**SAMPLING FFTF SODIUM COOLANT
FOR ANALYTICAL PURPOSES**

F. A. SCOTT

SEPTEMBER, 1967

**AEC RESEARCH &
DEVELOPMENT REPORT**

ARCHCO for 60013 2740	DEC 5 1967
LF 60013 61644 2710	DEC 7 1967

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission,

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

3 3679 00060 6196

BNWL-491
UC-4, Chemistry

SAMPLING FFTF SODIUM COOLANT FOR ANALYTICAL PURPOSES

By

F. A. Scott

Chemical Research Section
Chemistry Department

September, 1967

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

TABLE OF CONTENTS

INTRODUCTION.	1
SUMMARY	2
GENERAL DISCUSSION	3
SELECTION OF AN INITIAL SAMPLING TECHNIQUE	5
Vacuum Thief Sampler.	6
The Dipping Cup Sampler	8
The Drain Sampler	10
The Bypass Loop Sampler	12
SELECTION OF A SECONDARY (ALIQUT) SAMPLING TECHNIQUE	14
Extrusion	22
Dipping Cup	22
Sectioning	23
IDEALIZED SAMPLER FOR FFTF EXPERIMENTAL LOOPS	25
REFERENCES	28
DISTRIBUTION	32

SAMPLING FFTF SODIUM COOLANT FOR ANALYTICAL PURPOSES

F. A. SCOTT

INTRODUCTION

The function of the FFTF will be the testing of fast reactor fuel in prototypical environments. To do this, tests must be carried out under defined and controlled experimental conditions including coolant flow, temperature, neutron flux, and coolant chemistry. Of particular importance are tests to determine the level of trace impurities in the sodium, since knowledge of coolant impurities is essential for sustained reactor operation. This report reviews the present state of the art of liquid metal sampling for analytical purposes. Emphasis is placed on the sampling of operating reactor coolants and on relating this to the FFTF program needs.

Control of sodium impurities will be more important for the FFTF than for sodium cooled power reactors because of the large effects that variations in these parameters have on the results or interpretation of the fuel tests. It is essential, for example, that a continuous daily record of coolant impurities be available when a six-months' fuel test is complete. The test environment must be held constant so that the data can be directly extrapolated to service in some other reference case. Each off-standard "excursion" reduces confidence in the final test results.

If the coolant impurities fluctuate significantly from those expected in the reference reactor, the value of the test may be seriously prejudiced. The coolant chemistry in various loops of the reactor will differ, and operating standards for impurity control will fluctuate as experiment requirements change. To attain both impurity level control and standard operating conditions, precise, current measurements of impurity levels must be available.

One of the major problems which must be overcome to permit the measurement of coolant impurity concentrations is that of obtaining representative and reliable samples of the coolant.⁽¹⁾ In fact, some investigators believe that considerably more than half the analytical effort should be expended in taking and protecting the sample.⁽²⁾ The results of an AEC-sponsored round robin on carbon determination⁽³⁾ indicate that it may actually be impossible to obtain a representative sample, at least in the case of this element. Extensive experience has been gained in the area of sampling non-radioactive sodium loops for analytical purposes.^(4,5) Much less experience has been gained in the sampling of the highly radioactive sodium occurring in an operating reactor such as FFTF, and no entirely satisfactory method is presently available.

Information for this report has been obtained primarily from two sources: published literature and personal contacts at operating liquid-metal-cooled reactor sites. The sites visited included:

1. Atomics International (AI), where the sampling of Sodium Reactor Experiment (SRE), Hallam Nuclear Power Facility (HNPF) and the Liquid Metal Engineering Center (LMEC) were discussed with Dr. C. D. Bingham, Roger Woodruff, W. A. Olson, Larry J. Johnson, R. E. Durand, G. A. Carlson, and F. W. Murbach
2. The Experimental Breeder Reactor-II (EBR-II), where D. W. Cissel, C. Charothers, Earl Ebersol, C. C. Miles, and W. J. Richardson were contacted
3. Los Alamos Scientific Laboratory (LASL), where Dr. C. F. Metz, Dr. Glen R. Waterberry, Karl S. Bergstresser, and V. J. Rutkauskas were contacted
4. Atomic Power Development Associates (APDA), where sampling of the sodium technology loop and the Fermi reactor were discussed with E. F. Hill, Ray Hunter, and J. P. Lagowski
5. Argonne National Laboratory (ANL), where J. Ross Humphreys, George A. Bennett, F. Smith, R. Jaross, S. Skladzien, and I. Filewitz were contacted
6. General Electric (GE), Vallecitos and San Jose, where D. Dutina, G. Billures, L. Pohl, and R. W. Lockhart discussed the sampling of Southwest Experimental Fast Oxide Reactor (SEFOR), the PA-15 loops, and Submarine Intermediate Reactor (SIR).

Sampling procedures at foreign sites were reviewed by discussions with recent visitors and literature reviews.

SUMMARY

The current state of the art of liquid metal coolant sampling has been reviewed with particular emphasis on the sampling of highly radioactive streams in operating reactors and on the requirements of the FFTF program. The advantages, disadvantages, available experience, and applicability to FFTF needs of each of the four most promising means of removing a small representative portion of the loop coolant (initial sampling) have been compared. Similar comparisons have been made for the techniques commonly used to obtain the actual analytical sample from this initial sample (secondary sampling).

Based on these comparisons, a conceptual design for the FFTF sodium sampling system is described. It is based on the use of a bypass loop for the initial sampling phase and is versatile enough to permit the addition of the more complex dipping bucket-distillation sampler if development of this device proves that it can be successfully operated remotely with a high degree of reliability. Secondary sampling is accomplished by removal of a portion of the loop and subsequent sectioning. Backup and initial and secondary sampling techniques are considered.

Additional information and experimental evaluation will be necessary in order to make a choice between candidate sampling operations and to permit

the final design of the FFTF sampling system. The areas in which additional information is vital have been defined. The major vital areas are: impurity segregation, sampler preconditioning, general sampler requirements, blind leg problems, the integrity of high temperature mechanical seals, and the effects of atmospheric exposure on sample ends.

The experimental program required to develop and test prototypical samplers has been outlined. It entails the construction and remote operation of prototype samplers in non-radioactive environments, followed by the design, construction, and proof testing of prototypes on radioactive streams.

A major design choice will have to be made between individual sampler locations for each test loop and sample point and a centralized location to which all samples are piped. This choice will have a major impact on reactor design and costs.

GENERAL DISCUSSION

Considerable effort has gone into the development of techniques to obtain reliable estimates of the impurity levels in alkali metals. The magnitude of this effort can readily be grasped from recent reviews and literature searches⁽⁵⁻⁹⁾ on the subject and the large number of symposia and round-robin sample exchange programs^(10,3) which have taken place.

A digestion of this work reveals that there are certain fundamental steps which are more or less common to all sampling and analysis procedures. For the purposes of this discussion, we

will divide these steps as follows:

1. A small representative sample of the material to be analyzed is separated from the bulk of the sodium (initial sampling).
2. The initial sample is divided to provide a characteristic portion for each analytical determination (secondary or aliquot sampling).
3. The bulk of the sodium is separated from the constituent to be measured (concentration of the impurity).
4. The separated impurity is quantitatively measured.
5. The impurity content of the sample is correlated with the impurity concentration in the bulk of the sodium.

This review covers only the first two of these steps: namely, the mechanical isolation and protection of a small representative portion of the bulk sodium in the loop (initial sampling) and the separation of a characteristic portion of this sample for analytical purposes (secondary or aliquot sampling). Subsequent analysis steps will be discussed only insofar as they influence the manner in which the first two steps are performed. Of these, the impurity concentration step will naturally have the greatest influence on the sampling method.

There are many factors which are desirable in all sampling operations and especially apply to the sampling of loop coolant. Some of the more obvious of these might be listed as follows:

- The sample must be representative of the source being sampled. In the case of reactor coolant, the sample should be taken under loop operating conditions of temperature, pressure, etc.

- The sample must not be contaminated by the sampling device.
- The sample must not be contaminated by the atmosphere.
- The sample should be as homogeneous as possible. Sodium, therefore, should either be chilled as rapidly as possible or maintained at precisely the conditions of sampling at all times.
- The sampling procedure must be safe. The sampling procedure should not seriously contaminate the material being sampled.
- The sample should be taken as close to the point of interest in the loop as practical. This becomes particularly important if there is a possibility of concentration gradients from one point to another within the loop.
- The sample must be of adequate size.
- The sampler should operate independently of other system components.

Although there is general agreement on what is desirable in a sampling procedure and the resulting sample, there is considerable disagreement concerning the steps and procedures necessary to attain these goals. This disagreement exists both within and between locations and can be illustrated by a few examples. For instance, the duration of sampler pretreatment which is considered necessary to obtain good samples for oxygen analysis varies all the way from APDA's minimum of four hours continuous flush with sodium^(11,12) (under operating conditions) to EBR-II's very short preconditioning⁽¹³⁾ in which less than one sample cup volume of sodium is used to rinse and precondition the aluminum cup before sampling for oxygen determina-

tions. Both EBR-II and APDA appear to obtain good oxygen numbers and present experimental data to support the use of their pretreatment procedure. Differences of opinion also exist within a single location. An excellent example of this might be the fact that APDA believes they obtain good numbers on both carbon and oxygen. In their oxygen sample handling, extreme care is believed necessary to prevent atmospheric contamination of the sample. They go so far as to place the completely sealed sampling loop within an inert atmosphere enclosure. In the case of carbon samples, precautions are much less stringent and the combustion tube and sample are even momentarily exposed to the laboratory air while being transferred to the combustion train.

