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Dental Materials Research

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Dental Materials Research

Proceedings of the 50th Anniversary Symposium
Held at the National Bureau of Standards
Gaithersburg, Md., October 6–8, 1969,
in Recognition of Fifty Years of Dental Research at NBS

George Dickson and James M. Cassel, Editors

Institute for Materials Research
National Bureau of Standards
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Abstract

A Symposium on Dental Materials Research was held at the National Bureau of Standards, October 6–8, 1969, on the occasion of the fiftieth anniversary of the dental research program at NBS. The Symposium brought together outstanding researchers in the dental materials field from throughout the world for a comprehensive examination of the present state of research and a look at future dental needs and expectations. The program covered the broad dental materials field—from an examination of the oral environment to a consideration of future needs from the viewpoints of dental practice, dental education, dental industry, and basic science. Invited papers covered metals research, new developments in nonmetallic restorative materials, dynamic methods for determining the mechanical properties of dental materials, and problems of evaluating dental materials and making such evaluations useful to clinical dentistry through the development of specifications.

Key words: Adhesives; composite restorative materials; dental materials research; dental restorative materials; future dental needs; laboratory testing and clinical research; mechanical properties; metals research; specifications.

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Foreword

The Dental Research Section, a unit within the Polymers Division of the Institute for Materials Research, National Bureau of Standards, renders a unique assistance to efforts to improve dental health. The research program is a cooperative effort both in personnel and funding involving several agencies of government and a major professional health association. The specific aim is to bring physical science expertise and instrumentation to bear on those aspects of dental research which may yield only to this approach.

The current collaborative dental research program at NBS is conducted in cooperation with the Council on Dental Research of the American Dental Association; the National Institute for Dental Research; the Dental Research Division of the U. S. Army Medical Research and Development Command; the Dental Sciences Division of the School of Aerospace Medicine, U.S.A.F.; and the Veterans Administration.

Dental research was begun at the National Bureau of Standards in 1919 in response to a request from the War Department for assistance in evaluating dental materials purchased by the Government. From 1919–1922 the research staff consisted of Dr. Wilmer Souder, in whose honor the present symposium has been dedicated. From 1922–1928, the Weinstein Research Laboratory supported Research Associates as assistants to Dr. Souder. In 1928, the American Dental Association established its Research Associate Program and this continuing collaboration has encouraged close rapport among this physical science laboratory, dental manufacturers, and practicing dentists.

The achievements of the Dental Research Section during the past 50 years have transformed the practice of dentistry in many ways. Early accomplishments included the development of precision casting techniques for gold alloys. Later innovations included a high-speed contra-angle turbine drill, a panoramic dental x-ray machine, spherical particle amalgam alloy, and composite restorative materials. Current efforts are directed toward a better understanding of the fundamental properties of tooth structure, the physical and chemical mechanisms relating to initiation and development of caries, and toward the development of new and improved materials and instrumentation.

It is particularly important, in paying tribute to a half century of dental research, that opportunity be provided in this symposium to see not only where we have been but where we need to go. The response of dental materials experts from around the world in meeting the challenge of delineating the research needs for the future is especially exhilarating.

J. D. Hoffman, Director
Institute for Materials Research
National Bureau of Standards

Preface

This book is the formal report of the proceedings of the 50th Anniversary Symposium on Dental Materials Research sponsored by the National Bureau of Standards and the American Dental Association with the cooperation of Johnson and Johnson, Kerr Manufacturing Company, and Surgident, Ltd. The Symposium brought together many outstanding researchers for a comprehensive examination of the present state of research and a look at future dental needs and expectations.

The papers included herein encompass the broad dental materials field—from an examination of the oral environment to a consideration of future needs from the viewpoint of dental practice, dental education, dental industry, and basic science. Invited papers cover metals research, new developments in nonmetallic restorative materials, dynamic methods for determining the mechanical properties of dental materials, and problems of evaluating dental materials and making such evaluations useful to clinical dentistry through the development of specifications.

