium content. The fact that these latter two do not show new peaks in this region indicates that the peaks found in Pellets 5 and 8 are not caused by external contamination.

Although the peaks in Pellet 5 and Pellet 8 appear to be growing in a curious manner, it is too soon to draw any conclusions. If new peaks are caused by a helium-containing compound they should continue to grow over the coming months; in six or eight months the picture should be considerably clearer.

### III. SAMPLE DEVELOPMENT

Three different techniques are applicable to the incorporation of tritium into a suitable sample: the single-crystal method; the pressed-pellet method; and the liquid-suspension (mull) method. The optimum method would:

- 1) Provide for incorporation of the necessary quantity of tritium
- 2) Produce a sample transparent to IR
- 3) Be amenable to a test program up to a year's duration
- 4) Minimize the possibility of radioactive contamination

All three methods were initially considered; however, the mull technique, which is inherently more hazardous because the sample is liquid, was dropped early in the program. The results of the studies described in the following pages indicated that the pressed-pellet technique offered the best chance for success. In this technique, a small amount of polycrystalline  $\text{NaHF}_2$  is mixed with KBr and cold-pressed into a transparent disk; the KBr serves as a support for the dispersion of the polycrystalline bifluoride grains.

Initial studies were performed with normal hydrogen to eliminate the hazards of radioactive contamination until the techniques could be well developed. Since the chemical behavior of normal hydrogen is virtually indistinguishable from that of tritium, its use permits rapid and safe development in techniques and procedures.

Development of the crystal-growing technique (Section A, below) was aborted when it was determined that excessive amounts of tritium would have

to be handled to obtain a 25-curie specimen, and 12 potential vendors refused to bid on the fabrication of a tritiated, encapsulated specimen. Major effort under this phase of the program was then shifted to the production of a composite pressed disk (Section B, below).

#### A. CRYSTAL-GROWING

A short screening program was performed to compare the formation of crystals at room temperature with the use of rapid quenching from higher temperatures (c.f. Quarterly Reports No. 1 and 2; AN-1410, April 1965 and AN-1437, June 1965). Common laboratory salts (such as copper sulfate, sodium bromate, potassium ferricyanide, and nickel sulfate) were used in aqueous solutions during these tests. The results showed that temperature control was important, and that room-temperature precipitation was superior to the rapid-quench approach.

It was anticipated that the use of tritiated  $\text{NaHF}_2$  single crystals might be the optimum approach, although either  $\text{NaHF}_2$  or  $\text{KHF}_2$  has a suitable lattice for the purpose of this study. Effort initially was concentrated on the  $\text{NaHF}_2$  because it is less hygroscopic and thus will provide greater transparency to IR with less effort. The greater solubility of  $\text{KHF}_2$  compared to  $\text{NaHF}_2$ , and other factors, led to investigation of the growth of single crystals to  $\text{KHF}_2$ .

There were two approaches to the production of tritiated single crystals of  $\text{NaHF}_2$ : the first approach investigated the reaction of  $\text{Na}_2\text{CO}_3$  with HF (48% aq.); the second investigated repeated recrystallization of  $\text{NaHF}_2$  from tritiated water. The latter approach was also used with  $\text{KHF}_2$ .

##### 1. Methods

A common method was used in each of the three investigations with minor differences: the crystals were grown in saturated solutions on a dacron thread suspended in the solution as well as on the sides of the beakers. Paper tissues were then used to remove the moisture from the crystals and X-ray diffraction patterns were obtained.

The dacron threads proved to be suitable substrates for nucleation of the crystals, and also simplified removal of crystals from a solution. Crystals formed on the thread in much the same fashion in

either HF or water solutions; in each case, the crystals apparently form from the surface of the solution down, and grow together if left undisturbed.

Recrystallization involved the selection of the largest crystals on the dacron thread. These selected crystals were then used as seeds in another, saturated mother liquor.

## 2. Na<sub>2</sub>CO<sub>3</sub> Plus HF

Anhydrous Na<sub>2</sub>CO<sub>3</sub> was slowly added to boiling 48% HF until saturation was reached. The solution was then allowed to cool slowly and the supernate transferred to a Teflon beaker. Crystals were observed on the sides of the beakers in two or three days. Crystals with sharp edges were observed on the dacron strand at 35-power magnification; after 10 minutes, the microscope slide was noticeably etched and the crystals were less transparent, presumably due to moisture absorbed from the air. The crystals were then transferred to a petri dish and submerged in a halocarbon oil to prevent contact with airborne moisture.

Crystals scraped from the side of a beaker were oven-dried and ground to a fine powder in an alumina mortar. The powder was placed in an X-ray sample cell, covered with Mylar and examined in a Phillips Norelco X-ray Diffractometer. The resulting pattern contained only NaHF<sub>2</sub> and Mylar lines.

## 3. NaHF<sub>2</sub> Solution

Five pounds of technical grade (the best commercially available) NaHF<sub>2</sub> were obtained. X-ray diffraction analysis of the powder revealed only NaHF<sub>2</sub> lines. Screening studies of the solubility of NaHF<sub>2</sub> in HF (48% aq.) and in distilled water indicated that HF increases the solubility of NaHF<sub>2</sub>; for example, the solubility of NaHF<sub>2</sub> in water was found to be 4.5 g/100 ml at 26°C, [compared to 4.0 g/100 ml reported by Bradley and Otts (Ref. 9)]; in HF (48% aq.), the solubility was 14.7 g/100 ml.

Crystals of  $\text{NaHF}_2$  were grown in six saturated solutions of  $\text{NaHF}_2$  in 48% aq. HF and six saturated solutions of  $\text{NaHF}_2$  in  $\text{H}_2\text{O}$ . The solutions were prepared by slowly adding technical grade  $\text{NaHF}_2$  to the aqueous medium until complete saturation was reached. The solutions were then transferred to 100-ml Teflon beakers and placed in a fume hood. A thin dacron thread, equipped with a Teflon anchor, was added to each solution and the beakers were covered with paper tissue to prevent contamination. The crystals were grown by slow evaporation; the growth of the crystals was frequently observed to determine the best medium.

The results of 20 days of growth confirmed the hypothesis that 48%-aq. HF is a better medium than water for crystal formation. Crystals of  $\text{NaHF}_2$  grew readily in all six 48%-aq. HF solutions, whereas only a few crystals were observed in three of the water solutions. (Crystals were not observed in the other water solutions.)

X-ray diffraction patterns were obtained for the  $\text{NaHF}_2$  crystals nucleated from both types of solution. The crystals were removed from the mother liquid, dabbed with tissue paper, and ground in an alumina mortar. The resultant powder was placed on a glass slide, covered with Mylar (to reduce water absorption during analysis, although later work showed this step to be unnecessary) and mounted in the Phillips Norelco X-ray Diffractometer. The resulting Cu-K $\alpha$  spectrum of the HF-grown crystals contained the published lines for the  $\text{NaHF}_2$  lattice with the same relative intensities. In addition, there were two lines corresponding to d-spacings of 3.42 and 2.197 Å. The first of these is known to be caused by Mylar, but the second was not identified. These results indicate that the crystals grown from aqueous and HF (aq) solutions are essentially pure  $\text{NaHF}_2$  and do not contain appreciable amounts of hydrates (i.e.,  $\text{NaHF}_2 \cdot n\text{H}_2\text{O}$ ) or extra HF (i.e.,  $\text{NaHF}_2 \cdot n\text{HF}$ ).

#### 4. KHF<sub>2</sub> Solutions

Although either the NaHF<sub>2</sub> or the KHF<sub>2</sub> lattice was considered suitable for this study, the former is far less hygroscopic; in consequence, most of the work during the first two quarters of the program dealt with the NaHF<sub>2</sub> lattice. (Since water absorbs IR in the region of interest, its concentration must be minimized.) A rather detailed report (Ref. 10) indicated, however, that the absorption of water by KHF<sub>2</sub> is less serious than anticipated. On the other hand, the solubility of KHF<sub>2</sub> (41 g/100 ml) is much greater than that of NaHF<sub>2</sub> (4 g/100 ml), thus KHF<sub>2</sub> should crystallize more rapidly. Furthermore, more information is available on the growth of KHF<sub>2</sub> crystals than on NaHF<sub>2</sub>. Accordingly the growth of KHF<sub>2</sub> single crystals was also investigated.

A saturated solution of KHF<sub>2</sub> in distilled H<sub>2</sub>O was prepared, using the same arrangement as for NaHF<sub>2</sub> except that polyethylene containers were used. Very thin plates with areas of several square centimeters grew in a matter of a few hours. Temperature control of the solution is extremely important because KHF<sub>2</sub> has a large positive heat of solution and its solubility has a large temperature dependence. Crystal-growing studies were suspended while attempts were made to locate a controlled-temperature water bath.

It became evident that the single-crystal method was not the best way to produce the desired sample. The incorporation of tritium into a bifluoride lattice by growing a single crystal from a tritiated aqueous solution is hindered by the fact that sodium and potassium bifluoride are very soluble so that large (up to 2500 curie) amounts of tritium would have to be handled to obtain a 25-curie specimen. Furthermore, eleven nuclear firms and Harshaw Chemical Company refused to bid on fabrication of a tritiated, encapsulated specimen. Major effort for the program was therefore shifted to the production of a composite pressed disk.

#### B. PREPARATION OF NaHF<sub>2</sub>

In the pressed-pellet technique, a small quantity of tritiated bifluoride is mixed with diluent and cold-pressed into a disk. Because there is an upper limit on the concentration of bifluoride in this technique (about 4%), the isotopic concentration of tritium must be as high as possible

(ideally, 100%). The method used in this program to achieve fully tritiated  $\text{NaHF}_2$  was to react tritium with fluorine and then react the resultant TF with  $\text{NaF}$ . The procedures were developed using normal material.

This method was appropriate because of the availability of people experienced in the handling of reactive fluorides, and of equipment for handling reactive fluorides. This capability was developed over the past several years during research for the U. S. Air Force.

### 1. Formation of Anhydrous HF

Desiccation of HF is difficult because of its strong affinity for water. In addition, HF reacts with both sulfuric acid and phosphorous pentachloride to form water (Ref. 11). On the other hand, fluorine and hydrogen can be satisfactorily dried by passage through liquid-nitrogen traps and the desiccated elements can then be reacted for form anhydrous HF.

The gases were stoichiometrically introduced into a 300-cc Monel container at a pressure of 2 atm and at a rate that kept the container temperature below about  $100^\circ\text{C}$ . The resultant HF was examined for purity with an all-Monel gas chromatograph, the column of which is a single, Monel U-tube initially immersed in liquid nitrogen. The sample is injected into the helium carrier and the lower vapor-pressure components condense on the column. Any other component present (e.g.,  $\text{N}_2$  or  $\text{H}_2$ ) continues on to the thermal-conductivity and electron-capture detectors. The liquid-nitrogen dewar is then removed, allowing the column to warm at a known rate. As the column approaches the normal boiling point of a component, it is released into the carrier and delivered to the detectors. Several gases have been found to elute near their normal boiling points (e.g.,  $\text{OF}_2$ ,  $\text{NF}_3$ ,  $\text{FNO}_2$  and  $\text{N}_2\text{F}_4$ ).

The HF produced by reaction of the purified elements showed only the gas-chromatographic peak characteristic of HF. No water could be detected.