The importance of impurity segregation can be cited as another example of an area in which considerable divergence of opinion exists. Several investigators have found that segregation,^(11,14) particularly at vessel walls, significantly affects the analytical numbers. On the other hand, Mills⁽¹⁵⁾ and others⁽¹⁶⁾ obtain good numbers using extrusion methods which leave some sodium on the walls of the sampling tube.

The examples cited are in no way criticisms of any of the work mentioned; for indeed, it appears that good results are obtained in all cases. They are merely illustrations of the fact that the exact requirements are not clearly defined. As a result, each investigator goes as far as he feels necessary to get good results.

Efforts are being made in several areas to define the general requirements. One such effort is that of the

ASTM through its committee on sodium sampling (Subcommittee G-1-8 Task Force B), whose last meeting was February 8, 1967, in Detroit. As yet, the committee's recommendations have not been put into practice extensively. For instance, the ASTM suggests that the entire surface of the sampling apparatus which is exposed to the liquid metal be made of either tantalum, molybdenum, tungsten, or zirconium. They also suggest a maximum cooling time of 3 min from withdrawal temperature to complete freezing of the sample. The samplers most frequently used at EBR-II, AI, LASL, or APDA do not meet these suggested conditions. Efforts should be continued to define over-all desirable features of a general alkali metal sampler and to obtain experimental data which indicate not only the need for each design restriction but also the consequences of ignoring the restriction.

In addition to meeting the general requirements of all good analytical sampling techniques, the FFTF sampler will have several restrictions and objectives which are unique. Some of the more significant of these are:

- Sampling will be performed at higher temperatures (1200 to 1400 °F) than has been done extensively in the past.
- Radiation levels will be high due to the high flux levels anticipated in FFTF. Therefore, completely remote operation of the sampler will be essential.
- In order to use sampling and analysis as an operational control method, data must be returned in time to permit operational adjustment of the FFTF impurity control system. This

will require the handling and analysis of highly radioactive sodium.

- Capability must exist for taking a series of samples rapidly. Some investigators estimate that sampling as frequently as once an hour will be required in unusual cases.
- It will be desirable to have all samples valid for any determination requested by the customer.
- It will be desirable to obtain the samples in such a form that a portion of them can be stored for the duration of the test run without danger of contamination.

SELECTION OF AN INITIAL SAMPLING TECHNIQUE

The first of the five steps commonly taken in the acquisition of information concerning the impurity content of sodium is the separation of a small representative portion of material from the large reservoir to be analyzed. In this survey, we shall refer to this as the initial sampling. The second of these steps is the actual separation of the analytical sample from this portion. We shall refer to this as the secondary sampling. Table I lists the more common techniques used to perform each of these operations. The reader may be perturbed by the absence of what is perhaps the most commonly known sampling technique - namely, vacuum distillation. This method is not included because vacuum distillation is actually a sample preparation or impurity concentration step rather than a sampling operation. The most widely known "vacuum distillation sampler" design is the ANL sampler. A dissection of the operations involved

TABLE I. *Commonly Used Initial and Secondary Sampling Techniques*

<u>Initial</u>	<u>Secondary</u>
1. Vacuum Thief	1. Coring
2. Dipping Cup	2. Extrusion
3. Drain	3. Sectioning
4. Bypass Loop	4. Pouring
	5. Dipping Cup

in the use of this sampler would classify it according to our nomenclature as follows:

Initial sampling - drain
 Secondary sampling - dipping cup
 Separation technique - vacuum distillation.

In a given analytical procedure, any combination of initial and secondary sampling techniques can be used, and a search of the literature reveals that every combination has been used to advantage at one time or another. Frequently, one of these combinations is particularly advantageous and, as a result, two techniques are habitually linked together. This is the case of the "vacuum distillation" sampler. However, to make comparisons as quantitative as possible, let us discuss the steps individually and first compare the advantages and disadvantages of the four primary sampling techniques.

VACUUM THIEF SAMPLER

The term "vacuum thief sampler" usually refers to an evacuated bulb, either metal or glass, one entrance of which is placed below the surface of the molten metal. A port is then opened and the metal is allowed to fill the void space, the port is sealed, and the

tube is removed and allowed to cool.

This method of sampling was developed early in the days of Knolls Atomic Power Laboratory (KAPL)⁽¹⁷⁾ and has been extensively used until recently by G. E., San Jose.^(18,19) There have also been numerous other occasions where the technique has been used to sample liquid alkali metals. Woodward⁽²⁰⁾ describes the sampling of NaK test rigs by controlled vacuum withdrawal into stainless steel tubing. The tubes are sealed and crimped to provide separate samples and are opened only in inert atmosphere dry boxes for analysis. The sampling tubes are preconditioned by dry hydrogen firing before evacuation.

The only use of the vacuum thief method for the sampling of highly radioactive sodium which has been reported in the literature is that in the SNAP-8 program at AI^(21,22) where samples for fission and corrosion product analysis were taken. There was no interest in oxygen or carbon determination, so minimal precautions were needed to prevent atmospheric contamination.

If we consider the advantages of the vacuum thief method, we see that one is the simplicity of the sampler itself. Therefore the method should lend itself to remotization. This simplicity is a bit deceiving, however, in that the equipment required to move the thief into and out of the inert atmosphere blanket surrounding the sodium may be quite complex and may add considerably to the problem of remotization. The thief has an advantage over the dipping cup in that the resulting sample is completely contained and therefore protected from contamination by the atmosphere, both during cooling and in

subsequent operations. The sample size is also rigidly controlled and measured by the thief's complete containment. Because of the lack of sodium pretreatment of the sampling vessel, samples can be obtained in quite rapid succession by the technique. The principal limitation is the time required to remove the sampler from the inert atmosphere of the reactor and replace it with an empty thief while insuring the integrity of the atmosphere. Such a sampler can operate completely independent of any other loop functions on either a dynamic or static system.

Vacuum thief sampling has several disadvantages or limitations, particularly when associated with FFTF sampling. One of the most important of these is that adequate sodium preconditioning of the sampling vessel is quite difficult to attain. Therefore, there is considerable hazard that the sample will be contaminated by material adhering to the walls of the sampler, particularly in the case of oxygen. A form of preconditioning of stainless steel thieves has been attained by hydrogen firing.⁽²⁰⁾ Sodium preconditioning in a limited sense has also been achieved by alternately evacuating and purging the thief to fill and refill it with molten metal before the final sample is taken.⁽⁵⁾ The added equipment necessary for this operation removes some of the simplicity of the method.

White et al.⁽²³⁾ have investigated the effect of precleaning glass thief samplers and conclude that properly cleaned and degassed sampling tubes do not measurably alter the oxygen content of the sample taken in the

tube at the higher oxygen levels. White did not investigate sampling sodium containing extremely low oxygen levels or the use of thieves made of stainless steel. Sample contamination by the sampler is an extremely serious matter, and, before the technique could be considered for FFTF application, considerable experience would have to be gained with a sampler pretreatment procedure known to be adequate at low levels of impurity concentration.

Sabol and Lockhart⁽¹⁸⁾ feel that one disadvantage of the vacuum thief technique is that there is a practical limit to the size of the sample which can be taken, although this size may well be adequate for FFTF needs. There is a definite limit, however, on the location at which samples can be taken: namely, close to the surface of the liquid metal where manipulations are possible. This restriction on the sampling location also limits consideration for FFTF use.

In reviewing the use of the vacuum thief method of sampling, one finds that very little experience has been accumulated with the method on highly radioactive sodium and none on operating reactors. A backlog of such experience must be accumulated before the technique can be considered for FFTF application. The accumulation of this backlog does not appear to be in the offing since the method is not presently being used or planned at any reactor sampling station. In fact, it has recently been abandoned by G.E., San Jose, on the PA-15 program mass transfer loops.⁽²⁴⁾

THE DIPPING CUP SAMPLER

The usual dipping cup sampler consists of a chemically inert cup which is filled by dipping it into a quiescent pool of molten metal, removing it into an inert atmosphere (either vacuum or gas), allowing it to cool, and then removing it from the inert atmosphere through some form of air lock for transport to an analytical facility. Operations have been successfully carried out with and without the use of an inert atmosphere transportation capsule.

The dipping cup method was reported in 1950 by Lee and Walters⁽²⁵⁾ who used a large bore stopcock as an entry port and a removable inert atmosphere chamber to transport the sample to the laboratory. Many applications to the sampling of nonradioactive sodium have subsequently been reported. Goldberg et al.⁽²⁶⁾ modified the Lee and Walters sampler by making it vacuum tight in 1956. Sampling remained on a laboratory scale with a 1/2 in. diam cup. A similar sampler was described by Weech and Fluke⁽²⁷⁾ in which a solenoid and magnet are used to move the sampling cup. More recently, Savage et al.⁽²⁸⁾ made use of a dipping cup sampler in the SNAP-8 corrosion program studies. Here, connections are made to the system with "O" ring seals. Similar samplers have been used in France at Saclay,⁽²⁹⁾ and the technique is presently being used at Mine Safety Appliance Corporation to sample systems containing rubidium and lithium at temperatures up to 1600 °F.⁽³⁰⁾

Some experience has been gained with the technique on actual operating

reactors. Both HNPF and SRE coolants have been sampled by the method. Experience at both locations has been limited, however, with roughly 20 samples taken at SRE and between 6 and 12 at HNPF.

