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SURVEY OF METHODS
USED AT U. S. LABORATORIES
TO MEASURE IMPURITIES IN SODIUM

T. F. Demmitt

March 1968

AEC RESEARCH &
DEVELOPMENT REPORT

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SURVEY OF METHODS USED AT U. S. LABORATORIES
TO MEASURE IMPURITIES IN SODIUM

By

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February 1968

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SURVEY OF METHODS USED AT U. S. LABORATORIES
TO MEASURE IMPURITIES IN SODIUM

ABSTRACT

A survey was conducted to determine the manual analytical procedures used routinely to measure oxygen, carbon, hydrogen, nitrogen, and trace metal impurities in sodium. All of the major U. S. laboratories that either are or recently have been engaged in sodium analytical chemistry studies were surveyed during the course of this work. The results of the survey are presented. No attempt is made to include specific information concerning analysis methods for other impurities, e.g., fission products, particulates, etc.

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SURVEY OF METHODS USED AT U. S. LABORATORIES
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T. F. Demmitt

INTRODUCTION

Sodium metal will be used extensively to cool the fast reactors scheduled for construction in the United States in the next few years. This includes the Fast Flux Test Facility (FFTF) and the Liquid Metal Fast Breeder Reactor (LMFBR) plants. This situation requires evaluation of the factors affecting performance of materials and components in sodium at temperatures to 1400 °F. One of the important factors involved is sodium purity; thus, considerable effort has been and is being expended to evaluate the effects of various types and amounts of impurities.

A primary consideration in evaluating this work is the methods employed to measure the impurities present in the sodium. The problems involved in collecting and analyzing sodium samples for trace impurities are formidable, and in general there is a lack of agreement concerning optimum methods and techniques. It seems likely that much of the apparently contradictory information that has been obtained for materials tests under supposedly identical conditions is in fact directly attributable to the existence of significant but undetected changes in impurity species and/or concentrations present.

PNL has recently been involved in establishing an analytical laboratory to perform manual analyses for impurities in sodium so that such services can be provided for the various on-site development programs. This establishment

involved surveying work performed at other laboratories and adopting those methods considered best suited for PNL needs. The purpose of this report is to tabulate the results of the method surveys and to indicate the methods selected for use at PNL. This report is not intended as a review of the various methods since this has already been accomplished in several recent papers.⁽¹⁻⁵⁾

DISCUSSION

The impurities of primary initial concern from PNL's viewpoint included oxygen, carbon, hydrogen, nitrogen, and trace metals because of the significant effects they exert on results of materials tests. Accordingly, these are the methods that were actively surveyed at other sites and that are currently being set up and calibrated at PNL. No attempt will be made in this report to summarize specific analytical methods used for other impurities, e.g., fission products, particulate matter, etc.

OXYGEN

Oxygen is conceded to be the most important impurity normally encountered in sodium systems. Accurate knowledge of the oxygen concentration is mandatory in evaluating corrosion and mass transport phenomena. A considerable amount of work has been performed at many sites to develop and evaluate methods for measuring oxygen.

There are four major methods for oxygen measurement: (1) mercury amalgamation; (2) vacuum distillation; (3) vacuum fusion; and (4) radiometry, which includes neutron and photon activation methods. However, of these methods only amalgamation and vacuum distillation are being used routinely in U. S. laboratories. The other two are presently being evaluated.^(6,7)

The mercury amalgamation and vacuum distillation methods involve two distinct steps: (1) separation of impurities from the bulk sodium and (2) analysis of the impurity residue. The procedure names are derived from the method used to accomplish the separation step. Analysis of the residue from both amalgamation and distillation can then be accomplished by one of several methods including titrimetric alkalinity determination or sodium measurement of the hydrolysis product, or Karl Fischer titration of the residue after dissolution in alcohol. It should also be mentioned that other separation methods have been tried in the past--for example, n-butyl bromide and ammonia--but are not being used at present for various reasons.

Table I summarizes the procedures used routinely for oxygen analyses in U. S. laboratories, including the procedure employed by PNL.