### 2. Formation of $\text{NaHF}_2$

$\text{NaHF}_2$  was successfully prepared by the reaction of HF with  $\text{NaF}$ . An amount of HF calculated to be sufficient for complete reaction was condensed with liquid nitrogen into a Monel bomb containing 1 g of  $\text{NaF}$ . The

bomb was closed, removed from the charging apparatus and heated at 100°C for 15 min, reattached to the loading apparatus and connected to an evacuated pressure gauge. It was found to have an immeasurable residual pressure (less than 0.1 atm). When opened, the bomb contained a white sample. The X-ray diffraction pattern of this sample was indistinguishable from that for NaHF<sub>2</sub>. (The X-ray diffraction pattern of the starting material agreed with the published pattern for NaF.) Subsequent experiments showed that complete reaction occurs rapidly at room temperature, obviating the heating step.

### 3. Formation of Higher-Acid Fluorides

Higher-acid fluorides (e.g., NaF · 2HF) were undesirable in the final sample because they produce additional IR absorption lines. For example, KH<sub>2</sub>F<sub>3</sub> contains H<sub>2</sub>F<sub>3</sub><sup>-</sup> ions which can be expected to produce absorption lines in addition to the two IR lines of the HF<sub>2</sub><sup>-</sup> ion (Ref. 12). Solid KH<sub>2</sub>F<sub>3</sub> can be formed by reacting two moles of the HF with one of KF.

Three higher-acid fluorides of NaF are known: NaF · 2HF, NaF · 3HF and NaF · 4HF (Ref. 13). Froning, *et al.* (Ref. 14) describe them as semifluorides. The sodium system was chosen in preference to the potassium system because anhydrous NaF is readily obtainable whereas KF is usually hydrated; and the undesirable, higher-acid fluorides are readily converted to the bifluoride because of their high HF partial pressure.

A study of the higher-acid fluorides was then performed by reacting HF with NaHF<sub>2</sub>. The experiments were performed similarly to the NaF-HF experiments: HF/NaHF<sub>2</sub> molar ratios of 0.1 through 0.7 were obtained by condensing HF into a liquid-nitrogen-cooled vessel containing NaHF<sub>2</sub>. After heating at 100°C for 10 to 15 min the vessel was attached to an evacuated vacuum gauge and the interconnecting valve was opened. In all cases the pressure gauge indicated 0.33 atm. (The vapor pressure of HF at 20°C is 1.1 atm.) Even after removal of some of the HF by alternate evacuation and back-filling with helium, the pressure over the sample was still 0.33 atm. These results are, of course, consistent with the presence of a two-phase system.

The resultant samples were slushy at low HF/NaHF<sub>2</sub> ratios and very fluid (like water) at higher ratios. When the samples were removed

from the vessel, they immediately lost HF, increased in viscosity and then became solid. Some of the slushy material was cooled with liquid nitrogen for observation with an X-ray diffractometer; the resultant spectrum showed only the  $\text{NaHF}_2$  lines.

Apparently, the HF partial pressure over the two-phase mixture of  $\text{NaHF}_2$  and the next higher fluoride is so high at room temperature that HF is readily lost, leaving only the  $\text{NaHF}_2$  phase. This phase, having an HF partial pressure at room temperature of about  $10^{-5}$  atm, is stable at room temperature.

#### 4. The HF Partial Pressure Over the NaF- $\text{NaHF}_2$ Two-Phase Region

It is essential that the partial pressure of HF (TF) over the tritiated sample be low enough to prevent the escape of tritium and the resultant health hazards. The HF partial pressure over  $\text{NaHF}_2$  at any temperature can have any value over a range of several orders of magnitude according to the stoichiometry. Because  $\text{NaHF}_2$  does not sublime congruently, the HF partial pressure over any  $\text{NaHF}_2$  single phase will be a value between that for the NaF- $\text{NaHF}_2$  two-phase region and the  $\text{NaHF}_2$ -NaF · 2HF two-phase region. Furthermore, knowledge of the expected rate of tritium loss was a necessary part of the application for amendment to AGN's radioactive-handling license. Consequently, a study was initiated to determine this pressure as a function of temperature.

The HF partial pressure on the HF-rich side of  $\text{NaHF}_2$  (at room temperature) was found to be 0.33 atm. The HF partial pressure on the NaF-rich side has been measured by Froning, *et al* (Ref. 14) who report values obtained between  $147^\circ$  and  $269^\circ\text{C}$ . Although the results are in fair agreement, the experimental range is too wide for confident extrapolation to room temperature; however, extrapolation gives a value of  $10^{-5}$  atm, a value readily measurable by the Knudsen-cell technique (Ref. 16).

A room-temperature Knudsen-cell experiment was performed with a platinum cell. The orifice size and vaporization time were selected to give a 10-mg weight loss for an HF partial pressure of  $10^{-5}$  atm, yet the experimentally determined weight loss was less than 0.1 mg, a factor of 1/100 of the extrapolated literature value.

Additional Knudsen-effusion experiments were performed to determine the reason for the low experimental room-temperature value compared to the value extrapolated from References 14 and 15. The experimental value could be low because of:

- 1) A low sublimation coefficient,
- 2) A previously unrecognized phase transition,
- 3) The data in the literature are wrong, or
- 4) An error in the AGN room-temperature experiment.

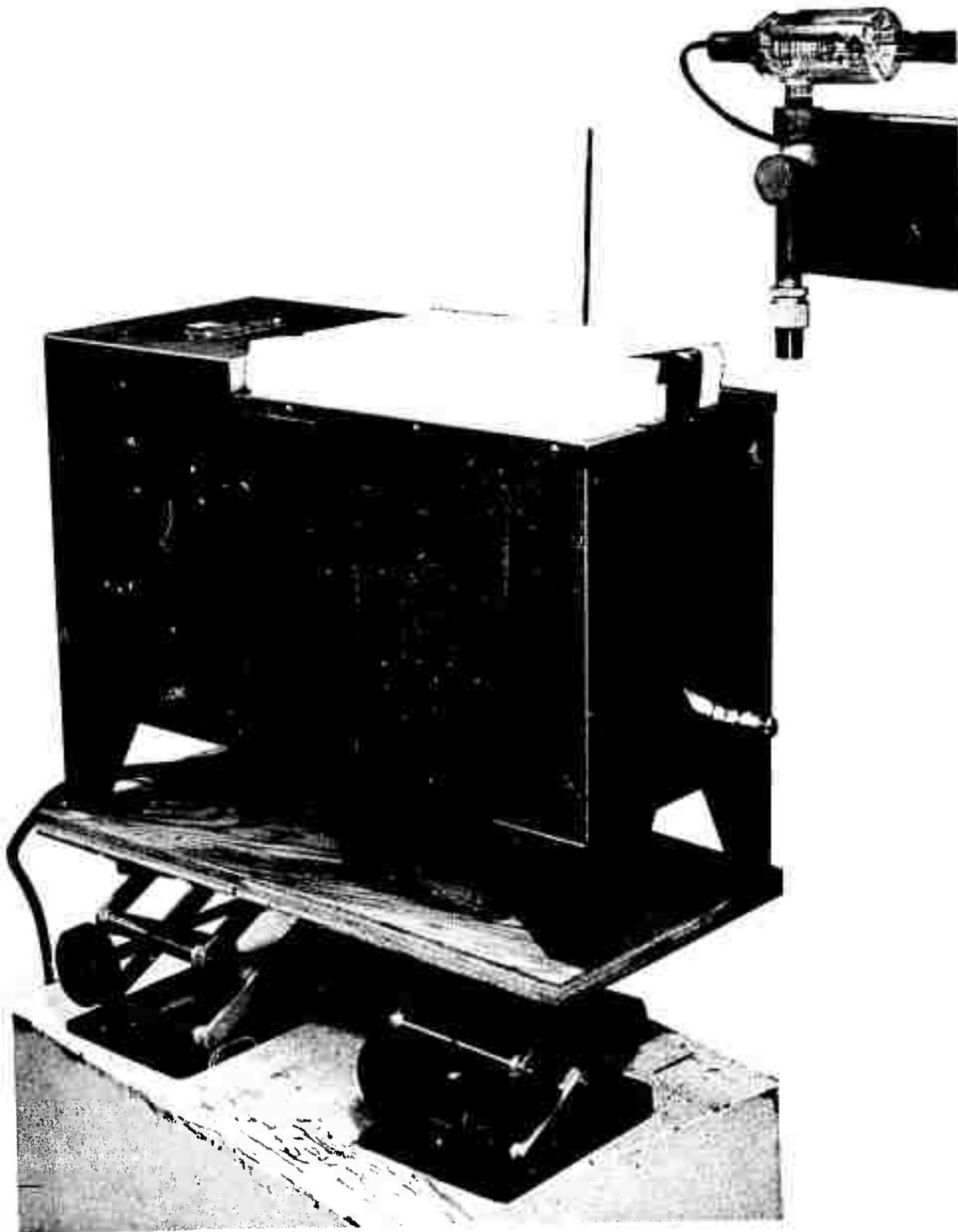
The additional experiments were performed at temperatures ranging from 127° to 198°C.

Three lids with different orifices as well as one without an orifice were used; the apparatus is shown in Figure 1. The  $\text{NaHF}_2$  sample previously heated to drive off a few percent of the HF (to ensure the presence of some NaF) was placed in a platinum crucible. The crucible was then placed in a copper outer crucible and one of the three platinum lids was placed on the inner crucible. The outer crucible was then attached to a vacuum system by means of an O-ring fitting.

When the residual pressure fell below  $10^{-5}$  torr, an isothermal water bath was raised around the crucible assembly. At the conclusion of the run, the bath was lowered and the crucible assembly was cooled with a room-temperature bath. The sample chamber was then brought to atmospheric pressure with helium and removed for weighing.

Temperatures and heating times were corrected by performing a series of calibration experiments in which a thermocouple was placed into the platinum cell containing NaF powder. (The NaF powder was the residue from the series of effusion runs.) Loss of sample by effusion through the opening between the lid and crucible was determined by using a lid without an orifice in performing experiments.

Apparent pressures calculated from Knudsen's formula are shown in Figure 2. The apparent increase in HF partial pressure with decreasing orifice size suggests that the sublimation coefficient (the free-surface sublimation rate divided by the equilibrium sublimation rate) is smaller than unity.