The SRE and HNPF samplers are significantly different in design. The one at SRE^(31,4) is a specially designed shield plug in the top of the reactor. The plug contains a bucket which can be lowered into the reactor pool, withdrawn above an off-set, and rotated into this off-set for both thermal and radiochemical cooling. The plug is handled by the fuel handling machine and must be installed before reactor startup. Once installed, any number of samples can be taken. Samples cannot be taken in rapid succession, however, as they are normally left in the shielded position for approximately two weeks to allow for the decay of ²⁴Na activity. Primary interest has been in carbon and corrosion product rather than oxygen determinations and, as a consequence, extensive care has not been required or taken to protect the sample from minor amounts of oxygen contamination. Because of potential contamination from the sample cup, samples for corrosion product determinations were taken with glass lined cups. A significant scum on the surface of the reactor pool has been observed visually from time to time. The cup must pass through this scum twice during sampling. These observations have caused some concern lest the scum adhere to the sample cup walls and significantly contaminate the sample.

Two samplers were developed for the HNPF. One for the upper plenum was developed in the field and resembled the one at SRE closely.⁽⁴⁾ The second sampling did not occur directly in the main reactor pool but rather in a pool created for the immersion of metallurgical tab samples used for carburization measurements.⁽³²⁾ The HNPF sampler might be termed a hybrid between a bypass loop, dipping cup, and spigot sampler, as all three operations occur.

Again, oxygen determinations were not of concern, and contamination by the atmosphere, particularly during the transportation of the sample, was not rigidly controlled. Because of the addition of the spigot feature through which the surface of the sodium was continually renewed, no scum would be expected; and therefore, this potential source of contamination was effectively eliminated. The operation of the sampler is briefly described by Wickes.⁽³³⁾ He also mentions the use of an alternate means of sampling HNPF sodium by taking a dip sample from the core while the reactor was shut down. The core sampler is a tubular cup of one pound capacity suspended from a reactor shield plug. It is inserted and withdrawn with the fuel handling machine, as at SRE. The sample does not remain in the plug for cooling, however, but is placed in one of the service cells.

Present plans call for sampling the sodium coolant of the SEFOR reactor by the dipping cup technique. Samples will be taken three at a time through a head plug only during periods in

which the reactor is down. The method is particularly well suited for SEFOR in two respects. The reactor is scheduled to be "down" quite frequently, so, adequate sampling should be available in spite of the restriction. The reactor has a hot cell facility and an inert atmosphere in place over the head plugs; thus, all necessary equipment is available to perform the sampling in this manner. The dipping cup approach was therefore simplest and entailed the minimum cost. Present plans are to allow the decay of ^{24}Na before the sample is removed for analysis.

One of the primary advantages of the dipping cup technique is that it can be used to sample either a dynamic or a static system. It can readily be adapted to operate independently of any of the other functions of the system. As a secondary sampling technique, it provides the sample in a form well suited for some subsequent operations, such as vacuum distillation. Much of the advantage gained here is lost in initial sampling, however, unless one plans to perform the entire sampling operation in a single step, take a small dipped sample, and use the entire sample for the subsequent analysis. (One school of thought goes so far as to hold that analyzing the whole sample is the only way in which it is possible to obtain a truly representative sample.) Still another advantage of the dipping cup technique is that it is potentially capable of quite rapid sampling.

The primary limitations are the time and operations required to get

the sampling vessel and the sample in and out of the reactor's inert atmosphere while insuring the integrity of that atmosphere.

The primary disadvantages of the dipping cup sampling technique are the difficulties encountered in obtaining and protecting a representative sample of the coolant. Samples can only be taken at or near the surface of the coolant. There is considerable danger of contamination of the samples from several sources. Adequate sodium preconditioning of the sample cup is difficult because of the quiescent nature of the sampling location, and contamination by the sampler is therefore an ever-present threat. Contamination from the inert gas atmosphere is possible as the sample is cooled and handled with a significant amount of surface exposed. Remotization of the dipping cup technique is moderately difficult. The sampler itself is quite simple; however, the manipulations required to move the sample out of the inert atmosphere of the reactor coolant are complex and, when associated with the safety and shielding requirements, have proven to be difficult in the experiences to date.

Samples of adequate size can undoubtedly be taken by the technique, but precise measurements of sample size are difficult because of uncertainties in the position of the meniscus in the cups. Segregation of impurities undoubtedly occurs during freezing and presents a more severe hazard than in the other methods as cooling must occur in the vertical position.

More experience on highly radioactive systems has been gained with

the dipping cup technique than with the vacuum thief technique. Experience is still far from adequate, however. It has been limited to a relatively few samples at SRE and HNPF.

The major problems of the dipping cup samples are the acquisition and protection of a representative sample and the complexities of remotization which make the approach unattractive. Most investigators agree that when a dynamic system is available, better approaches exist.

THE DRAIN SAMPLER

Sodium can be drawn from almost any point in a loop system provided sufficient head is available and a spigot or opening exists. Material separated in this manner has been used as an analytical sample for some time, and the sampling technique is usually referred to by the term "drain". As early as 1953 Burgman and Billures⁽³⁴⁾ described an apparatus capable of taking samples by manipulating cups under a flowing sodium stream inside a steel box containing an inert atmosphere. The method was intensively developed by Humphries at ANL,⁽³⁵⁾ who tied it closely with a cup sampler and vacuum distillation sample preparation. The method has remained closely tied to vacuum distillation, and the terms "Argonne Sampler" and "Vacuum Distillation Sampler" have become synonymous with the particular sampling technique, while drain sampling has been restricted to use with a relatively elaborate sampler design. No such restriction is, of course, inherent and solid samples are presently being taken with this type sampler at EBR-II⁽³⁶⁾ and at G.E. Space Power

and Propulsion Section.⁽³⁷⁾ The original ANL sampler has also been used extensively at ANL⁽³⁸⁾ and Oak Ridge National Laboratory (ORNL).^(39,40) Many modifications of the ANL sampler have been made, but these have been primarily to the vacuum distillation phase of the operation. Drain sampling has been developed in both France⁽⁴¹⁾ and Great Britain,^(42,43) again intimately coupled with cup sampling and vacuum distillation as subsequent steps.

Considerable use is presently being made of the drain sampler. Both the primary and secondary loops of EBR-II are being sampled with it⁽³⁶⁾ and plans are under way to substitute a modified and improved version^(44,45) for the samplers presently in use. The original use of the distillation step was abandoned after about 100 samples were taken. Presently, cups full of solid sodium are being removed from the samplers and used as analytical samples. This EBR-II experience, involving perhaps as many as 150 samples of radioactive sodium, is undoubtedly the most extensive in the U.S. on an operating reactor. In this sense, the drain approach is the most thoroughly tested of the sampling methods. A drain sampler is presently planned for use on the Components Test Loop at ANL,⁽⁴⁶⁾ again without coupling to a subsequent distillation step. Rutkauskas⁽⁴⁷⁾ at LASL is presently testing a modification of the ANL or distillation sampler in a bypass loop. This sampler combines many of the features of the dipping bucket, the bypass loop, and the original ANL distillation sampler and will be discussed

in more detail in the section on bypass loop sampling.

The simple drain or spigot sampler has several distinct advantages. It eliminates almost completely the possibility of the contamination of the primary loop during sampling. It is extremely simple and therefore should be easily remotized. No special passage of the sample into and out of the inert atmosphere over the sodium is required. All that is required is a single spigot; it should therefore be readily possible to sample many points on the system. Sampling can be rapid and completely independent of other loop functions. Samples of any size can be obtained in forms which can be completely sealed and stored indefinitely. Both static and dynamic systems can be sampled.

One of the major disadvantages of the drain approach is the difficulty in obtaining adequate container preconditioning and, thus, preventing contamination of the sample by the sampler. Even if the loop being sampled is of such a large size that the volume of discarded sodium is negligible, the disposal of the discarded sodium, particularly if it is highly radioactive, is a major problem. Many investigators believe adequate sampler preconditioning is obtained by this technique, however, and more experimental data are needed to reconcile opposing views regarding the amount of preconditioning required to obtain a completely uncontaminated sample.

A second problem with a drain sampler is that of obtaining a representative sample under loop operating

conditions. The sample line and vessel of a drain sampler constitute, by necessity, a blind line, and such lines are known to be troublesome in several ways. If, for any reason, they are held below loop temperature for any length of time, they may well act as impurity sinks and accumulate impurities by precipitation. If the technique is used to provide solid samples, segregation of impurities undoubtedly occurs just as in the other techniques. The drain sampler method is a prime contender of FFTF sampling, and, before a final decision between it and bypass loop sampling can be made, additional experimental evaluation of sampler preconditioning requirements and blind leg problems will be required.

THE BYPASS LOOP SAMPLER

In the bypass loop technique, molten metal is passed continuously through a small bypass loop placed across some unit in the main system which provides an adequate pressure drop. Any type of secondary sampler can be placed in this loop and can be completely preconditioned by a prolonged flow. Any of the five secondary sampling techniques mentioned earlier can be used, but sectioning (a deliberately provided removable pipe section) is used most frequently.