CARBON

Carbon is also an impurity of major concern to experimenters due to the effects of this element on materials of construction. The behavior of carbon in sodium is complex and is not well understood. Thus, a very significant amount of work has been performed to develop analytical methods for this element and for the various species that may be encountered in combination with other impurities. Dutina⁽¹⁾ has stated:

"The determination of carbon has attracted even more effort than that expended on the measurement of oxygen. At least nine methods are described in the literature. All the methods have two basic steps in common: (1) the conversion of carbon to a gaseous form, generally carbon dioxide; (2) the quantitative estimation of the gas by several sensitive instrumental techniques. The methods differ in the manner in which these two operations are performed. For example, the measurement of gases may be made by specific methods, such as gas chromatography, mass spectrometry, or infra red analysis, or by non-specific techniques, such as conductometry, gravimetry, or manometry. Similarly, a variety of means are used in converting the carbon to a gaseous form."

TABLE I. Summary of Routine Procedures for Oxygen Measurement in Sodium

Laboratory	Separation Method	Analysis Method	Reference	Contact
Aerojet General	(1) Mercury amalgamation (2) Vacuum distillation	(1) Titrimetric (2) Titrimetric	Personal communication	G. R. Zellars
Argonne National Lab.	(1) Mercury amalgamation (2) Vacuum distillation	(1) Titrimetric (2) Atomic absorption spectrometry	(1) ANL-7123 (2) Personal communication	B. D. Holt S. L. Skladzien
Atomics International	Mercury amalgamation	Flame photometry	Gatlinburg paper, September 1966	J. M. Scarborough
Atomic Power Development Associates	Mercury amalgamation	Titrimetric	APDA-168	E. F. Hill
Battelle Memorial Institute	Mercury amalgamation	Titrimetric	Personal communication	F. E. Huber, Jr.
Brookhaven National Lab.	Mercury amalgamation	Titrimetric	Personal communication	L. H. Newman
Douglas Aircraft Co.	Mercury amalgamation	Titrimetric	Douglas SM-48883	W. S. Ginell
General Electric (Vallecitos)	Mercury amalgamation	Titrimetric	Personal communication	D. Dutina
General Electric (Evendale)	Mercury amalgamation	Titrimetric	GE 03-0018-00-A	H. E. Bradley
General Motors	Mercury amalgamation	Titrimetric	Personal communication	G. R. Zellars
Los Alamos Scientific Lab.	Vacuum distillation	Flame photometry	LA-3343	K. S. Bergstressor
Mine Safety Appliance Research Corp.	Mercury amalgamation	Titrimetric	Personal communication	S. J. Rodgers
NASA (Liquid Metals Branch)	(1) Mercury amalgamation (2) Vacuum distillation	Titrimetric	(1) Anal. Chem., vol. 36, p. 430, 1964 (2) Personal communication	G. R. Zellars ^(a)
NASA (Chemical Services)	Mercury amalgamation	Titrimetric	NASA-TP-6-63	---
Oak Ridge National Lab.	Mercury amalgamation	Flame photometer	GG-68	G. Goldberg
Pratt and Whitney	Mercury amalgamation	Titrimetric	Personal communication	E. W. Hobart
United Nuclear Corp.	Mercury amalgamation	(1) Titrimetric (2) Karl Fischer titration ^(b)	NDA-2154-2	C. Gregg
Westinghouse Electric	Mercury amalgamation	(1) Titrimetric (2) Flame photometry	WCAP-4321	J. Herb
Pacific Northwest Lab.	Mercury amalgamation	(1) Titrimetric (2) Flame photometry	---	---

(a) Provided information concerning Aerojet General and General Motors methods also.

(b) Use Karl Fischer titration only for samples with known oxygen concentration <10 ppm.

A major point of clarification is required at this point. The PNL program requirement was twofold: (1) to provide an on-site analytical capability for measurement of total carbon concentration, and (2) to review methods for performing carbon species analyses and ultimately to establish analytical capability for this determination.

Table II summarizes the procedures used routinely for total carbon analyses in U. S. laboratories, including the method employed by PNL.