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FIGURE 1. KNUDSEN - EFFUSION APPARATUS

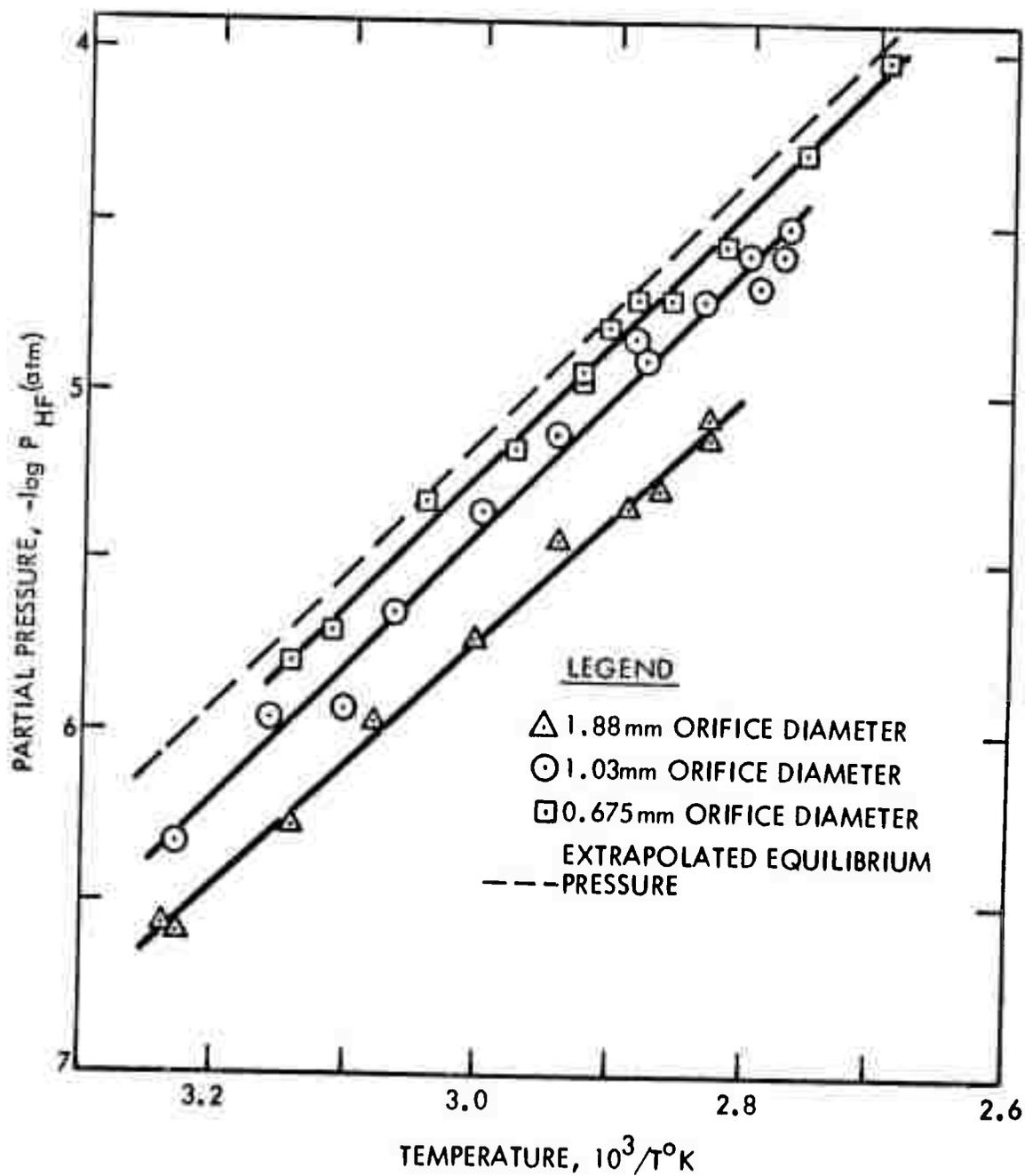


FIGURE 2. THE HF PARTIAL PRESSURE AS A FUNCTION OF TEMPERATURE OVER THE  $\text{NaHF}_2\text{-NaF}$  TWO-PHASE REGION

The use of Motzfeldt's relation (Ref. 17) suggests that the equilibrium HF partial pressure is lower by a factor of 15 than the value obtained by extrapolation of the data in References 14 and 15, and that the sublimation coefficient is approximately 0.05. The maximum credible TF-loss rate from the final sample was then calculated to be an acceptable  $8 \times 10^{-12}$  microcuries/cc in a vacuum. The rate in air will, of course, be much smaller.

### C. PRESSED-PELLET TECHNIQUE

The first three pellets were pressed from sodium bifluoride without the use of a diluent. The samples which had thicknesses of 0.9, 1.1, and 2.9 mm were translucent to visible light and opaque to IR. Two additional samples, prepared by mixing 0.5 mole %  $\text{NaHF}_2$  with KBr, were transparent to visible light. The thicker one (5.3 mm) was opaque to IR, but the thinner one (1.2 mm) transmitted about 65% of the IR beam, giving a spectrum similar to that reported by Ketelaar, Haas, and van der Elsen (Ref. 7).

Two pellets containing only KBr were prepared in evaluating the pressing technique. The pellets were of high quality; their IR spectra showed only a trace of water; they transmitted nearly 100% of the IR beam.

An evacuable, Perkin-Elmer KBr die was initially used for pellet fabrication. This die produces pellets 13 mm in diameter and any thickness up to 25 mm. A pressure of 50,000 psi for 1 minute was initially used.

A rectangular (2.5 x 16 mm) evacuable die (Fig. 3) was also obtained for the pellet work. This die has two advantages over the circular die used previously: 1) the shape of sample it produces more nearly approaches the shape of the IR beam, reducing the quantity of tritium needed, and, 2) after the sample has been pressed, the central laminar layer of the die can be removed (with the sample still ensconced) covered with windows and mounted directly in the IR beam.

At the conclusion of the pellet-pressing step, the middle section of the pellet-pressing die is removed with the sample firmly attached and placed into the IR spectrometer for analysis. The two sample holders originally received are 4 mm thick, limiting the final sample to 3 mm in the beam-path direction. Thicker sample holders which allow production of samples of 10 mm beam-path length were obtained locally.



FIGURE 3. EVACUABLE DIE USED FOR PRESSURE KBr SAMPLES

It then became apparent that the combination of  $\text{NaHF}_2$  as a potential tritium carrier and KBr as a matrix diluent offered the best possibility for success. The second choice, AgCl, was dropped from further consideration as a matrix when exothermic reactions were found to occur during power-grinding;  $\text{NaHF}_2$ -KBr samples were then used exclusively.

IR observations on the final samples were made in the region 650 to  $2000\text{ cm}^{-1}$ . Initially, the only absorption lines will be those caused by the asymmetric stretch and bending modes at  $846$  and  $730\text{ cm}^{-1}$  for the  $\text{TF}_2^-$  ion. The total observation period of several months is so short relative to the half-life of tritium that these absorptions of the  $\text{TF}_2^-$  ion will not appear to change. Absorption caused by formation of any helium compound will increase by 0.11% per week. Since the  $\text{TF}_2^-$  peaks are always present, it is important that they be well resolved so that they do not obscure too much of the IR scan.

The parameters which affect the infrared spectrum of a KBr- $\text{NaHF}_2$  pressed pellet were studied so that samples of maximum transmission and resolution could be produced. These parameters include:

- 1) Particle sizes of KBr and  $\text{NaHF}_2$ ,
- 2) Homogeneity of KBr and  $\text{NaHF}_2$  mixtures,
- 3) Magnitude and duration of applied pellet-pressing pressure,
- 4) Concentration of  $\text{NaHF}_2$  in KBr,
- 5) Thickness of pellet in the IR beam path, and
- 6) Amount of moisture present in the pressed pellet.

The study showed the optimum conditions for pellet-pressing include:

- 1) Mechanical-grinding time (includes consideration for homogeneity) -- 10 to 15 minutes,
- 2) Pellet-forming pressure -- 80,000 to 100,000 psi
- 3) Duration of applied pressure -- 1 to 10 minutes
- 4) Evacuation period of pellet die -- 3 to 10 minutes
- 5) Concentration -- < 4%

#### 1. Mechanical Grinding

To facilitate the grinding and mixing of the  $\text{NaHF}_2$ -KBr powders, grinding was performed in an agate vial with agate ball pestles mounted on a mechanical grinder (Wig-L-Bug, Crescent Dental Manufacturing Company). Samples containing Infrared Quality KBr (Harshaw Chemical Company) and 0.0, 0.1, 0.3, 0.5, 1.0, 1.5, 2.0, 3.0 and 10%  $\text{NaHF}_2$  (both technical grade and material synthesized as described earlier) were studied to determine the optimum grinding time. Grinding times were investigated through the range from 1 to 25 minutes.

The optimum grinding time was 10 to 15 minutes for a 1.5g sample for all concentrations of  $\text{NaHF}_2$  in KBr. Within this range, optically clear KBr pellets and translucent-to-opaque  $\text{NaHF}_2$ -KBr pellets were prepared. For grinding times less than 10 minutes, individual grains of  $\text{NaHF}_2$  were observable in the pellet, and one minute of grinding produced optically clear disks except for an irregular dispersion of  $\text{NaHF}_2$  grains through the pellet. Pellet flaking, the predominant symptom of excessive grinding, was observed for grinding times longer than 20 minutes for 0.5g samples.

#### 2. Optimization of Pressure and Grinding Time

The optimum conditions for pressing  $\text{NaHF}_2$ -KBr disks with acceptable IR-transmission properties were determined experimentally. This phase of the program was performed in a helium-pressurized glove-box to minimize moisture absorption by the KBr and to simulate work with tritium (the next phase of the program). Anhydrous  $\text{Mg}(\text{ClO}_4)_2$  was used as the desiccant in the glove-box. Fogging of the samples, which occurred with technical-

grade  $\text{NaHF}_2$ , did not occur when AGN-synthesized  $\text{NaHF}_2$  was used. The period of die evacuation (prior to pressure application) was investigated over the range from 1 to 30 minutes. The best samples were produced in the 3- to 10-minute range. The absorption peak at  $1640 \text{ cm}^{-1}$  (attributed to  $\text{H}_2\text{O}$ ) was never completely removed by the die-evacuation step but was reduced to an acceptable level.

The isostatic pressure used to form the disks was varied from 40,000 to 100,000 psi over periods ranging from 1 to 10 minutes. Although the duration of pressure application was not critical, the applied pressure was subject to limitations. At pressures below 80,000 psi, the pellet-rejection rate was fairly high; the major problem here was opaque pellet centers, apparently caused by improper leveling of the powder in the pellet press and inadequate pressing pressure. This opacity problem was minimized at pressures above 80,000 psi.

### 3. Optimization of Tritium Concentration and Sample Lengths

Because relatively large amounts of tritium must be incorporated into the sample, both sample length (in the IR-beam-path direction) and tritium concentration must be maximized. The effects of these parameters on sample resolution and transmittance were therefore studied. The results showed that resolution decreases with increasing  $\text{NaHF}_2$  concentration but is unaffected by sample length; as expected, transmittance decreases with increasing path length.

Stacking several thin pellets (each about 1 mm thick) gave equal or better IR absorption spectra than a single pellet of equivalent thickness.

### D. LOW-TEMPERATURE-CELL STUDIES

Since the pressed disk technique presents certain problems, an alternate technique involving the use of a low-temperature IR cell to observe a liquid-nitrogen-cooled tritium fluoride film was investigated. This method had been developed almost to the operational stage under an AGC-sponsored IR&D program; it was estimated that the experimental apparatus could be completed with about two man-weeks of effort. The problem to be solved was the construction of a vacuum-tight internal sample cell. In previous experiments

(under the IR&D program), the inner cell had leaked TF into the evacuated area between the inner and outer cells. For the current work, the Teflon gaskets originally used to seal the AgCl windows were replaced by epoxy\* cement developed for use in liquid nitrogen.

The low-temperature IR cell was made operational with a 0.4-mm-thick natural-HF film maintained between silver chloride crystals and functioned for 72 hr at  $-196^{\circ}\text{C}$  under about 1 micron of pressure. (An equivalent TF film would have contained 120 curies.) The 0.4-mm HF film proved too thick to transmit IR.