The bypass flow method was used in 1954 at KAPL⁽⁴⁸⁾ and has been used intermittently for some time.⁽⁴⁹⁾ However, only in the last few years has bypass flow become intensively used. Hill et al.⁽⁵⁰⁾ at APDA have made perhaps the most extensive laboratory

investigations into the problems involved in connection with the sampling of the Sodium Technology Loop. They have evaluated methods for sample tube pretreatment⁽⁵¹⁾ and Hunter^(52,53) is presently making an extensive statistical evaluation of the effects of variables such as sampler preconditioning time, impurity segregation, sampler tube material, etc, on the validity of samples taken for oxygen determination.

The bypass loop technique had been selected for use at Pratt and Whitney,⁽⁵⁴⁾ and many of the newer sodium programs such as those at United Nuclear⁽⁵⁵⁾ and AI^(56,57) have adopted it.

Provisions have recently been made to sample the PA-15 program loops at G.E.⁽⁵⁸⁾ by the bypass loop technique. A flowmeter and a means of evacuating the removable section prior to the admission of the sodium have been included in this installation.

Some experience has been gained with the method on an operating reactor at Fermi.⁽⁵⁹⁾ This sampler consists of a coil of stainless steel tubing, 12 ft long and approximately 400 cm³, located in a positive pressure argon-purged box. It is connected in parallel with a cold trap and the main system overflow pump must be operated to provide circulation. Normally an eight-hour circulation time is used to precondition the sampler. No measurement of flow rate is made and at times there have been questions concerning the adequacy of the flow. The ²⁴Na is allowed to decay before the section is removed from the sampler.

Recently, Rutkauskas⁽⁶⁰⁾ at LASL has introduced a fountain or weir into a bypass loop and adapted the technique to vacuum distillation sample preparation with the aid of a dipping cup. Flow is continuous and the cup can be more adequately preconditioned than in the older ANL sampler placed in a drain line. The inclusion of the weir insures a clean sodium surface, thereby eliminating the hazard of contamination by surface film which is frequently associated with the use of a dipping cup. The sampler is an attempt to combine the desirable features of the bypass loop, the dipping cup, and distillation, and all of these operations are required to obtain a sample. As a consequence, the sampler and its operation are complex and may well be difficult to remotize. Problems are also created by the maintenance of an additional sodium surface. A prototype sampler has been constructed but has not yet been placed in operation.

The growth in popularity of the bypass loop technique can be attributed primarily to the fact that the method assures representativeness of the sample. The loop can conveniently be operated at the temperature and pressure of the system being sampled for sufficient time to assure complete preconditioning of the sampler, thus eliminating the possibility of contamination of the sample from this source. Good control over atmospheric contamination can also be maintained because normally the loop is completely sealed. Remotization of the operation of the loop is simple since no special entry is required into the inert atmosphere of the reactor coolant. Remote

removal of a section from the loop can be readily accomplished. This operation is an exact duplicate of the replacement of a jumper in a remotely operated chemical separations plant. A vast amount of experience has been gained over the years in this area and should prove useful in guiding efforts toward sodium sampling.

Samples of almost any size may be obtained safely from all points in the system where sufficient pressure drop is available to maintain flow in the sampling bypass. If sufficient pressure drop is not available and the added complexity is warranted, a small electromagnetic pump and flowmeter can be placed on the bypass itself to assure a sample flow.

The primary concern with the use of the technique arises from the possibility of impurity segregation within the sample during cooling. The only method of overcoming all segregation problems is to analyze the entire sample taken. Indeed, this is being done presently on removable section samples taken at APDA and is one of the primary arguments for the use of the dipping cup sampler. Effective steps are being taken to minimize the hazards of segregation, such as to cool the sample section in a horizontal position and to analyze at least a complete cross section of this sample. One precaution which has promise but is not being used extensively would be to provide for rapid freezing of the sample; a second would be to precrimp the sampling tube so that it is almost completely divided into segments of the proper size for ultimate use, as suggested by Woodward.⁽²⁰⁾ The degree

of segregation of impurities is directly related to their concentration and is therefore of less concern at low concentration levels. Fortunately, because of their nature, most of the tests in the FFTF loops will be made at low impurity levels, so the problems caused by impurity segregation during sampling can be expected to be minimal.

Because of the nature of the sampler pretreatment process, some contamination of the loop being sampled is inherent in the method. Since this becomes significant only if the sampled loop is small, no problems of system contamination of FFTF are probable. The duration of the sample loop pretreatment dictates a delay of several hours between samples unless multiple sampling loops are used in parallel.

The routine remote use of a bypass loop sampler requires mechanical seals of extremely high integrity. Several devices such as Conoseal flanges, Parker Triple-Lok, and Swagelok fittings have been found to be adequate at low or moderate temperatures (up to 900 °F) but insufficient experience has been accumulated at higher temperatures (1200 to 1400 °F) to assure a highly reliable system. Considerable trouble with leaky seals was encountered in early work at AI. Presently, at AI, the direct welding of the removable section into the loop is contemplated⁽⁶¹⁾ for larger sections and Parker Triple-Lok tube fittings for sections 1/2 in. or under.⁽⁴⁾

The bypass loop approach to sampling appears to be, by far, the most adequate, primarily because it is the most certain of providing a valid and reli-

able sample. It is replacing the other methods in the view of most investigators and should receive prime consideration as a FFTF sampling technique. Secondary consideration should be given the drain technique. More data should be sought concerning the relationship between sampler preconditioning and sample quality before the ultimate decision is made between the two techniques.

Comparisons for the four initial sampling techniques are summarized in Table II. The comparisons clearly show that each technique has certain inherent advantages, disadvantages, and limitations. The table also contains a listing of the locations which have used each technique and a qualitative indication of the amount of experience which has been gained with it.

SELECTION OF A SECONDARY (ALIQOT) SAMPLING TECHNIQUE

Assuming either bypass loop or drain samples have been isolated from the bulk of the loop coolant, analytical samples can be obtained from these by any of the five common techniques listed in Table I. Each has its advantages and disadvantages which are summarized in Table III.

All of the methods listed have been used or suggested. Coring has been suggested by Davidson.⁽⁶²⁾ Pouring is being used presently at Vallecitos⁽⁶³⁾ on the PA-15 program. The remaining three methods are by far the most popular, however, and have been much more extensively used. They are extrusion, the dipping cup, and sectioning.

TABLE IIa. *Comparison of Initial Metal Coolant Sampling Techniques*

<u>Technique: Vacuum Thief</u>	
<u>Principal Desirable Features</u>	<u>Principal Undesirable Features</u>
1. Maintains good control over contamination by atmosphere	1. Remotization complex because of need to enter reactor atmosphere
2. Provides accurate measure of sample size	2. Poor sampler preconditioning: therefore poor control over contamination by sampler
3. Provides rapid sample sequence if needed	3. Does not provide ideal control of sampling conditions such as temperature and pressure
4. Provides safe sampling	4. Limited to sampling near sodium surfaces
5. Provides completely enclosed samples in storable form	5. Some limit to sample size although probably adequate for FFTF requirements
6. Can sample both dynamic and static system	6. Segregation of impurities undoubtedly occurs during cooling
7. Sampler can operate completely independent of other loop	7. Some danger of contaminating the loop being sampled
8. Offers possibility of obtaining valid FP sample	

<u>Location Using</u>	<u>Amount of Experience Accumulated</u>
SNAP-8	Only one sample on a radioactive system
Pratt & Whitney Canel	Limited
G.E., Vallecitos and San Jose	Extensive on non-radioactive samples Recently abandoned the method, however

TABLE IIa. (Contd)Technique: Dipping Cup or Bucket

<u>Principal Desirable Features</u>	<u>Principal Undesirable Features</u>
1. Samples are obtained under operating conditions of temperature, pressure, etc	1. Representativeness of sample questionable as only the surface can be sampled
2. Rapid sequence of samples possible	2. Poor control of sample contamination from surface film
3. Provides safe sampling	3. Poor control of sample contamination from atmosphere as sample is open during cooling
4. Can sample both dynamic and static systems	4. Poor sampler preconditioning; therefore, poor control over contamination by sampler
5. Sampler can operate completely independent of other loop functions	5. Remotization complex because of need to enter reactor atmosphere
6. Offers possibility of obtaining valid FP sample	6. Precise measurement of sample size difficult
	7. Segregation of impurities undoubtedly occurs during cooling and constitutes a major hazard as the sample must be cooled in the vertical position
	8. Danger of contaminating the sodium system being sampled

<u>Location Using</u>	<u>Amount of Experience Accumulated</u>
HNPF	Limited--between 6 and 10 samples on operating reactor
SRE	Limited--about 20 samples on operating reactor
MSAR ^(a)	

(a) *Mine Safety Appliance
Research*

TABLE IIa. (Contd)Technique: Dipping Cup or Bucket (Contd)

<u>Location Using</u>	<u>Amount of Experience Accumulated</u>
ORNL SNAP-8 Corrosion Studies	
Saclay, France	Limited
SEFOR	Reactor still under construction