HYDROGEN

Hydrogen is of concern in sodium cooled systems for several reasons: (1) it can react with refractory metals to cause embrittlement, (2) it can interact with other impurities present to give undesirable chemical compounds; and (3) it can lead to errors in measurement of oxygen by the amalgamation technique. Considerable effort has been expended to develop manual analysis methods for hydrogen measurement.

Table III summarizes the procedures used routinely for hydrogen analyses in U. S. laboratories, including the method selected for use at PNL.

NITROGEN

Nitrogen is of concern in sodium cooled reactors because of the potential for nitriding of refractory metals with resultant embrittlement, and of the interactions it may undergo with other impurities present--for example, formation of cyanide. It is not expected that nitrogen will be a significant factor in systems where ultrapure inert gas is used to blanket the sodium coolant unless it is introduced in substantial amounts with the sodium, for example, as lithium or calcium nitride.

TABLE II. Summary of Routine Procedures for Total Carbon Measurement in Sodium

Laboratory	Method	Reference	Contact
Argonne National Lab.	(1) Oxidize in O ₂ . Release CO ₂ by H ₂ SO ₄ . Measure manometrically (2) EBR-II: K ₂ Cr ₂ O ₇ oxidation. CO ₂ by chromatography	(1) Vienna Conf. 1966, SM-85/23 (2) Personal communication	A. Cosgarea, Jr. C. C. Miles
Atomics International	Van Slyke oxidation. CO ₂ by isotope dilution mass spectrometry	Anal. Chem., vol. 36, p. 1832, 1964	C. D. Bingham
Atomic Power Development Associates	Oxidize in O ₂ -He at 1100 °C. CO ₂ by chromatography	APDA-164	S. A. Meacham
Brookhaven National Lab.	Oxidize in O ₂ -A, then in O ₂ . Add H ₂ SO ₄ to release CO ₂ . CO ₂ by conductometric measurement of Ba(OH) ₂ .	Personal communication	L. Newman
Ethyl Corporation	Oxidize in air at 1100 °C. CO ₂ by chromatography	Anal. Chem., vol. 36, p. 70, 1964	T. G. Mungall
General Electric (Vallecitos)	Convert to sulfate followed by Van Slyke oxidation. CO ₂ by chromatography	GEAP-4540	D. Dutina
General Electric (KAPL)	Convert to sulfate followed by Van Slyke oxidation. CO ₂ by volumetric freeze out technique	Anal. Chem., vol. 28, p. 1606, 1956	L. P. Pepkowitz
Los Alamos Scientific Lab.	Oxidize in O ₂ at 1100 °C in vanadium pentoxide-boric anhydride flux. CO ₂ by gravimetry	Personal communication	C. W. Metz
Ledoux and Company	Oxidize in O ₂ -A, convert to sulfate. CO ₂ by conductometric measurement of Ba(OH) ₂	Anal. Chem., vol. 36, p. 590, 1964	Silve Kallmann
Mine Safety Appliance Research Corp.	Convert to sulfate and acidify. CO ₂ by chromatography plus carbon in salt residue after evaporation.	MSAR-64-41	S. J. Rodgers
NASA (Liquid Metals Branch)	Oxidize in O ₂ -A, convert to sulfate. CO ₂ by conductometric measurement of Ba(OH) ₂ .	GEAP-4540	D. Dutina
Oak Ridge National Lab.	Low temperature ignition in O ₂ then 1100 °C. CO ₂ by manometric method.	ORNL-3537	G. Goldberg
Pratt and Whitney	Oxidize in O ₂ -A convert to sulfate. CO ₂ by conductometric measurement of Ba(OH) ₂ .	TID-7607	E. W. Hobart
United Nuclear Corp.	Convert to sulfate followed by Van Slyke oxidation. CO ₂ by manometric measurement.	Personal communication	C. Gregg
Westinghouse Electric	Oxidize at 1100 °C by O ₂ from CuO. CO ₂ by chromatography.	WCAP-4321	J. Herb
Pacific Northwest Lab.	300 °C ignition in pure O ₂ then 1100 °C in O ₂ to release CO ₂ . CO ₂ by chromatography.	---	---