The symposium offered an opportunity to pay tribute to the founder and for many years guiding inspiration of the dental research program at NBS, Dr. Wilmer Souder. It also recognized the outstanding leadership of Dr. Irl C. Schoonover in the development of a unique organization for dental research which has directly involved a government laboratory, the National Bureau of Standards, and a private professional society, the American Dental Association, in a cooperative program supported and participated in by the National Institute of Dental Research, the Armed Services and the Veterans Administration Dental Corps.

Members of the Symposium Committee wish to express their appreciation to the authors and to all participants who contributed toward making the symposium a truly memorable event. Thanks are also given to Mrs. Marion Kumpula of the ADA Research Unit at NBS and to Mrs. Ruth Davenport for their attention to the many details involved prior, during, and immediately after the symposium. The NBS Office of Technical Information and Publications under the direction of W. R. Tilley, with special help from Robert T. Cook, gave invaluable assistance in many phases of the effort. Particularly appreciated is the assistance of Johnson and Johnson, Kerr Manufacturing Company, and Surgident Ltd. in contributing to the funding of the Symposium.

Committee for the 50th Anniversary
Symposium on Dental Materials Research

Gerhard M. Brauer
Walter E. Brown
James M. Cassel
Harold J. Caul
George Dickson
George C. Paffenbarger
William T. Sweeney, Chairman

Identification of some commercial materials and equipment has been necessary in this book. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment is necessarily the best available for the purpose.

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I. Introductory Session

NATIONAL BUREAU OF STANDARDS SPECIAL PUBLICATION 354,
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Held Oct. 6–8, 1969, Gaithersburg, Md. (Issued June 1972).

Dental Research at the National Bureau of Standards—Reminiscences

Wilmer Souder*

Chief, Dental Research Section, NBS, 1919–1945

In 1918 dental amalgams had a high rate of failure and few data on their physical properties were available. Using the interferometer for determination of the dimensional changes of amalgam and scientific test methods for other properties, NBS began to obtain information on the physical properties of dental materials. The specification for dental amalgam developed in the early days with numerical limits for physical and clinical properties and details of test methods has served as a model for specifications for dental materials for over 40 years. Although the early results were challenged and the program opposed by some, the dental profession soon recognized the value of the work and requested its expansion. In time schools, dental associations, and manufacturers joined in commending the research program.

Key words: Amalgam, dental; American Dental Association; dental materials; Dental Research Section, NBS; interferometer, dental; specifications, dental.

1. Reminiscences

Thank you, Mr. Chairman, for the kind invitation to attend and the liberty to address this symposium. More than ten years ago the Bureau said "Good Bye and Best Wishes". No attempt has been made to have succeeding leaders change their programs. I had my opportunity and am pleased with the results. The future opportunities and prospects are bright. Your request for reminiscences is dangerous. It means looking back. One of our former directors, Dr. Lyman J. Briggs, had a motto: "Never look back; something might be gaining on you". Any attempt to brag on the achievements would flavor of conceit. To criticize would be dangerous in the presence of this audience. So what is left? There are some personal errors, then some confrontations and a rapprochement of all interested parties. It seems proper to document these, as they were encountered.

No honest comment on the research can be made without an acknowledgement of the aid given by loyal assistants. Among the first of these were, Peters, Coleman, Hidnert, Sweeney, Swanger, Taylor, Isaacs, and Berger; and later Caul, Dickson, Paffenbarger, Lynch, Brauer, Jordon, Schoonover, and Richardson. Others are named in various publications and may be mentioned by those who follow on this program.