A new cell was assembled with a 0.1-mm-thick HF film, corresponding to a 40-curie sample. The film was lost as a result of difficulties during transport of the apparatus in the IR laboratory; however, the limited observations made with the film indicated IR translucency, and it appears likely a 0.1-mm HF film will transmit. No further activity is contemplated in this area, but the technique apparently is satisfactory and usable.

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\* 65 wt% Shell Epon 128 and 35 wt% General Mills Versamid 125.

#### IV. EQUIPMENT STUDIES

##### A. DETERMINATION OF IR SENSITIVITY

The work scope for this program specified fabrication of an IR sample containing 25 curies of tritium. This quantity of tritium will produce 10 micromoles of helium in 76 days, originally thought to correspond with the lower limit of detectability (estimated by Professor Pimentel to be 10 micromoles) by IR absorption spectroscopy. Because IR-transparent samples containing more than a few curies of tritium could not be produced, the lower limit of detectability was investigated in the hope that the value estimated by Pimentel was unduly conservative. The  $^1\text{HF}_2^-$  ion was chosen for this experiment because it can be studied easily and the results can be applied to the  $^3\text{HF}_2^-$  ion and the  $\text{HeF}_2$  molecule.

Samples containing from 0.08 to 0.8 micromoles of natural  $\text{NaHF}_2$  (corresponding to 1.2 to 12 millicuries in fully tritiated samples) were fabricated. The IR absorption spectra of selected samples (Figures 4 through 6, p 33 et seq.) indicate that the 0.2-micromole  $\text{NaHF}_2$  sample represents the lower limit of detectability for the  $^1\text{HF}_2^-$  ion. Although this value corresponds to a 3-millicurie level, the IR-absorption sensitivity for mass-one hydrogen is approximately twice that for mass-three hydrogen\*, and, consequently, the lower limit of detectability for the  $^3\text{HF}_2^-$  ion (and, it is believed, for the  $\text{HeF}_2$  molecule as well) should be 0.4 micromoles. Thus a 0.0-curie sample can, in principle, produce a detectable spectrum in three months. (A 3-curie sample could, in principle, produce a detectable spectrum in three to four weeks.)

The actual relationship is complex; see Section III.B.

## B. WINDOW-CEMENT STUDY

AGN's radioactive-material license requires double containment of radioactive samples. The TF partial pressure over the tritiated sodium bifluoride/potassium bifluoride samples will be low enough to satisfy the MPC requirements of  $2 \times 10^{-5}$  microcuries/cc so that the sample lattice can be considered a primary container. Secondary containment was accomplished by affixing IR-transparent windows to both sides of the sample holder immediately after the sample was removed from the press.

A study was made to find a suitable cement and curing-time/temperature combination for attaching the windows to the metal sample holder. The best combination was found to be 65/35 wt% mixture of Shell Epon 828 and General Mills Versamid 125 cured at room temperature.

## V. TRITIUM STUDIES

### A. INITIAL TRITIUM WORK

During the initial work with tritium, leaks were found in the tritium cylinders received from the vendor (ORNL). The purity of the gas in the cylinders (specified at 99% pure tritium) was experimentally determined. The gas was exposed to fluorine and then to NaF in the usual manner. After exposure to fluorine it was apparent that appreciable portions (later found to be  $O_2$  and  $N_2$ ) were unreactive to fluorine. Also the appearance of the NaF exposed to the gaseous mixture was atypical. Two methods were used to determine the tritium concentration in the cylinder.

The concentration of tritium in the original gas was determined by P-V-T measurements on the product TF (the most expeditious method then available). A quantity of gas from the tritium cylinder was allowed to react with an equal amount of  $F_2$  (as determined by P-V-T relations). The resultant TF was condensed with liquid nitrogen while the remaining residual gas (if any) was pumped out. (Because of the small quantities involved, relatively large amounts of non-condensable impurities, such as air, would not be detectable on the Bourdon gauge.) The pressure of the gas when warmed to room temperature was less than the vapor pressure; i.e., there was no liquid phase present. This measured pressure when used with the known volume of the system and the HF-association factor (1.1) given by Long, et al, (Ref. 18) yielded the total number of moles. The calculation showed that only about one-fifteenth of the cylinder gas was tritium, rather than the 99% stated by the vendor.

The second method placed an upper limit on the concentration of tritium in the gas cylinder. The experiment to synthesize  $\text{NaTF}_2$  was repeated, but with 15 times the quantity of gas removed from the tritium cylinder for the first method. The quantity of  $\text{F}_2$  was also increased by the same factor to assure complete reaction with the tritium in the apparatus. The resultant TF was condensed with liquid nitrogen and the residual non-condensables were pumped off. The TF was reacted with sufficient NaF to give stoichiometric  $\text{NaTF}_2$  if the gas in the original tritium cylinder contained only one-fifteenth tritium. The reaction produced a crusty solid.

From earlier experiments with natural HF and NaF, it was known that an excess of HF would produce a slushy  $\text{NaHF}_2$ . The crusty appearance of the resultant sample indicated that the gas in the cylinder was at least one-fifteenth tritium. The results of the TF pressure measurements, though less accurate, also placed a lower limit of one-fifteenth on the tritium content of the cylinder.

#### B. FORMATION OF TRITIATED SAMPLES

The optimum conditions for fabrication of rectangular tritiated pellets (2.5 by 16 mm cross section for this program) were determined to be:

- 1) Concentration of tritiated  $\text{NaHF}_2$  -- 1 wt%
- 2) Mixing period (Wig-L-Bug) -- 5 minutes for  $< 0.5$  g of material
- 3) Die-evacuation period -- 5 minutes
- 4) Applied pressure --  $9.7 \times 10^4$  to  $1.3 \times 10^5$  psi

The tritium concentration is controlled by varying the thickness of the pellet.

The first two pellets were produced before the discovery of the low tritium content in the gas cylinder. After pressing, the first tritiated sample was opaque to visible light; additional pressing did not improve transmittance. From earlier work with natural material, it was known that a sample opaque to visible light would not transmit IR. A second pellet pressed in the same manner was transparent to visible light.

At this point it was decided to produce a sample with less than the desirable IR transmission, but with sufficient tritium for detection of

any helium-containing molecule in a reasonable time. Therefore a pellet subsequently found to contain 7 curies was fabricated. This pellet, which was translucent to visible light, was opaque to IR radiation even below  $1000\text{ cm}^{-1}$ . The low tritium content of the cylinder was discovered and 200 additional curies were received without cost to the contract.

The second shipment of tritium cylinders was examined more closely; the contents were analyzed to determine the hydrogen isotopic composition and the concentration of impurities other than protium or deuterium. A CEC Model 21-611 mass spectrometer was modified to permit direct injection of a sample into the diatron section to increase the sensitivity. Known mixtures of gases suspected to be contaminants in the tritium were analyzed separately to determine relative sensitivities of the modified equipment. This calibration was necessary because the observed response is a function of both the electron-capture cross section of, and the detector sensitivity for, the species of interest. Results of the mass-spectrometric analysis (Table 3) indicated that the tritium content of the sample was 82.4%, with less than 1% mass-one hydrogen. Argon (11%) was the principal impurity.

Table 3

TRITIUM-SAMPLE ANALYSIS BY MASS SPECTROMETRY

<u>Gas</u>	<u>Mass</u>	<u>Composition, Mole %</u>
Hydrogen	2	0.4
Helium	4	0.6
Oxygen	32	0.5
Nitrogen	28	2.0
Argon	40	11.0
Water	18	2.0
Miscellaneous	--	1.1
Tritium	6	82.4

The concentration of mass-one hydrogen (protium) was of greatest concern since other impurities (totaling 17%), such as Ar or N, are readily removable during the bifluoride-forming step. The results of the mass-spectrometer study indicated insufficient protium content to interfere with the experiment.

A cursory examination of the mass-spectrometric results revealed apparent disagreement with the IR results. IR spectrograms of tritiated samples show absorption peaks for the  $\text{TF}_2^-$  ion at 730 and 846  $\text{cm}^{-1}$  (asymmetric stretch and bending vibrations, respectively), and for the  $\text{HF}_2^-$  ion at 1230  $\text{cm}^{-1}$  (the bending mode; the 1425  $\text{cm}^{-1}$  stretching mode peak is not visible because of poor transmission in this region). The bending absorptions are about the same magnitude, suggesting that the tritium-to-protium ratio is about 1, but this is not a valid conclusion because absorption intensities are a complex function of the mass (Ref. 19); simply stated, the lower-mass isotope will absorb more than the higher-mass isotope.

There is also the possibility that water originally absorbed in the KBr matrix can exchange with the  $\text{TF}_2^-$  ions to increase the magnitude of the observed  $\text{HF}_2^-$  absorption peaks. In this event, however, a  $\text{T}_2\text{O}$  molecule must be formed to replace every  $\text{H}_2\text{O}$  molecule that was exchanged with a  $\text{TF}_2^-$  ion.



The existence of absorption peaks attributable to  $\text{T}_2\text{O}$  would indicate the extent of absorbed-water contribution. A special pellet (Number 7), containing 0.1 curie of tritium, was fabricated in an effort to detect the  $\text{T}_2\text{O}$  molecule. The transmission of this pellet is excellent, indicating peaks at 970 and 2160  $\text{cm}^{-1}$ , corresponding, respectively, to the asymmetric-stretch and bending frequencies; however, the absorptions are not sufficient to satisfactorily account for a 1:1 tritium-to-protium ratio. The  $\text{H}_2\text{O}/\text{T}_2\text{O}$  exchange is estimated to contribute from 2 to 5% of the observed  $\text{HF}_2^-$  peak.

Since helium-containing molecules are detectable in a reasonable time by observing samples containing considerably less than 25 curies, three additional samples (Pellets 4 through 6) containing 0.62, 1.3 and 1.6 curies of tritium were fabricated. Such samples have a considerably greater range of transmission and, consequently, a higher probability of indicating helium-compound formation than samples containing larger quantities of tritium in the form of  $\text{NaTF}_2$ . Of course, any product absorptions will be correspondingly weaker for a given time.

During the last few months of the program, three additional samples (Pellets 7 through 9) containing 0.1, 2.0 and 3.0 curies were fabricated. The composition of the tritium carrier was chosen to be fully tritiated stoichiometric  $\text{NaHF}_2$ . In earlier samples, relatively less HF was added so that a two-phase mixture of a few percent NaF in  $\text{NaHF}_2$  was obtained. This ensured low enough HF partial pressure for safe handling, but the excess NaF reduces IR-transmission. Stoichiometric sodium bifluoride was used in an effort to obtain the best possible sample. This process does not increase health hazards, because the tritiated  $\text{NaHF}_2$  is exposed to vacuum after preparation long enough to shift the composition to the NaF-rich side of the  $\text{NaHF}_2$  single phase. The composition then has an HF partial pressure characteristic of the NaF- $\text{NaHF}_2$  two-phase region, yet is still single phase. In addition, the method of sealing the sample with cemented windows was demonstrably effective in retaining the tritium for safe handling and observation.