Technique: Drain

<u>Principal Desirable Features</u>		<u>Principal Undesirable Features</u>
1. Easily remotized; no need for entry into reactor atmosphere		1. Poor sampler preconditioning; therefore, poor control over contamination by sampler
2. Completely eliminates contamination of sampled loop during sampling		2. Adds a blind line to the system
3. Can provide any size sample		3. Segregation of impurities undoubtedly occurs during cooling
4. Provides rapid sample sequence if needed		4. Highly radioactive sodium used to flush sampler must be disposed of
5. Provides safe sampling		5. Valid FP sample difficult to obtain due to plating on sampler walls
6. Provides completely enclosed samples in storable form		
7. Can sample both dynamic and static system	<u>Location Using</u>	<u>Amount of Experience Accumulated</u>
8. Sampler can operate completely independent of other loop functions	EBR-II	Extensive, 100 hot samples distilled and 50 metal samples taken. Also 150 cold samples taken in secondary loop
9. Most versatile sampler with respect to location	LASL	Extensive on non-radioactive samples
	ANL	Several locations on nonradioactive samples
	ORNL	Nonradioactive samples only

TABLE IIa. (Contd)

Technique: Bypass Loop

Principal Desirable Features	Principal Undesirable Features
1. Easily remotized; no need for entry into reactor atmosphere Also pool of experience with similar operations available	1. Some contamination of loop being sampled occurs
2. Representative sample is assured	2. Must have a dynamic system; therefore, position of sampler restricted
3. Good sampler preconditioning; therefore control over contamination by sampler	3. Segregation of impurities undoubtedly occurs during cooling
4. Maintains good control over contamination by atmosphere	4. Long preconditioning of sampler prohibits rapid sampling sequence
5. Can provide any size sample	5. Valid FP sample may be difficult to obtain due to plating on sampler walls
6. Samples are obtained under operating conditions of temperature and pressure	
7. Provides safe sampling	
8. Provides completely enclosed samples in storable form	

Location Using	Amount of Experience Accumulated
AI	Nonradioactive sodium only
Fermi	About 40 samples on operating reactor loop
APDA	Extensive on non-radioactive sodium technology loop
UNC ^(a)	Nonradioactive sodium only

(a) *United Nuclear Corporation*

TABLE I Ib. Comparison of Initial Liquid Metal Coolant Sampling Techniques

Desirable Feature	Vacuum Thief Method	Dipping Cup Method	Drain Method	Bypass Loop Method
1. Representativeness of the sample	-	-	+	+
2. Control over contamination of sample during sampling	-	-	-	+
3. Control of contamination of loop during sampling	-	-	+	-
4. Simplicity - ease of remotization	-	-	+	+
5. Adequacy of sample size	±	+	+	+
6. Control or measurement of sample size	+	-	+	+
7. Ability to sample under operating conditions of temperature, pressure, etc	-	+	+	+
8. Uniformity of sample (segregation prevention)	-	-	±	±
9. Speed of sampling	+	+	+	-
10. Safety of sampling	+	+	+	+
11. Storability of resulting sample	+	-	+	+
12. Versatility (system types and locations which can be handled)	-	-	+	-
13. Independent operation	+	+	+	-
14. Shielding requirements	-	-	-	-
15. Prevent loss of impurities by volatilization or adsorption	+	-	-	+
16. Adaptability to subsequent analytical step	±	+	+	+
17. Adequacy of FP sample due to plating	±	+	±	±

TABLE IIIa. Comparison of Secondary Liquid Metal Coolant Sampling Techniques

Principal Desirable Features	Principal Undesirable Features
<u>Technique: Coring</u>	
1. Operation permits easy remotization	1. Poor control over contamination by the sampling device
2. Any size sample can be taken	2. Poor control over contamination by the atmosphere
3. Easy to obtain a precisely measured amount of sample	3. Poor control over impurity segregation effects
4. Sampling can be safely accomplished	4. Large shielding requirements at analytical facility
5. Sample remains in storable form	
6. Integrates well with next step of analysis	

TABLE IIIa. (Contd)

<u>Principal Desirable Features</u>	<u>Principal Undesirable Features</u>
<u>Technique: Pouring</u>	
1. Good control over impurity segregation effects	1. Poor control over contamination by the sampling device
2. Any size sample can be taken	2. Poor control over contamination by the atmosphere
3. Sample remains in storable form	3. Operations complex -- difficult to remotize
4. Integrates well with next step of Analysis	4. May have trouble obtaining accurate measure of sample size
	5. Large shielding requirements at analytical facility
	6. Not as safe as other methods due to remelting requirements and need to handle hot molten metal
<u>Technique: Dipping Cup Coupled with Vacuum Distillation</u>	
1. Good control over impurity segregation effects because entire sample is taken	1. Poor control over contamination by the sampling device
2. Shielding requirements at analytical location markedly reduced	2. Poor control over contamination by the atmosphere (vacuum in this case)
3. Subsequent step, vacuum distillation, already accomplished	3. Operation complex--difficult to remotize
	4. Difficult to obtain a precise measure of sample size
	5. Entire sample used for analyses; therefore, inadequate for recheck or for other determination
<u>Technique: Extrusion</u>	
1. Good control can be maintained over contamination by the sampling device	1. Impurity segregation jeopardizes sample representativeness
2. Fair control can be maintained over contamination by the atmosphere	2. Large shielding requirements at analytical facility
3. Operations permit easy remotization	
4. Any sample size can be taken	
5. Easy to obtain a precisely measured amount of sample	
6. Sampling can safely be accomplished	
7. Sample remains in storable form	
8. Integrates well with next step of analysis	

TABLE IIIa. (Contd)

<u>Principal Desirable Features</u>	<u>Principal Undesirable Features</u>
<u>Technique: Sectioning</u>	
1. Good control can be maintained over contamination by the sampler	1. Special precautions and sampling techniques are required to control impurity segregation effects
2. Good control can be maintained over contamination by the atmosphere	2. Large shielding requirements at analytical facility
3. Operations permit easy remotization	3. Integration with subsequent step is sometimes complicated by presence of sampling vessel on sample
4. Any sample size can be taken	
5. Easy to obtain a precise measurement of amount of sample	
6. Sampling can be safely accomplished	
7. Sample remains in storable form	

TABLE IIIb. Comparison of Secondary Liquid Metal Coolant Sampling Techniques

<u>Desirable Feature</u>	<u>Sampling Technique</u>				
	<u>Coring</u>	<u>Pouring</u>	<u>Distillation</u>	<u>Extrusion</u>	<u>Sectioning</u>
1. Control of contamination by sampler	-	-	-	+	+
2. Control of contamination by atmosphere	±	-	-	+	+
3. Control of impurity segregation effects	-	±	+	-	±
4. Simplicity - ease of remotization	+	-	-	+	+
5. Adequacy of sample size	+	+	-	+	+
6. Accuracy of measurement of sample size	+	±	-	+	+
7. Safety	+	-	-	+	+
8. Storability of remaining sample	+	+	-	+	+
9. Shielding requirements	-	-	+	-	-
10. Ease of integration with subsequent step	+	+	+	+	+

EXTRUSION

Probably the easiest and cleanest way to obtain a measured analytical sample from a removed section of a bypass loop or drain is by extrusion. In this process, pressure is applied to the confined solid metal by means of a ram which is usually sized to fit the inside diameter of the removed section as closely as possible. The alkali metal flows through a pre-sized orifice where it is usually cut with a hot wire. The movement of the ram can be calibrated to provide an accurate measurement of the sample size. The method is widely used as a secondary sampling technique. (4,15,16,64,65)

The primary concern with this method arises from the hazards created by the segregation of impurities within the sample during cooling and solidification. By the method's very nature, the outer portion of the sample remains in the sample tube and is not taken as part of the analytical sample. The sampler can be designed to leave only a small portion of the sample behind; nevertheless, if significant segregation or concentration of impurities has occurred in this section, a nonrepresentative sample will be analyzed. Considerably more data are required concerning the radial segregation of impurities before this method can be used with complete confidence. A complete understanding of the situation may reveal that impurities are concentrated in a relatively narrow band near the surface of the samples. On the other hand, the tube surfaces may scavenge impurities from the flowing sodium during

the long preconditioning of the sampler, in which case a complete cross section of the sample such as that obtained by normal sectioning is not what is desired. Under these conditions, the apparent impurity concentration of a complete cross section of the sample would be different from the system being sampled, and a portion extruded from the center of the sample would actually more closely represent material of interest.

Extrusion has a number of points to recommend it as a secondary sampling technique, however, and it should remain in contention until more definite information regarding the nature and importance of impurity segregation is available. Work to define the importance of segregation should be pursued as rapidly as possible.

DIPPING CUP

The dipping cup is used as a secondary, as well as initial, sampling technique. Its most widely accepted use occurs in the ANL "distillation type" sampler. The original sampler has the cup inserted from the bottom and acting as an overflow vessel. Recently several samplers have been constructed in which the cup is dipped into a pool whose surface is continually being renewed by overflowing the sodium. (57,66)

The primary advantage of the dipping cup is that it lends itself readily to vacuum distillation as a subsequent sample preparation step. Such a distillation minimizes two important problems. First, the entire sample is normally distilled and any effects

of impurity segregation are thus almost completely eliminated. Second, the sodium, and thus a major portion of the radioactivity, is removed very early in the analytical process at the sampling station. This simplifies shielding problems during transportation of the sample. Unless provisions are made to store the distilled sodium for an extended period to allow for ^{24}Na decay, shielding problems are simply transferred to the disposal of the sodium and not really eliminated.