2. A Dental Research Considered

A preliminary review of the dental situation in 1918 revealed a high degree of failures in dental restorations made from silver amalgams. Claims and endorsements were available and techniques were numerous and elaborate but not in technical terms. Tests to substantiate these claims in terms of physical, chemical, and engineering properties (necessary in restoring the needed functioning of a tooth) were not found. The pioneer who first pointed out this defect was Dr. G. V. Black. He had a clear understanding of the needs and methods for establishing the quality of an amalgam. His heroic efforts to create a micrometer sensitive enough to document, with definite accuracy, the length and volume changes in amalgams, and their dependence on chemical compositions and operational practices, were not entirely satisfactory. His micrometer was dependent on levers and gears which introduced friction in pivots plus hysteresis lags. This preliminary search pointed to the necessity of a more sensitive micrometer. The interferometer, having a normal sensitivity of one millionth of an inch, is such an instrument.

3. Precision Data

Mr. C. G. Peters, of the Bureau's optical laboratory, had an interferometer and gladly consented to measure the length changes in amalgam specimens which I condensed. These tests established, in definite terms, the changes and defects which Black had suspected. It is doubted that any dental college, dentist, or manufacturer had an instrument approaching the precision of the interferometer. Peters and I published our findings in the Physical Review [1].[1] Our data established a difference of three to one for the thermal expansions of amalgam to dentin; the amalgam having the higher value. This established the necessity for a positive setting expansion of all amalgams to cancel any separation between the amalgam and the tooth

*Present address: Landisville, Pennsylvania 17538

[1] Figures in brackets indicate the literature references at the end of this paper.

when exposed to cold foods or drinks. Several brands gave setting shrinkages. The dentist is called upon to create a restoration surpassing the perfection of the natural tooth which has failed. Furthermore he must completely exclude germs, acids, and all other hazards; always ready to destroy his restoration. No immediate response came from this publication. I decided to create an interest by dentists, manufacturers, and the public by writing a news item for release by the Bureau containing, among other information, a statement: "The public could better avoid the dentist who drills out a cavity and fills it with a shrinking amalgam". The news item was sent to the Department for approval. The item was returned with a statement (essentially) as follows: "There is no question on the accuracy of the tests; however, it is not considered wise to create a situation such as this would create unless, at the same time, a remedy is offered." So died the attempt to awaken the public.

4. Sparrings

Unfortunately or otherwise, a metallurgist, interested in amalgam alloys, made some disparaging remarks about our budding efforts and pointed out unimportant variations in our results when he made a report on his own tests. These were printed in a metallurgical journal. Peters and I set up a reply criticizing his results which revealed greater variations than any of ours. Also we referred to his great emphasis upon a transformation in amalgams when heated to 80 degrees Centigrade; a condition not compatible with dental health. We were were careful to make no reference to our connections with the Bureau and paid for the publication of our reply. We were elated at the neatness of our reply—until a few days after the appearance of the journal. We were asked to come to the office of the Director at our convenience. We were anticipating the approval of Director George K. Burgess, a metallurgist of the first water. He inquired about our work. Then he showed us a copy of the magazine containing our reply and asked what we knew about it. We said we prepared it and paid for its printing and purposely avoided any reference to the Bureau. Then the sky fell in. He chewed us out as they say in the Army. He reminded us we had stooped to put our abilities on a level of the one we had attempted to expose. He said the Bureau does not encourage scraps. It looked like the last day for two career Civil Service employees. Then his attitude changed. He said "You have abilities, you can develop positive approaches. Go back to your laboratories and prove it". From that day we kept within the traces, absorbing most criticisms.

5. Specifications

A request from the Army in 1918 asking for assistance in awarding contracts for dental amalgam alloys gave the Bureau its first opportunity to give service in this field. About twelve samples were submitted with the request. There were numerous claims for superiority and endorsements printed on the cartons, but not one numerical datum to support the claims. After making tests of setting expansion, compressive strength, and ease of amalgamation, it was possible to rate most of the samples as defective or inferior. The Army was advised which of the remaining alloys should give satisfaction. This experience pointed to a need for a real specification. Accordingly a study was inaugurated and a specification [2] was set up. This specification was modeled on the pattern of the American Medical Association's Pharmacopoeia specifications. It gives numerical limits for physical and chemical tests and refers to instruments and techniques for making the tests. These two are musts for any intelligible test. Otherwise quibblings are sure to erupt. I claim credit for this theft or appropriation of the American Medical Association's pattern. The limiting numbers may be changed as qualities are improved by the manufacturers. This type of specification for various dental materials has survived forty years and is basic for the Certification Plan adopted later by the American Dental Association.