TABLE III. Summary of Routine Procedures for Hydrogen Measurement in Sodium

Laboratory	Method	Reference	Contact
Argonne National Lab.	Isotope dilution with deuterium	Anal. Chem., vol. 31, p. 51, 1959	B. D. Holt
Atomics International	Vacuum extraction from sealed, hot, iron capsule. H_2 by chromatography	Personal communication	C. D. Bingham
Atomic Power Development Associates	Hg amalgamation followed by heating to decompose components. H_2 by chromatography	APDA-183	S. A. Meacham
Battelle Memorial Institute	Vacuum fusion	Personal communication	E. M. Simon
General Electric (Vallecitos)	Vacuum extraction from sealed, hot, iron capsule. H_2 by chromatography	GEAP-4833	D. Dutina
Los Alamos Scientific Laboratory	Reaction with silica at 1000 °C in A and O_2 . H_2O formed absorbed in $Mg(ClO_4)_2$, measured gravimetrically	LA-3049	C. W. Metz
Mine Safety Appliance Research Corp.	Isotope dilution using deuterium	Personal communication	S. J. Rodgers
NASA (Liquid Metals Branch)	---	---	---
Oak Ridge National Lab.	Hg amalgamation to separate residues. Hydrolysis of residue to release H_2 . H_2 by chromatography.	ORNL-3537	G. Goldberg
United Nuclear Corp.	Hg amalgamation followed by refluxing to decompose compounds. H_2 by chromatography.	UNC-MTL-4896	C. Gregg
Pacific Northwest Lab.	Hg amalgamation followed by refluxing to decompose compounds. H_2 by chromatography.	---	---

The majority of the methods available for measuring nitrogen in sodium involve modifications of the basic Kjeldahl distillation. In these procedures the nitrogen is released as ammonia for distillation and collection. Analysis of the ammonia is then accomplished by titrimetric or spectrophotometric methods. The basic differences between methods in use today is in the procedures used to (1) convert the nitrogen to ammonia and (2) measure the collected ammonia.

Table IV summarizes the analytical methods in use for nitrogen measurement in U. S. laboratories, including the method employed by PNL.

TRACE METALS

Measurement of the concentrations of trace metallic elements present in sodium coolants is of interest to aid in assessing corrosion and mass transport effects within the system. This requires utilization of ultrasensitive methods to measure impurities present in the makeup sodium, and concentration changes across various process equipment, e.g., heat exchangers, fuel channels and impurity traps.

Various methods have application to this problem area including emission spectroscopy, atomic absorption spectrophotometry, colorimetry, mass spectrography, and--in the case of reactor coolant samples--gamma spectrometry. Development work in this area is progressing at various laboratories and changes in the methods used routinely are occurring rather rapidly.

Table V lists methods in use in various U. S. laboratories at the time of the PNL methods survey, and includes the method selected for use at PNL.

GENERAL

A wide range of methods have been developed for various other impurities in sodium including the alkali metals, alkaline earths, halides, refractories, and various neutron poisons.

TABLE IV. Summary of Routine Procedures for Nitrogen Measurement in Sodium

Laboratory	Method		Reference	Contact
Argonne National Lab.	Kjeldahl distillation.	Titration and Nessler to measure ammonia	Personal communication	C. D. Bane
Atomics International	Kjeldahl distillation.	Titration for ammonia	Personal communication	C. D. Bingham
Battelle Memorial Inst.	Kjeldahl distillation.	Nessler reaction for ammonia	Personal communication	E. M. Simon
General Electric (Evendale)	Kjeldahl distillation.	Nessler reaction for ammonia	<u>Anal. Chem.</u> , vol. 37, p. 1287, 1965	H. Kirtchik
Los Alamos Scientific Lab.	Kjeldahl distillation.	Titration for ammonia	LA-2892	C. H. Ward
Mine Safety Appliance Research Corp.	Kjeldahl distillation.	Nessler reaction for ammonia	APL-TDR-64-34	S. J. Rodgers
Oak Ridge National Lab.	Kjeldahl distillation.	Nessler reaction for ammonia	NDA-38	N. I. Sax
United Nuclear Corp.	Kjeldahl distillation.	Nessler reaction for ammonia	UNC-5121	C. Gregg
Westinghouse Electric	Kjeldahl distillation.	Nessler reaction for ammonia	WCAP-4321	J. Herb
Pacific Northwest Lab.	Kjeldahl distillation.	Titration and Nessler reaction for ammonia	---	---