The close coupling to a subsequent vacuum distillation is not entirely without disadvantages as it also introduces a number of significant problems. Rather complicated laboratory-type operations must be done by operations personnel. Experience has shown that, just as might be expected, laboratory personnel perform these laboratory-type operations better than operations personnel do. Vacuum distillation also makes the simultaneous collection of multiple samples complex although not impossible. Multiple samplers have been constructed in France⁽⁴¹⁾ and Britain.⁽⁴²⁾ The samples produced are not in a sealed storable form, however, and, if use is made of the entire sample for each determination to avoid segregation problems, a larger number of distillation samples will be required to meet the need for all determinations. There is also some possibility of atmospheric contamination as the sample is open to an atmosphere (vacuum) both during sampling and distillation.

Another problem associated with distillation is the possibility of destroying sample integrity during

the sample preparation. Undoubtedly, all impurities which are unstable at 350 °C will be altered. In the case of FFTF loop sampling this would not appear to be a problem, however, as these loops are scheduled to operate well above this temperature range. The situation is by no means as clearly defined with respect to loss of impurity by volatilization or entrapment, however. Sinclair et al.⁽⁶⁶⁾ and Bergstresser et al.⁽⁶⁷⁾ have presented evidence to show that, at least in the case of oxygen, no significant loss occurs during distillation. On the other hand, Cosgarea et al.⁽⁶⁸⁾ have shown that distillation will not reduce carbon levels in sodium to less than 50 ppm. It can be inferred from this that volatilization of this element can occur during distillation and result in loss from the analytical sample. Dutina⁽⁶⁹⁾ has observed loss of carbon thread by mechanical carryover during distillation.

Several investigators have reported difficulties in obtaining accurate measurements of sample size using the dipping cup because of variations in the position of the meniscus from sample to sample. Actual weighing of each sample has been suggested but has not been attempted as it would add considerably to the complexity of the operation.

SECTIONING

A third method of sampling a bypass loop or drain line is by sectioning. This is usually carried out in two steps. The bypass loop or drain line

is deliberately designed with a section which is removable. Just before the sampling occurs, flow is stopped, the line cooled, and the sodium in the removable section frozen. The section is removed, capped, and a new section put in its place. Actual analytical samples are usually obtained by continued sectioning of the removed portion in an inert atmosphere analytical facility.

A unique approach to the removal of a sample from a bypass loop which can be classed as a form of sectioning has recently been proposed by Rau.⁽⁷⁰⁾ His invention makes use of two freeze seal valve stems to permit the passage of a sample container into and out of the sodium stream. The freeze stems have proven highly reliable and leak proof in valve application, and, if they prove as reliable in this application, the problems associated with leaky mechanical joints should be overcome. The device has not been tested in any manner as yet but plans are under way to construct and test a prototype at Pacific Northwest Laboratory.

Sectioning is used extensively as a secondary sampling technique^(11,12,36,56,58,59) usually associated with bypass loop sampling.

The primary advantage of the sectioning technique is its simplicity. As mentioned earlier, the remote operations required to perform the initial section removal are routinely carried out in radioactive chemical separations plants, and a vast amount of experience has been accumulated on highly radioactive systems.

Sectioning is also able to produce storable samples of high integrity

because of its ability to maintain a hermetically sealed container at all times, except for a brief instant when the disconnection is made. There is some debate among investigators concerning the validity of a sample whose ends have been momentarily exposed to the atmosphere during this operation. Hill et al.^(50,51) believe such exposure extremely undesirable and perform their sectioning operation in an inert atmosphere facility. EBR-II⁽³⁶⁾ and AI⁽⁵⁷⁾ personnel believe that only the end sections of such samples are altered. All agree that valid samples for carbon and oxygen can be obtained and contamination eliminated by the use of an inert atmosphere enclosure and that valid samples for fission product, corrosion product, uranium, plutonium, nitrogen, and perhaps hydrogen can be obtained without such an enclosure. Before adding the considerable complexity involved in the use of such an enclosure, an extensive investigation should be made to establish unequivocally the degree of sample contamination caused by momentary exposure of its ends to the atmosphere.

The principal objections to sectioning as a sampling technique are based on the fact that segregation of impurities occurs within the sample as it is frozen; therefore, the investigator is not absolutely assured a representative sample in spite of any precautions taken in the manner of sectioning. Little or no experimental work has been done to define the segregation across the diameter of such a sample tube.

Bypass sections are normally amalgamated with the stainless steel

jackets still in place during oxygen determinations. The surface of the stainless steel has an oxide coating which potentially could affect the results of the analysis. The effect of this coating should be studied to determine to what degree it should be removed before sectioning the sample. If complete removal is required, the operations necessary will add to the complexity of bypass loop sampling.

In summary, bypass loop sampling is simpler if questions regarding radial segregation of impurities can be answered. The dipping cup is more complex but offers the possibility of convenient direct coupling to vacuum distillation as a subsequent operation providing the complex operations necessary can successfully be remotized and vacuum distillation proves to have sufficient advantage over other approaches to make the effort worthwhile. The ultimate selection will hinge upon three factors:

- The importance of impurity segregation;
- Successful engineering of the manipulations necessary for cup sampling and distillation;
- Successful engineering of the shielding problems associated with the transport of a metallic sample.

IDEALIZED SAMPLER FOR FFTF EXPERIMENTAL LOOPS

FFTF loops are to be research facilities. As such, they should be as versatile as funding will permit. The sampling facility should also be designed with maximum flexibility. From a purely technical standpoint and

based on presently available information, the sampling facility would have the following features.

Sodium should be removed from each sodium system by a continually flowing bypass loop. A removable section sampler should be provided in the loop. Adequate space should be provided within the shielded station to permit the addition of one of the "descendants" of a distillation type sampler to the bypass. Remote manipulators and a viewing facility will almost assuredly be required. The essential features are shown in Figure 1.

These conclusions are, of course, open to debate as there is considerable subjectiveness involved in evaluating many of the features of the various sampling approaches. Different weights are placed on individual features by different investigators. For instance, many place overwhelming importance on the early removal of the sodium and the consequent reduction in the radiation levels associated with the samples, while others place primary emphasis on simplicity and reliability of operation to facilitate remote operation. Many other items are subject to considerable discussion and the selection of an "ideal" sampler for a given application is by no means cut and dried.

Two programs are necessary to the development of an adequate FFTF sampler: One to aid in the selection of the most advantageous sampling technique and to aid in the design of a sampler based on this technique, and a second to carry out the construction and

Neg 0672118

FIGURE 1. FFTF Coolant Sampling Station

testing of prototypical samplers. Ideally, these programs would be carried out sequentially, but, because of the time schedules involved, considerable overlap will be necessary.

The major areas of investigation in the base technology program might be listed as follows:

- A detailed study of the segregation of each impurity of interest during

the cooling and solidification of sodium and the effect of the segregation upon the validity of solid analytical samples--particularly those which have to be sectioned (Such a study should include the definition of means to minimize the problems associated with segregation)

- An extension of the breakdown of the steps (beyond the five major steps listed in this report) involved in the various sampling procedures and an analytical comparison of each step to aid in the development of a quantitative comparison of the complexities of the methods
 - A continued effort to define the over-all desirable features of a general alkali metal sampler and to obtain experimental data which indicate not only the need for each design restriction but also the consequences of ignoring each restriction
 - An extensive investigation of the requirements for sampler or container preconditioning, particularly, extension of oxygen studies to include the other trace elements of interest (This study should include the possible detrimental effects of running the sample to a centralized facility through long bypass loops)
 - Additional investigation of blind leg problems associated with drain sampling (Such an investigation should include means to minimize these problems)
 - The evaluation and long-term proof testing of various mechanical connections and seals in sodium application at high temperatures (1200 °F) to insure highly reliable connections to the removable section of a bypass loop
 - An investigation of the effects of exposing the ends of a section sample to the atmosphere on the integrity of the center of the sample
 - Studies to minimize the problems of maintaining a separate sodium surface within a bypass loop for use with the dipping cup vacuum distillation sampler
 - Studies of the effect of oxides on exterior surfaces of samplers on measured oxygen values.
- A detailed cost analysis of the candidate sampling techniques should be made, based upon the FFTF program needs and available information, and the most desirable approach selected. Once the selection is made, the program to design, construct, and test prototypical samplers should be quite straightforward and contain the following steps:
1. The design and construction of a prototypical sampler specifically for remote operation
 2. The installation, remote operation, and modification of this prototype under nonradioactive conditions
 3. The construction of a second prototype based on the modifications revealed during the testing of the first prototype
 4. Installation of this sampler on an operating reactor and its operation for sufficient time to insure reliable trouble-free operation
 5. The creation of the final sampler design based on the experience gained in these programs.
- If one looks into the engineering aspects of sampling the several FFTF loops, many benefits immediately appear if all the bypass loops are run to a centralized location, ideally either in the remote analytical facility or directly coupled to this facility.

Some of these benefits are the elimination of duplicate facilities such as manipulators and inert atmospheric purification facilities, the elimination of sample transportation problems and the resulting shielding requirements, and the ability to perform the complex operations necessary in the vacuum distillation operation with trained personnel and elaborate manipulators. Such a centralization creates many engineering problems, however, and decisions regarding its adoption will have to await complex cost analysis studies. Uncertainties also exist concerning the effects of long bypass loop lines on the validity of the samples taken, particularly with regard to fission product response, and a study will be required in this area before a decision regarding a centralized facility can be made.