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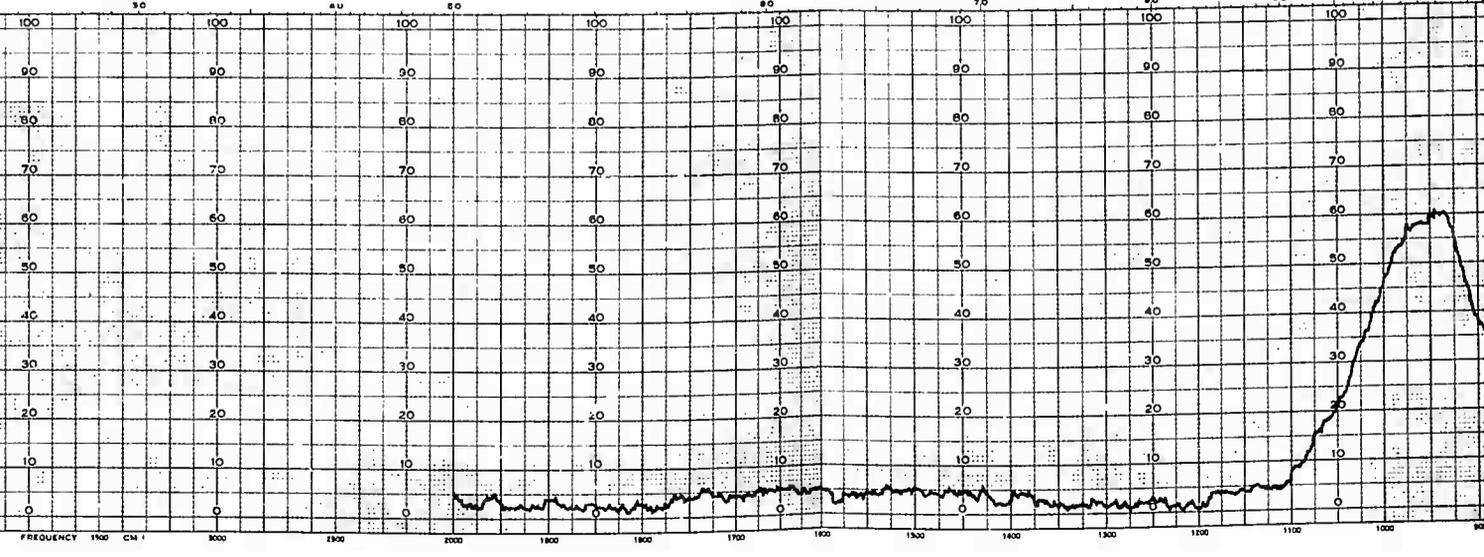
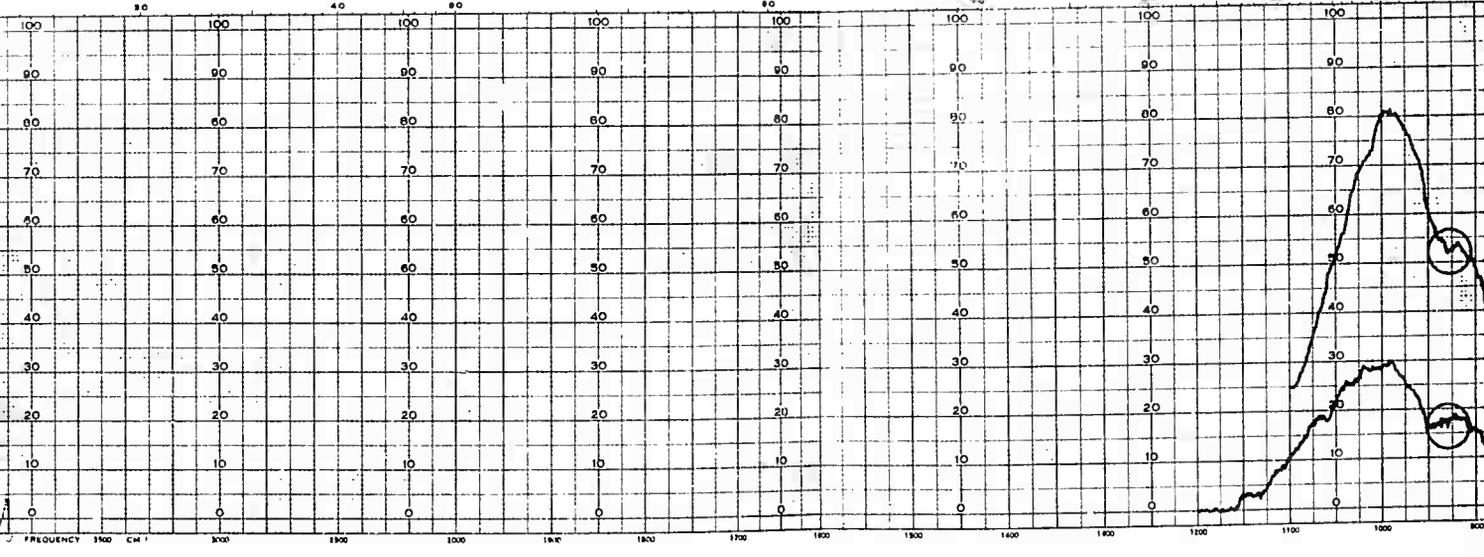
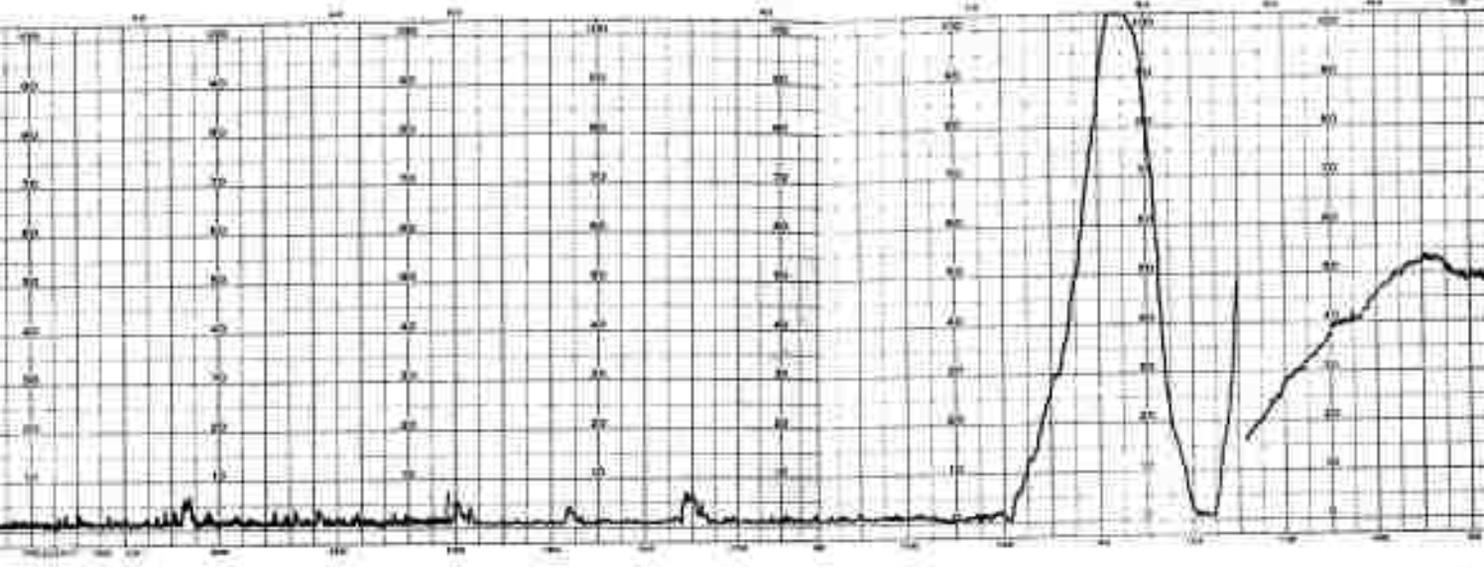
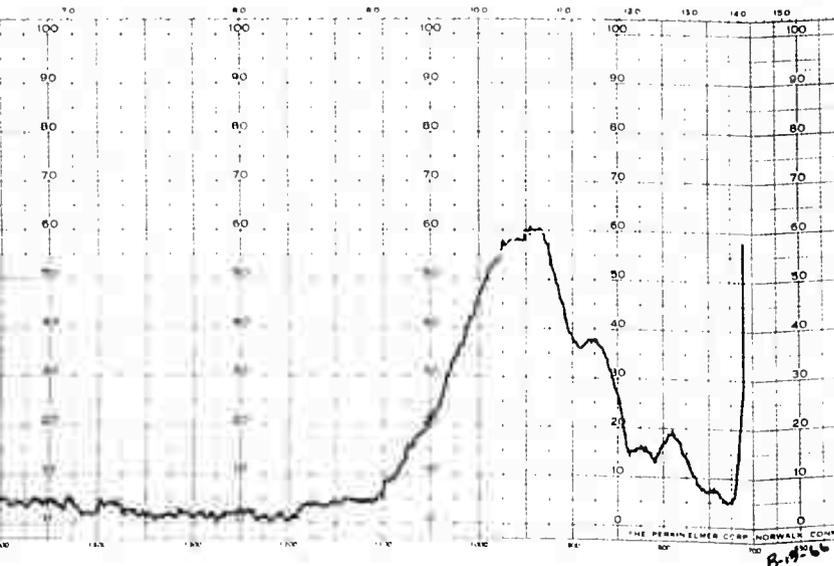
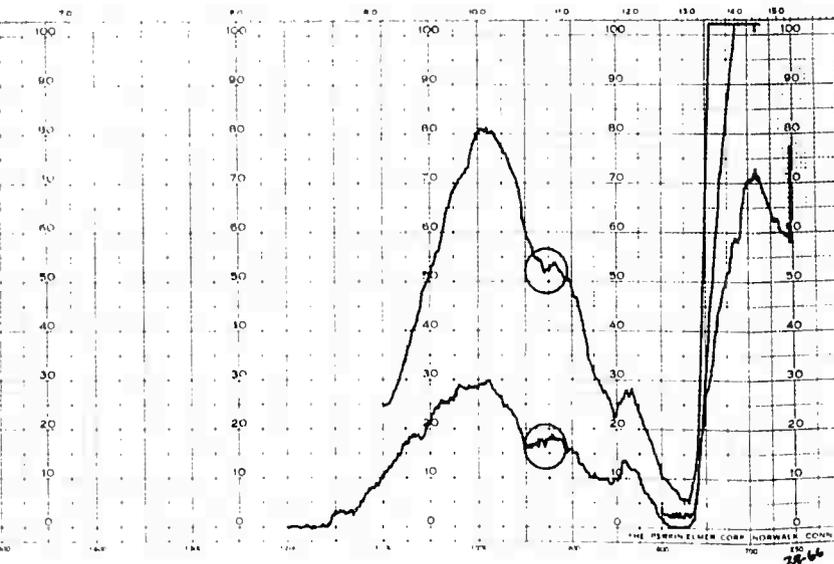
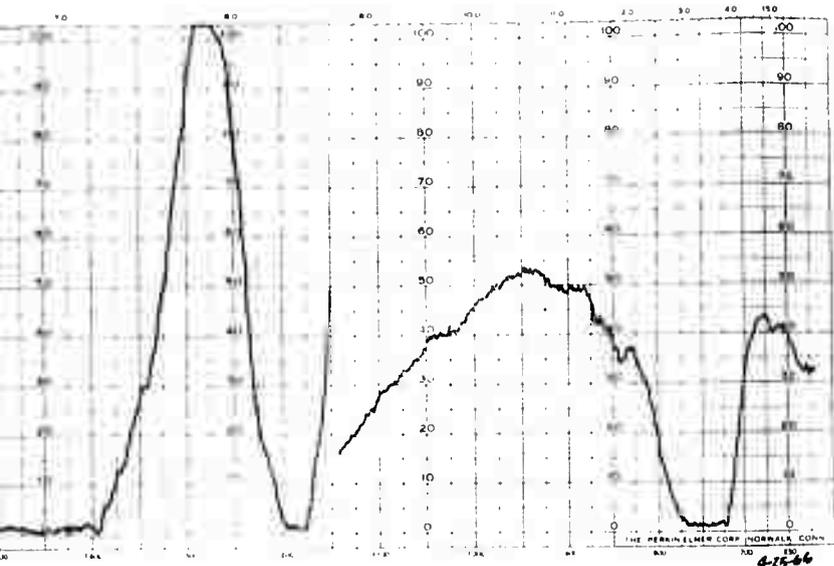