TABLE V. Summary of Routine Procedures for Trace Metals Measurement in Sodium

Laboratory	Method	Reference	Contact
Argonne National Lab.	Atomic absorption spectroscopy	Personal communication	S. Skladzien
Atomics International	Atomic absorption spectroscopy	"Determination of Trace Metallic Impurities in Sodium Using Emission and Atomic Absorption Spectroscopy" Paper presented at 10th Annual Conference on Analytical Chemistry, Gatinsburg, Tennessee, September 1966.	C. D. Bingham
Atomic Power Development Associates	Atomic absorption spectroscopy	"Analysis of Iron, Nickel, and Chromium in Sodium Metal," an APDA report, in press.	S. A. Meacham
Battelle Memorial Inst.	Arc-emission spectroscopy	Personal communication	E. M. Simon
Brookhaven National Lab.	Arc-emission spectroscopy	Personal communication	L. Newman
Douglas Aircraft Company	Spectrophotometric	Personal communication	R. S. Dunn
General Electric (Vallecitos)	Sodium-residue separation and X-ray, and wet chemistry analysis of residue	CONF-650411 (See Reference 1)	D. Dutina
General Electric (Evendale)	Arc-emission spectroscopy	03-0018-00-A	B. Hand
Los Alamos Scientific Lab.	Arc-emission spectroscopy	Personal communication	C. W. Metz
Mine Safety Appliance Research Corp.	Arc-emission spectroscopy	Personal communication	S. J. Rodgers
Oak Ridge National Lab.	Arc-emission spectroscopy	ORNL-2218	M. T. Kelley
United Nuclear Corporation	Spectrophotometric	Personal communication	C. Gregg
Westinghouse Electric	Arc-emission spectroscopy	WCAP-4321	J. Herb
Pacific Northwest Lab.	Atomic absorption spectroscopy	---	---

However, these are generally classified as "special" analyses rather than analyses of interest from the standpoint of reactor operation and control. Analytical procedures for these impurities usually involve converting the sodium sample to an aqueous salt solution and performing conventional chemical analysis operations. A detailed listing of the methods employed for these analyses at various laboratories is beyond the scope of this paper; however, an excellent source of this kind of information is the Liquid Metal Information Center at Canoga Park, California which Atomics International operates for the USAEC.

REFERENCES

1. D. Dutina. "The Current State of the Art of Alkali Metal Analysis," CONF-650411. Presented at AEC-NASA Liquid Metals Information Meeting, Gatlinburg, Tennessee. April 21-23, 1965.
2. H. Kirtchick and S. F. Melzer. The Method for Chemical Analysis of Nitrogen in Potassium, R63FPD302, September 16, 1963.
3. V. A. Stenger, O. U. Anders, C. L. Van Hall, R. J. Moolenaar, W. R. Kramer, and H. H. Gill. Analytical Methods for Impurities in Cesium Metal, ML-TDR-64-199. Dow Chemical Company, Midland, Michigan, August 1964.
4. E. W. Hobart. Status of Methods for Determining Carbon, Oxygen and Nitrogen in Alkali Metals, TIM-900. Pratt and Whitney Aircraft, Middletown, Connecticut, April 1, 1965.
5. E. M. Simons, J. H. Stang, S. J. Basham, W. A. Glaeser, and C. J. Bell. FY-1965 Sodium Technology Support Program, BMI-X-10129. Battelle Memorial Institute, Columbus, Ohio, July 9, 1965.
6. D. W. Shannon. Fast Reactor Corrosion and Chemistry Interim Technical Progress Report No. 1, October, 1966-April, 1967, BNWL-483. Pacific Northwest Laboratory, Richland, Washington, June 1967.
7. D. M. Holm, J. M. Williams, and W. M. Sanders. "Determination of Oxygen and Carbon in Sodium by Gamma-Neutron Activation," presented at Tenth Conference on Analytical Chemistry in Nuclear Technology, Gatlinburg, Tennessee, September 27, 1966.

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