REFERENCES

1. D. W. Shannon and V. H. Troutner. Unpublished Data. Pacific Northwest Laboratory, Richland, Washington, June 11, 1966. (Trip report)
2. C. F. Metz, C. R. Waterbury. Unpublished Data. Los Alamos Scientific Laboratory, Los Alamos, New Mexico, 1966. (Private communication)
3. R. W. Lockhart, R. C. Blair, D. Dutina, J. L. Laech, and W. W. Sabol. Results of the USAEC Round-Robin Analyses for Carbon Impurity in Sodium, GEAP-4602. General Electric, San Jose, California. March 1, 1964.
4. D. R. Christianson and J. O. Nicholson. FFTF Materials Surveillance and Sodium Sampling, NAA-SR-MEMO-12317. North American Aviation, Inc., Downey, California. March 3, 1967.
5. Kurt Goldmann and Bertram Minushkin. "Sodium Technology," Reactor Technology Selected Reviews, edited by Leonard E. Lenk, available as TID-8514, pp. 321-425. 1965.
6. D. Dutina. "The Current State of the Art of Alkali Metal Analysis," The Gatlinburg Conference on Analytical Chemistry and Nuclear Technology. April 21, 1965.
7. S. H. Fenney. Bibliography on Liquid Metals, 1958-1963, TRGIS-312 (R). United Kingdom Atomic Energy Authority, Thurso, Scotland. 1966.
8. E. E. Garcia and B. D. La Mont. An Annotated Bibliography of Analytical Methods for Alkali Metals, WCAP-2540. Westinghouse Electric Corp., Pittsburgh, Pa. (Undated).
9. E. W. Hobart. Status of Methods for Determining Carbon, Oxygen and Nitrogen in Alkali Metals, TIM-900. Pratt and Whitney Aircraft Div., United Aircraft Corp., Hartford, Conn. April 1, 1965.
10. Glenn R. Zellars. Analysis of Oxygen in Potassium, NASA Round-Robin Meeting, NASA-TM-X-1085. National Aeronautics and Space Administration, Washington, D. C. June 4, 1964.
11. Quarterly Technical Progress Report on AEC-Sponsored Activity, APDA-192. Atomic Power Development Associates, Detroit, Michigan. March 15 - June 15, 1966.
12. Quarterly Technical Progress Report on AEC-Sponsored Activities, APDA-195. Atomic Power Development Associates, Detroit, Michigan. June 15 - September 15, 1966.
13. D. W. Cissel and C. Carothers. Unpublished Data. National Reactor Testing Station, Idaho Falls, Idaho, 1966. (Private Communication)
14. Charles Tuner, A. Cosgarea, Jr., and H. M. Feder. Solubility of Carbon in Sodium, SM-85123, p. 6. Argonne National Laboratory, Lemont, Illinois. (Undated).
15. C. C. Miles. "Oxyacidic Flux Method for the Determination of Carbon in Sodium," The Gatlinburg Conference on Analytical Chemistry and Technology. October 1966.

16. W. A. Dupraw, J. W. Graab, and R. F. Gahn. "Determination of Oxygen in Potassium," Anal. Chem., vol. 36, no. 2, pp. 430-431. 1964.
17. L. P. Pepkowitz and W. C. Judd. "Determination of Sodium Monoxide in Sodium," Anal. Chem., KAPL-127, vol. 22, no. 10, pp. 1283-1286. March 1949.
18. W. W. Sabol and R. W. Lockhart. Sodium Mass Transfer VII Methods of Determining Impurities in Sodium, GEAP-4178. General Electric, San Jose, California. September 1963.
19. R. W. Lockhart, G. Billures, and M. R. Lane. Sodium Mass Transfer I, Test Loop Design, GEAP-3725. General Electric, San Jose, California. June 1962.
20. C. E. Woodward. NaK Sampling of Engineering Test Rigs, TIM-711. Pratt and Whitney Aircraft Div., United Aircraft Corp., Hartford, Conn. February 23, 1962.
21. Knox M. Brown Jr., Carlton D. Bingham, Thomas B. Crockett, and Nancy M. Toohey. "Post-Irradiation Chemical Analyses of SNAP-8 Experimental Reactor Coolant," The 1965 Winter Meeting of the ANS. Also published in Nuclear Applications. December 1966.
22. S. L. Rosen. Results of SPER Sampling Program, NAA-SR-TDR-11131. North American Aviation, Inc., Downey, California. January 14, 1966.
23. J. C. White. Effects of Pre-cleaning of Glass Sampler on the Oxygen Content of Sodium, CF-55-7-16. Oak Ridge National Laboratory, Oak Ridge, Tenn. 1965.
24. D. Dutina. Unpublished Data. General Electric, San Jose, California, 1966. Private Communication.
25. R. E. Lee and S. L. Walters. "Technique of Sampling and Analyzing Hot Flowing Sodium-Potassium Alloys," Technical Report IV, NP-1527. Division of Technical Information Extension, AEC, Washington, D.C. May 1950.
26. G. Goldberg, A. S. Meyers, and J. C. White. The Sampling of Alkali Metal Systems with a Modified MSA Sampler, ORNL-2147. Oak Ridge National Laboratory, Oak Ridge, Tenn. 1956.
27. M. Weech and G. Fluke. "How to Take Samples from Liquid Metal Loops," Nucleonics, vol 15, p. 112. October 1957.
28. H. W. Savage, E. L. Campere, R. E. McPherson, W. R. Huntly, and D. A. Taboada. SNAP-8 Corrosion Program Quarterly Progress Report for Period Ending November 30, 1963, ORNL-3604. Oak Ridge National Laboratory, Oak Ridge, Tenn.
29. H. Chevelliard. Liquid Sodium Sampler, CEA-834. Commissariat a l'Energie Atomique, Paris, France. 1959.
30. Sheridan J. Rodgers and John C. Gerkin. Determination of Carbon and Carbon Compounds in Alkali Metals, MSAR-64-41. MSA Research Corporation, Calbrrie, Pa. Also presented at the 1964 Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, March 5, 1964.
31. G. E. Dugan, et al. Design Modification to the SRE during FY-1960, NAA-SR-5348. North American Aviation Inc., Downey, California.
32. R. E. Durand and G. A. Carlson. Unpublished Data. Atomics International Division, North American Aviation, Canoga Park, California, 1966. Private Communication.
33. W. H. Wickes. Procedure and Analytical Methods for HNPF Carburation Surveillance, NAA-SR-Memo-2214. North American Aviation Inc., Downey, California. February 1963.
34. W. H. Bruggeman and G. Billuris. Sampling of High Temperature Alkali Metals, AECU-2143. Division of Technical Information Extension; AEC, Washington, D.C. 1953. Also described in KAPL-P-777, also Liquid Metals Handbook, Sodium-NaK Supplement, TID-5277, p. 102. Also, Industrial Bulletin, vol. 4, p. 47. 1953.

35. J. R. Humphries, Jr. "Sampling and Analysis for Impurities in Liquid Sodium Systems," Chemical Engineering Progress Symposium Series, vol. 53, no. 20, pp. 7-10. 1957.
36. Chuck Chrothers and D. W. Cissel. Unpublished Data. National Reactor Testing Station, Idaho, Falls, Idaho, 1966. Private Communication.
37. R. B. Hand. Alkali Metal Handling and Control Procedure. General Electric Space, Power and Propulsion Section, Engineering Specification Number 03-0018-00-A. June 1965.
38. R. M. Adams. Reactor Development Program Progress Report, ANL-6253. Argonne National Laboratory, Lemont, Illinois. October 1960.
39. M. T. Kelley and C. D. Susano. Analytical Chemistry Division Annual Progress Report for Period Ending December 31, 1965, ORNL-2212. Oak Ridge National Laboratory, Oak Ridge, Tenn.
40. R. D. Peak. Operation of the Distillation Method for the Determination of Sodium Oxide in NaK during Calibration of a Plug Indicator, ORNL-CF-4-115. Oak Ridge National Laboratory, Oak Ridge, Tenn. April 1957.
41. J. Sannier and R. Vingot. Sodium Sampling Device on a Circuit for Impurity Analysis, CEA-2369, AEC-TR-6304. Commissariat a l'Energie Atomique, Paris, France. October 1963.
42. J. L. Phillips. "Full Power Operation of the Dounreay Fast Reactor and Fast Reactor Technology," American Nuclear Society ANS-100, pp. 7-24. April 1965.
43. Leo F. Epstein. Notes on Liquid Metal Studies in France and Great Britain, NASA-TM-X-884. National Aeronautics and Space Administration, Washington, D. C. June 1963.
44. C. C. Miles. Unpublished Data. National Reactor Testing Station, Idaho Falls, Idaho, 1966. Private communication.
45. I. Filewitz. Unpublished Data. Argonne National Laboratory, Lemont, Illinois, 1966. Private communication.
46. Fred Smith. Unpublished Data. National Reactor Testing Station Idaho Falls, Idaho, 1966. Private communication.
47. V. J. Rutkauskas. Unpublished Data. Los Alamos Scientific Laboratory, Los Alamos, New Mexico, 1966. Private communication.
48. W. W. Kendall. Radioactive Accessibility Report, January 1 - February 28, 1954, KAPL-M-CTU-9, p. 33. Knolls Atomic Power Laboratory, Schenectady, N. Y.
49. H. Kertchech and G. Riechman. Developments in the Analyses of Oxygen in Alkali Metals, TID-7626, pt. 1, p. 3. 1962.
50. E. F. Hill. Quarterly Technical Progress Report on AEC-Sponsored Activities, APDA-170. Atomic Power Development Associates, Detroit, Michigan. March 1965.
51. E. F. Hill. Quarterly Technical Progress Report on AEC-Sponsored Activities, APDA-174. Atomic Power Development Associates, Detroit, Michigan. April - June 1965.
52. Quarterly Technical Progress Report on AEC-Sponsored Activities, APDA-193. Atomic Power Development Associates, Detroit, Michigan. March 15 - June 15, 1966.
53. Quarterly Technical Progress Report on AEC-Sponsored Activities, APDA-195. Atomic Power Development Associates, Detroit, Michigan. June 15 - September 15, 1966.
54. SNAP-50 SPUR Final Summary Report on Coolants and Working Fluids, PWAC-491. Pratt and Whitney Aircraft Division, United Aircraft Corporation, Hartford, Conn. November 1965.
55. H. Steinmetz and B. Minushkin. Experimental Determination of Contaminants in Sodium, NDA-2154-6. United Nuclear Corp., Development Division, White Plains, N. Y. August 1961.
56. E. W. Murbach. Quarterly Technical Progress Report, AEC Unclassified Programs, NAA-SR-11900. North American Aviation Inc., Downey, California. January - March 1966.