FIGURE 4: PELLET 4 (0.62 curies): INFRARED SPECTRA  
 (From top to bottom, 25 April, 8 July and 19 August 1966)

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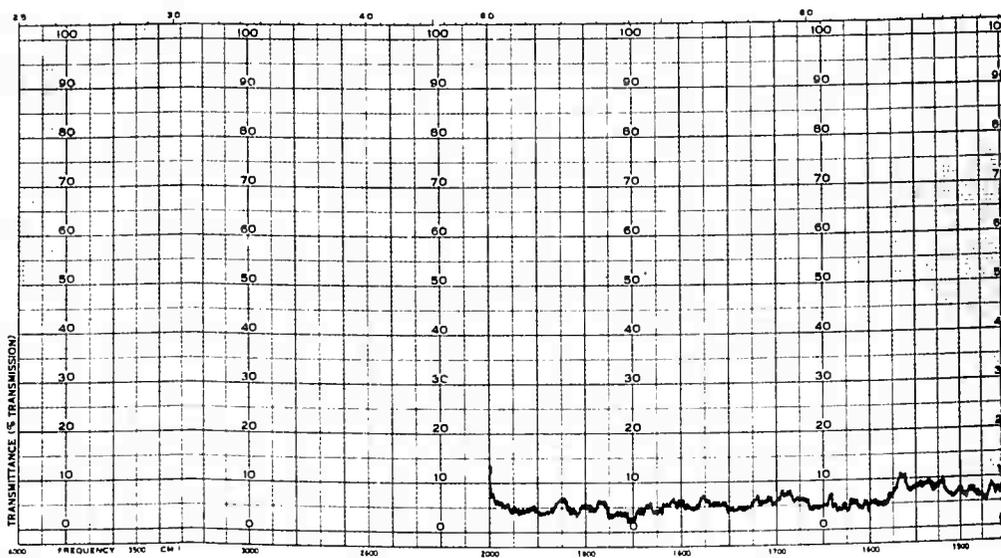
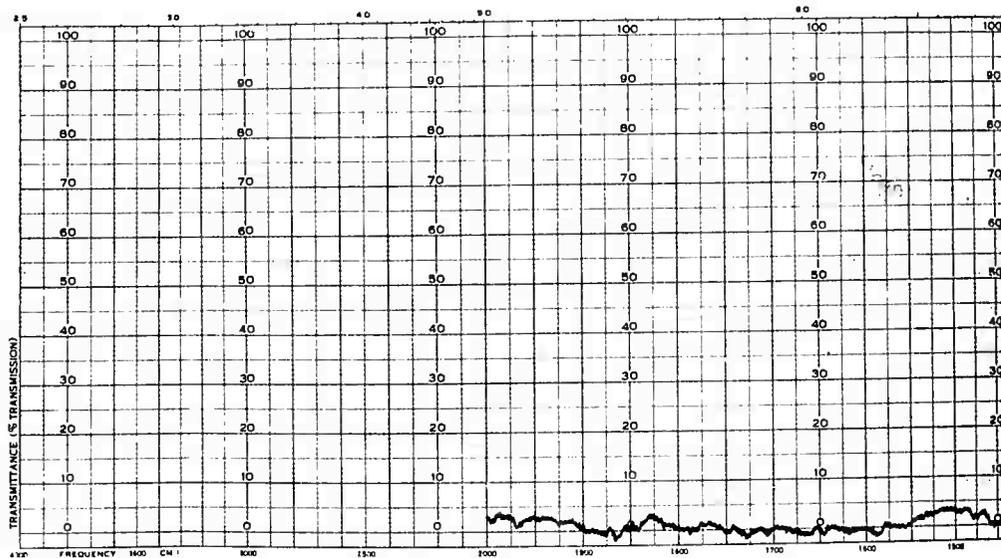
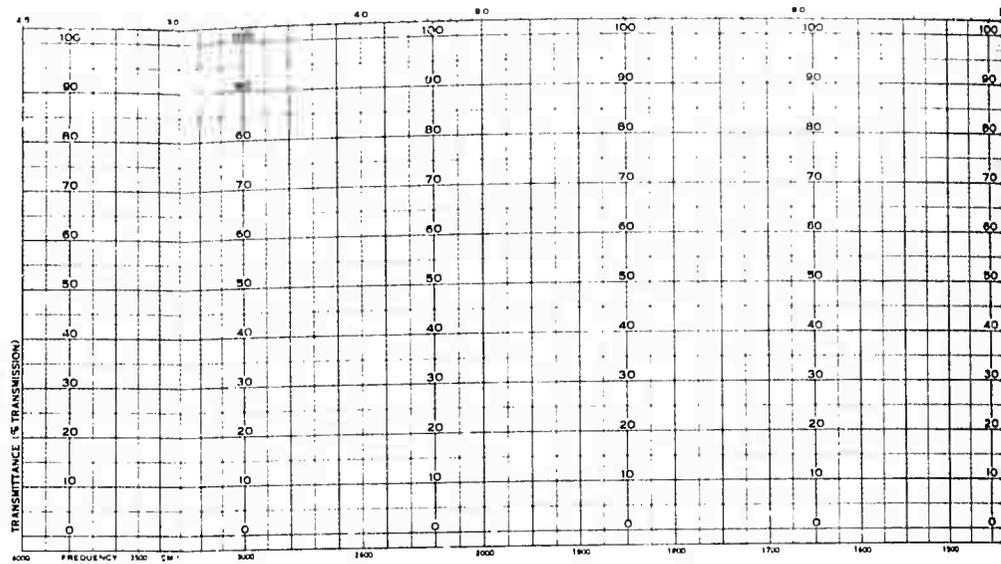
AGN 1530



ories): INFRARED SPECTRA  
(8 July and 19 August 1966)

B

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39.1-66-1291

A

FIGURE 5: PELLETT 5 (1.3 curies)  
(From top to bottom, 25 April, 6 April)

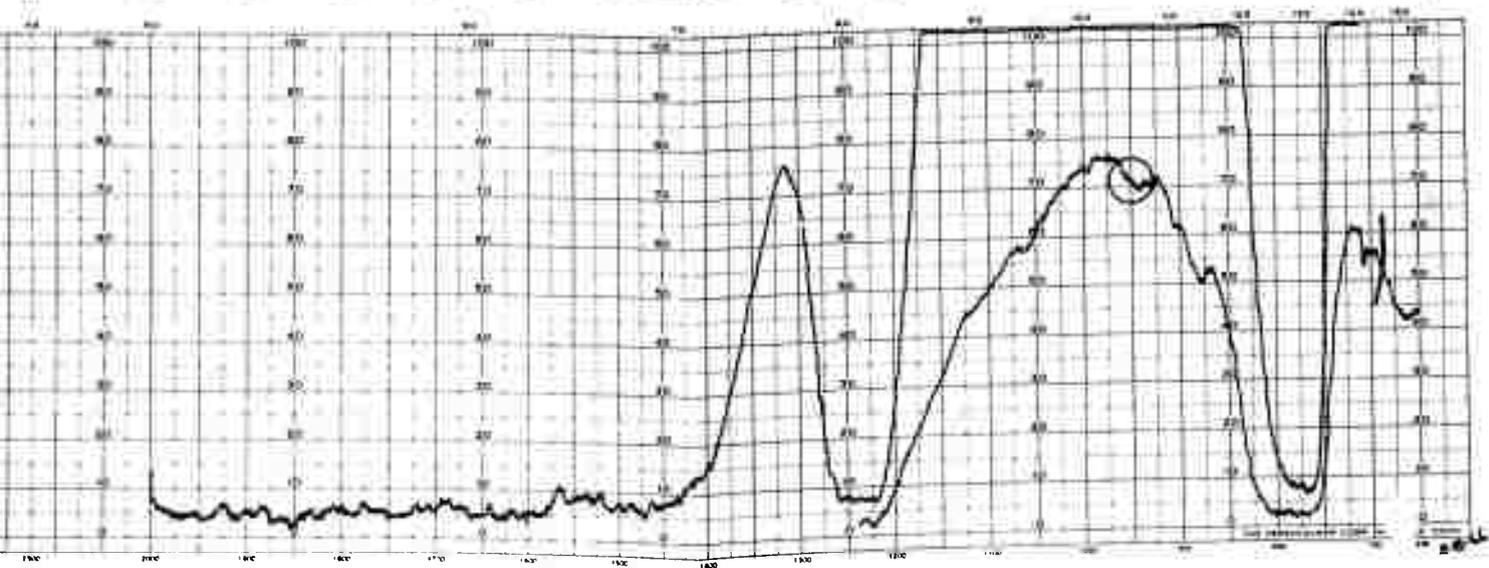
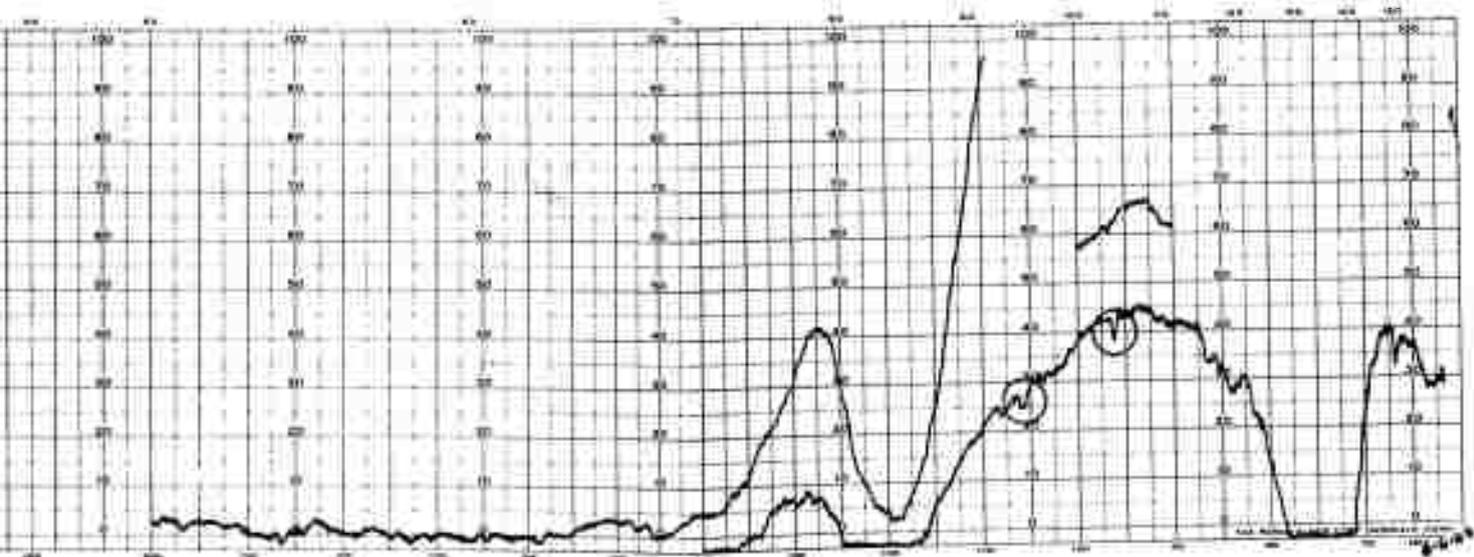
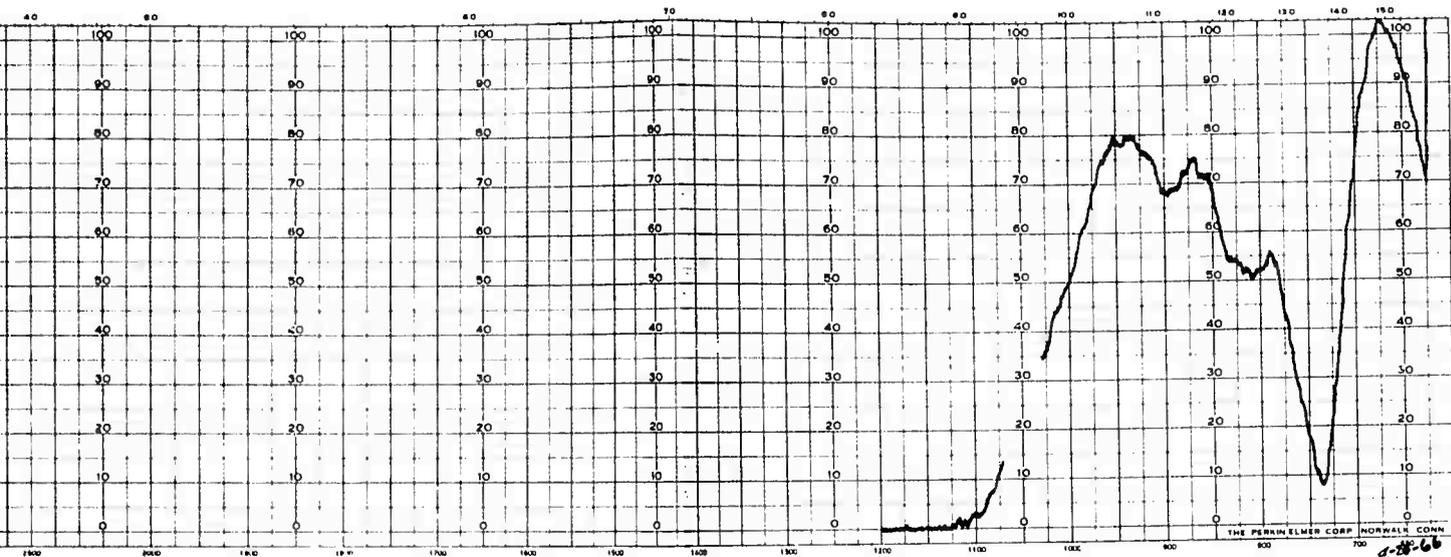


FIGURE 5 : PELLET 5 (1.3 curies) : INFRARED SPECTRA  
 (From top to bottom, 25 April, 6 June and 8 August 1966)

12

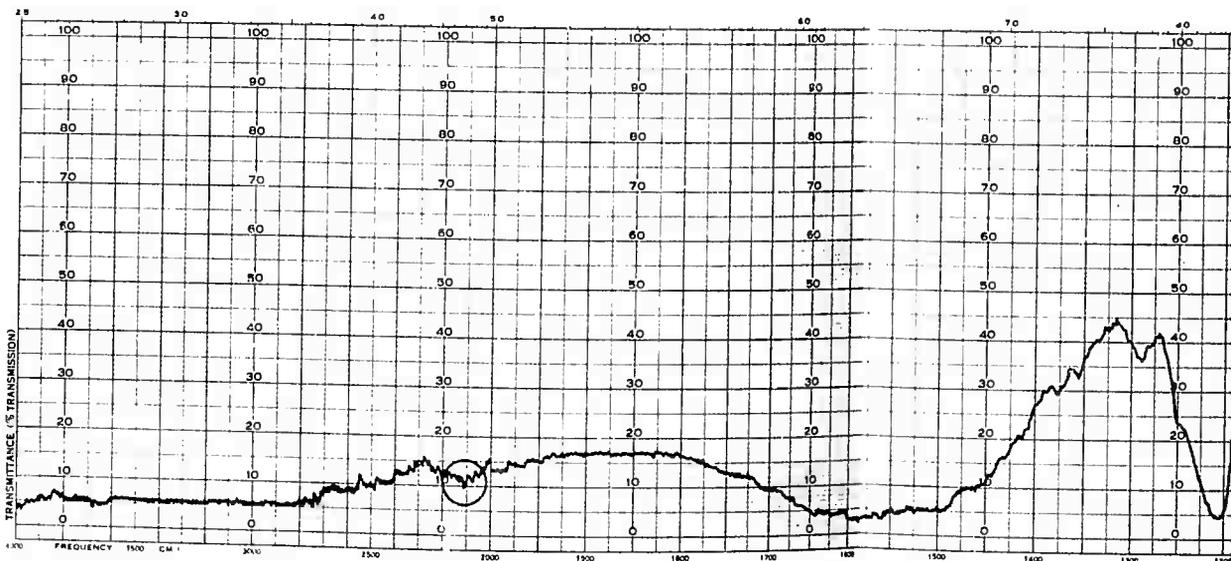
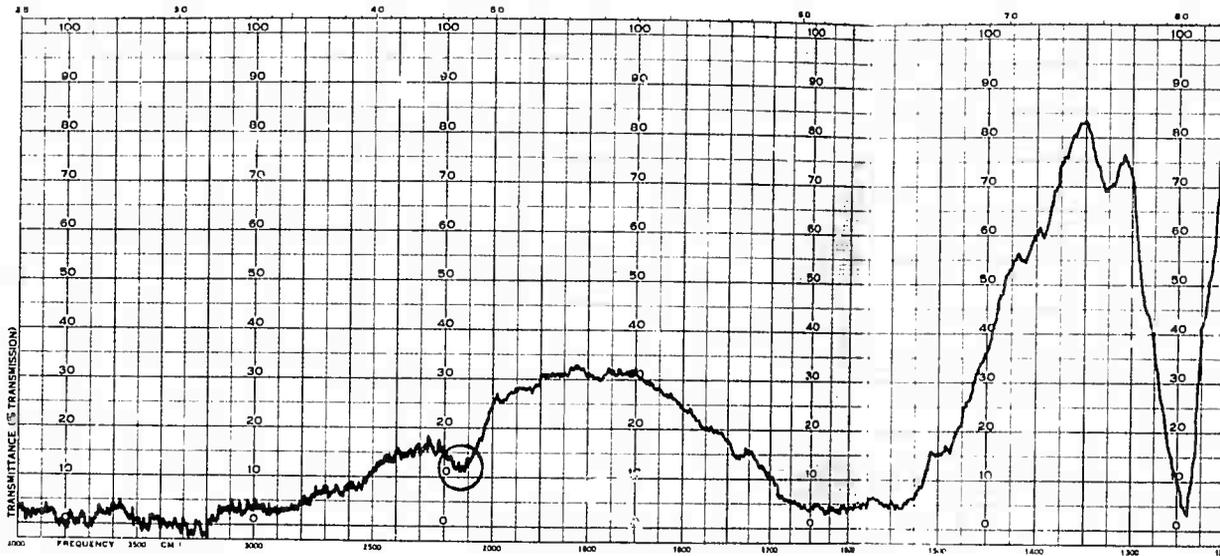
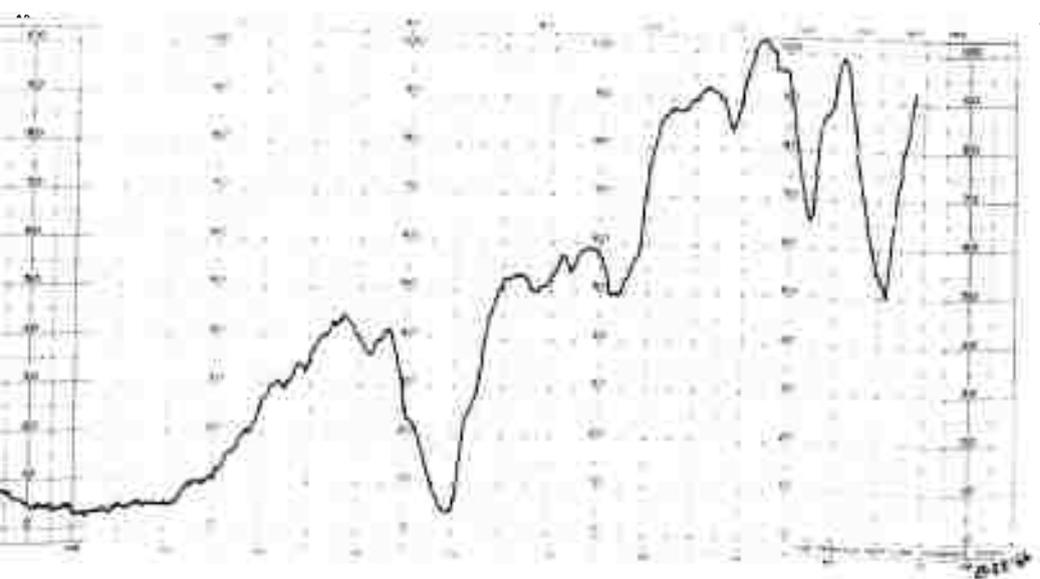
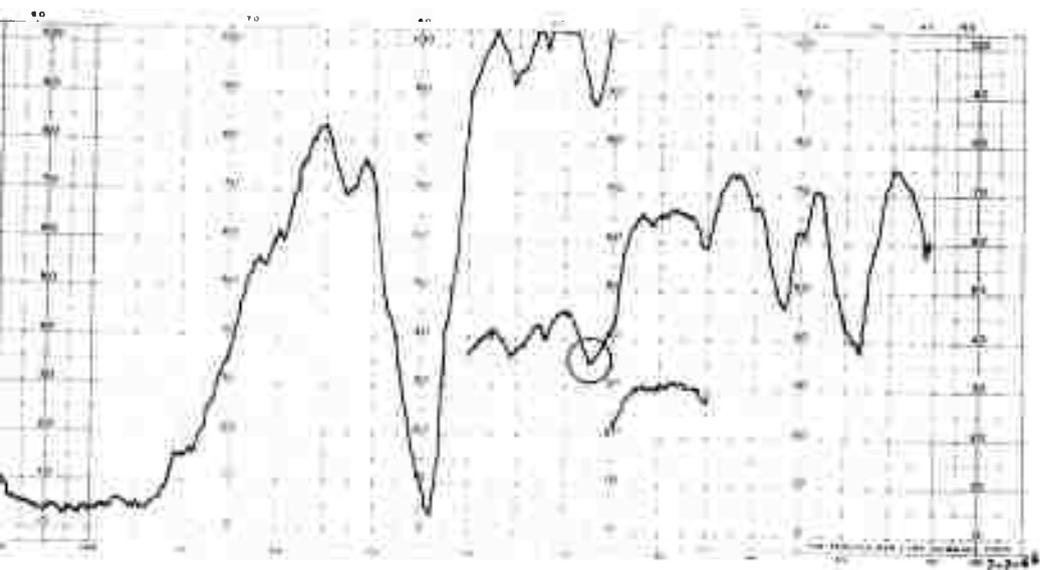