57. E. W. Murbach. Unpublished Data. *Atomics International Division, North American Aviation, Canoga Park, California, 1966. Private communication.*
58. L. Pohl. Unpublished Data. *General Electric, San Jose, California, 1966. Private communication.*
59. J. P. Lagowski. Unpublished Data. *Atomic Power Development Associates, Detroit, Michigan, 1966. Private communication.*
60. V. J. Rutkauskas. Unpublished Data. *Los Alamos Scientific Laboratory, Los Alamos, New Mexico, 1966. Private communication.*
61. L. J. Johnson. Unpublished Data. *Atomics International Division, North American Aviation, Canoga Park, California, 1966. Private communication.*
62. J. M. Davidson. Unpublished Data. *Pacific Northwest Laboratory, Richland, Washington, August 1965. Personal communication.*
63. D. Dutina. Unpublished Data. *General Electric, San Jose, California, 1966. Private communication.*
64. L. E. Dostson and R. B. Hand. Potassium Corrosion Test Loop Development Topical Report, No. 4, R-66-SD-3012. NASA, Lewis Research Center, Cleveland, Ohio. Undated.
65. V. T. Kharlamov. "Preparation of Analytical Samples of Alkali Metals for Vacuum Extraction," *Trudy Komusu, Anal. Khim Akad. Nauk. SSR, vol 10, p. 117. 1960. Also FTD-TT-62-1338, 1 and 2.*
66. V. M. Sinclair, J. L. Drummond and A. W. Smith. The Analyses of Carbon in Sodium, TRG Report 1185 (D). United Kingdom Atomic Energy Authority, Thurso, Scotland. February 1966.
67. K. S. Bergstresser, G. R. Waterbury and C. F. Metz. Determination of Trace Amounts of Oxygen Added to Metallic Sodium, LA-3343. Los Alamos Scientific Laboratory, Los Alamos, New Mexico. August 1965.
68. A. Cosgarea, Jr., H. M. Feder, and M. Ader. Progress Report, July - December 1965, ANL-7125, p. 140. Argonne National Laboratory, Lemont, Illinois.
69. D. Dutina. Unpublished Data. *General Electric, San Jose, California, 1966. Private communication.*
70. Melvin O. Rau. Unpublished Data. *Pacific Northwest Laboratory, Richland, Washington, 1966. Private communication.*

DISTRIBUTION

<u>No. of Copies</u>		<u>No. of Copies</u>	
28	<u>Atomic Energy Commission, Washington</u> Division of Reactor Develop- ment and Technology M. Shaw, Director, RDT Asst Dir for Nuclear Safety Analysis & Evaluation Br, RDT:NS Environmental & Sanitary Engrg, RDT:NS Research & Development Br, RDT:NS Asst Dir for Plant Engrg, RDT Applications & Facilities Br, RDT:PE Components Br, RDT:PE Instrumentation & Control Br, RDT:PE Systems Engrg Br, RDT:PE Asst Dir for Program Analysis, RDT Asst Dir for Project Mgmt, RDT Liquid Metals Projects Br, RDT:PM FFTF Project Manager, RDT:PM (3) Asst Dir for Reactor Engrg Control Mechanisms Br, RDT:RE Core Design Br, RDT:RE Fuel Fabrication Br, RDT:RE Fuel Handling Br, RDT:RE Reactor Vessels Br, RDT:RE Asst Dir for Reactor Technology Chemistry & Chemical Separations Br, RDT:RT (2) Fuels & Materials Br, RDT:RT Reactor Physics Br, RDT:RT Special Technology Br, RDT:RT	4	<u>AEC RDT Site Representative (PNL)</u> P. G. Holsted (2) L. R. Lucas A. D. Toth
		4	<u>AEC RDT Site Representative</u> Atomics International Argonne National Laboratory Atomic Power Development Assoc. General Electric
		8	<u>Argonne National Laboratory</u> R. A. Jaross LMFBR Program Office J. R. Humphries J. E. Draley S. Greenburg F. A. Smith C. Carothers, EBR-II D. W. Cissel, EBR-II
		4	<u>Atomics International</u> L. E. Glasgow R. W. Dickinson C. D. Bingham R. E. Durand
		2	<u>Atomic Power Development Assoc.</u> B. V. D. Farris E. F. Hill
		2	<u>Babcock & Wilcox Company</u> S. H. Esleeck T. P. Farrell
		2	<u>Brookhaven National Laboratory</u> D. H. Gurinsky (2)
		255	<u>Division of Technical Information Extension</u>
1	<u>AEC Idaho Operations Office</u> C. W. Bills, Director	2	<u>General Atomic Division (SAN)</u> D. Coburn
5	<u>AEC Richland Operations Office</u> D. E. Crouter (2) J. H. Krema R. K. Sharp Technical Information Files	4	<u>General Electric Company, Sunnyvale</u> K. Cohen (3) B. Wolfe
1	<u>AEC San Francisco Operations Office</u> Director, Reactor Division	4	<u>General Electric (San Jose)</u> R. S. Young D. Dutina E. L. Zebroski (2)

No. of
CopiesBattelle-Northwest (Contd)

1	<u>Idaho Nuclear Corporation</u>	J. C. Fox
	D. R. deBoisblanc	S. M. Gill
5	<u>Los Alamos Scientific Laboratory</u>	K. M. Harmon
	R. H. Perkins	R. A. Harvey
	C. F. Metz	B. R. Hayward
	V. J. Rutkauskas	J. W. Helm
	W. R. Wykoff (2)	R. J. Hennig
1	<u>Mine Safety Appliance Co.</u>	G. M. Hesson
	<u>Callery, Pa.</u>	P. L. Hofmann
	S. J. Rodgers	J. A. Jarosch
2	<u>Oak Ridge National Laboratory</u>	B. M. Johnson
	J. C. White	H. G. Johnson
	J. H. Devan	R. L. Junkins
1	<u>Stanford University</u>	V. P. Kelly
	Dr. R. Sher	J. H. Kinginger
1	<u>United Nuclear Corp.</u>	P. L. Koehmsted
	K. Goldman	E. L. Kovacevich
3	<u>Westinghouse Electric Corp.</u>	D. D. Lanning
	Dr. J. C. R. Kelly	H. D. Lenkersdorfer
96	<u>Battelle Northwest</u>	C. W. Lindenmeier
	J. A. Atwood	H. E. Little
	W. G. Albert	W. W. Little
	E. R. Astley	C. E. Love
	J. M. Batch	H. P. Maffei
	R. A. Bennett	W. B. McDonald
	G. R. Bloom	M. H. Meuser
	J. R. Boldt	R. A. Moen
	C. L. Boyd	R. L. Moore
	D. C. Boyd	C. A. Munro
	W. H. Brehm	D. M. Nero
	C. L. Brown	R. E. Nightingale
	W. L. Bunch	M. G. Patrick
	C. P. Cabell	T. J. Owen
	J. R. Carrell	J. A. Perry
	W. E. Cawley	R. E. Peterson
	W. L. Chase	W. E. Roake
	T. T. Claudson	J. D. Schaffer
	P. D. Cohn	F. A. Scott (10)
	D. L. Condotta	F. H. Shadel
	J. H. Cox	D. W. Shannon (10)
	J. M. Davidson	D. E. Simpson
	G. M. Dalen	R. J. Squires
	D. R. deHalas	G. H. Strong
	T. F. Demmitt	C. D. Swanson
	R. L. Dillon	J. C. Tobin
	D. R. Doman	K. G. Toyoda
	G. E. Driver	U. L. Upson
	R. V. Dulin	M. A. Vogel
	J. F. Erben	E. E. Voiland
	L. M. Finch	D. M. Walley
		J. H. Westsik
		L. A. Whinery
		R. D. Widrig
		N. G. Wittenbrock
		M. R. Wood
		F. W. Woodfield
		FFTF Record File
		FFTF Reference File
		Technical Information
		Files (5)
		Technical Publications