FIGURE 6: PELLET 7 (0.1 curies): INFRARED SPECTRA  
 (Top, 7 July 1966, and bottom, 22 August 1966)

AGN 1530



NET 7 (0.1 curies): INFRARED SPECTRA  
, and bottom, 22 August 1966)

5

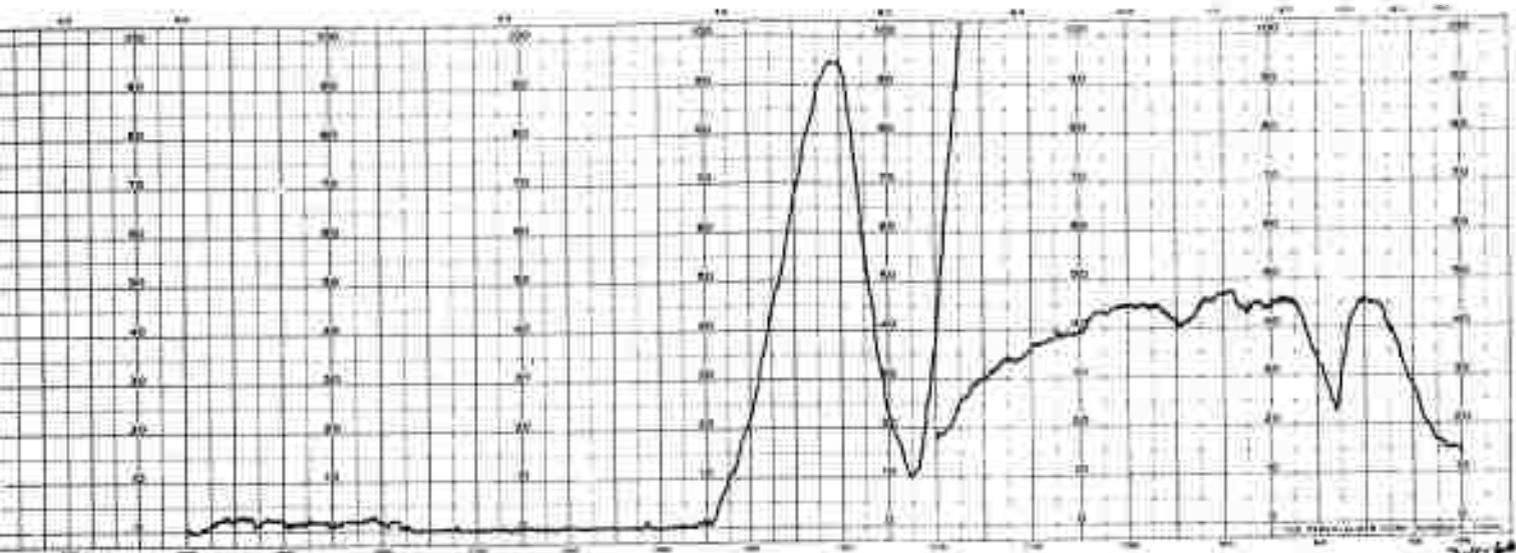
AGN 1530



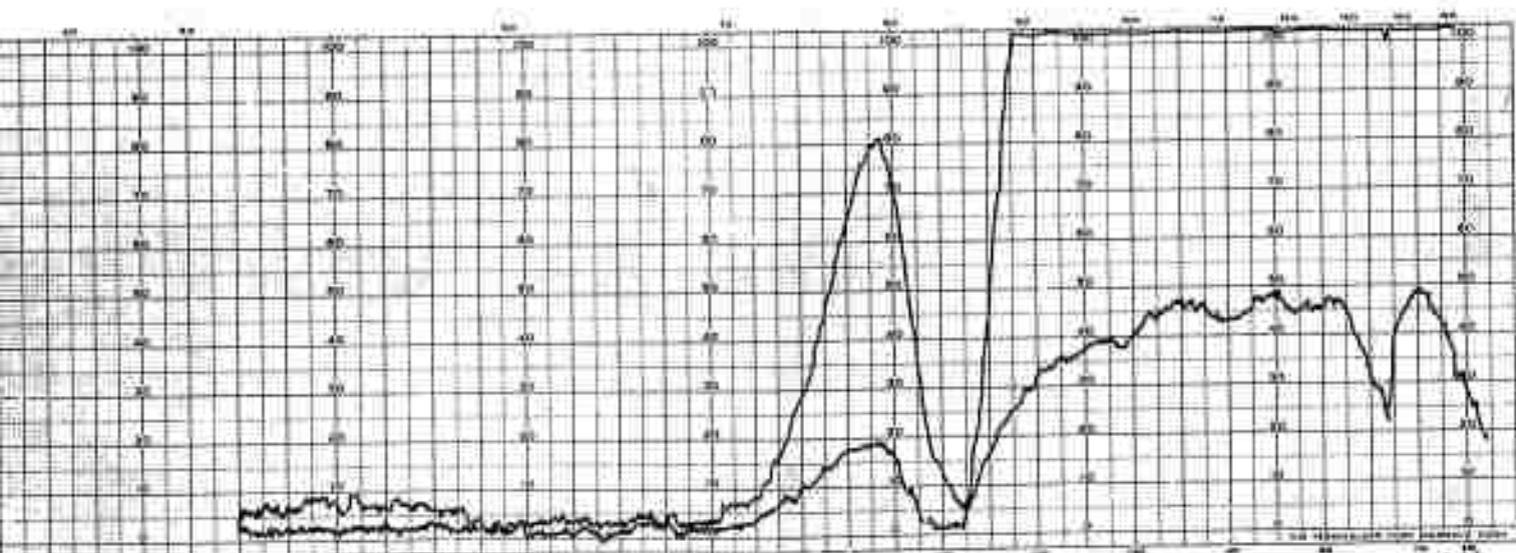
FIGURE 7 : PELLET 8 (2.0 curies) : INFRAR  
(From top to bottom, 11 July, 2 August and

A

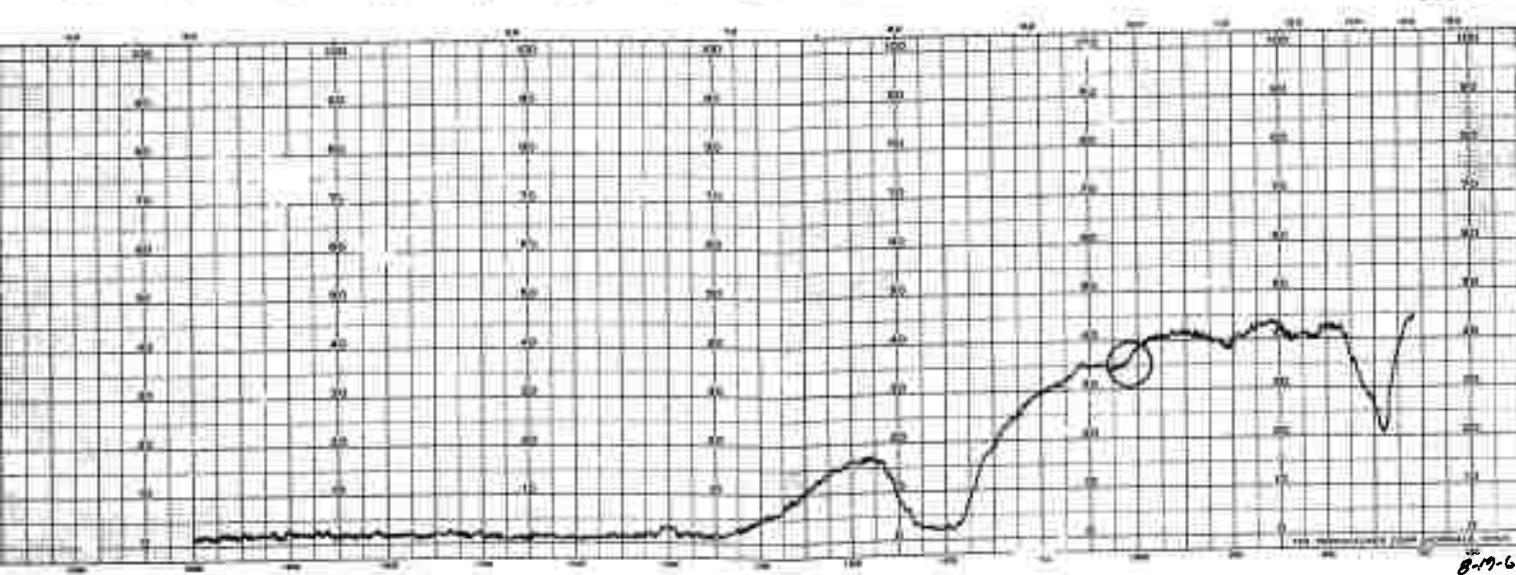
39,1-66-1293



7-11-66



8-2-66



8-19-66

FIGURE 7 : PELLET 8 (2.0 curies) : INFRARED SPECTRA  
 (From top to bottom, 11 July, 2 August and 19 August 1966)

B

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		2b. GROUP	
3. REPORT TITLE PRODUCTION AND IDENTIFICATION OF HELIUM DIFLUORIDE			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Summary Report (1 December 1964 thru 31 August 1966)			
5. AUTHOR(S) (Last name, first name, initial) Miller, Alan R.			
6. REPORT DATE October 1966	7a. TOTAL NO. OF PAGES 37	7b. NO. OF REFS 19	
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d. Program Code 5910			
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11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Office of Naval Research Department of the Navy Washington, D. C.	
13. ABSTRACT - An 18-month program to produce and identify the helium difluoride molecule is summarized in this final report. Nine tritiated samples were produced during the program; new IR absorption peaks found in two samples suggest that tritium decay is producing observable changes. It appears too soon to assign these new peaks to helium-compound formation. Experiments during the program indicated it is possible to detect helium-containing compounds in samples containing as little as one-half curie of tritium.  The beta decay tritium in a bifluoride-containing specimen was followed by infrared spectrophotometry for evidence of the conversion of F-T-F <sup>-</sup> ions into F-He-F molecules.  It was experimentally determined that the optimum method of producing samples was to mix a small amount of polycrystalline NaHF <sub>2</sub> with KBr, and cold-press the mixture into transparent pellets. The nine tritiated samples produced under this contract were fully encased to prevent the escape of radioactive material.			

14. KEY WORDS	LINK A		LINK B		LINK C	
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