6. Questioned Progress

The service to the Army Dental Corps was the first signal of a serious interest in the Bureau's work in the selection of dental materials. As might be expected, some manufacturers (whose products might not meet a specification) were not enthusiastic about the plan. Deans, prominent lecturers, and dentists whose personal endorsements were ignored in the specifications were in a clouded area. We were disappointed when the Journal of the American Dental Association in 1920 could not find it possible to print our first extensive (32 page) report, "Physical Properties of Dental Materials". However, another agency was quite willing to print the report [3] with a volunteered commending editorial. Later, consideration of the refusal was understandable. With certain members of the Association lukewarm and several manufacturers suspicious of the outcome of the Bureau's work, they can be excused for the decisions to wait for more assurance of the purposes. When convinced of the ability and integrity of the Bureau, the American Dental Association became one of our loyal supporters.

7. Genuine Interest

After the publication of the first extensive report, interest developed rapidly. Correspondence with dentists, schools, and associations requesting lectures and clinics piled up. The Director approved many of these requests. (The Bureau position, relating to such requests assumed that the Bureau official would be reimbursed for travel and

subsistence costs and that no honorarium would be accepted.) Requests for an extension of the program to include a study of dental gold alloys, cements, and accessory materials came to the Bureau. The Bureau felt that after having set up a pattern for research in the field, it should not assume the responsibility and expense for extensions. However, it did ask for advice [4] on the problem. Dr. Louis J. Weinstein, Director of the Weinstein Research Laboratory in New York, expressed a genuine interest in seeing the research continued.

8. The Research Associate Plan

Dr. Weinstein's request was simple and direct: "I want to see data on dental gold alloys and accessories which will stand up when presented before schools and private groups and not be confused by data in present day texts and glaring advertisements." The Bureau Research Associate plan was explained to him whereby qualified scientists may work at the Bureau on problems of public interest. The Bureau directs and supervises the work and publishes the results. The sponsor pays the salary of the associate. Dr. Weinstein accepted the opportunity and supported the program for six years (1922–1928).

9. Organized Opposition

The first comprehensive report [5, 6, 7] on the Weinstein Research Associate's achievements was given at the Dallas meeting of the American Dental Association. It was quite evident at this meeting and in other happenings that a fission between vested interests and the research associates was developing. These interests wanted to crush the research. They appealed to the Secretary of Commerce, insisting that the reports were creating confusion among the dentists and in the schools and requested that the work be stopped. The Bureau was asked for a statement on the claims. The Director explained to the Assistant Secretary that the research was a public operation and all findings were announced promptly. Furthermore, he stated that the program was a health-saving research needed by every citizen of the United States. No cease or desist order was issued. By some means the dentists across the Nation become aware of what was about to happen and were preparing for a fight. Had this developed, with the support of 90,000 dentists across the Nation, it would have made the Bureau's later AD–X2 confrontation look like child's play.

10. American Dental Association

Meanwhile, the American Dental Association had expressed an interest in and a desire to cooperate formally and actively in the program. The details for this cooperation were completed in 1927 and the cooperative program has continued unbroken from 1928 to date. In 1942 Dr. M. D. Huff, Chairman of the Research Commission, expressed the feelings of the American Dental Association in the following words [8]: "It was a fortunate day when Doctors Barber, Brown, and Volland of the Research Commission went to the National Bureau of Standards in 1927 to complete the details of the cooperative research which has become so valuable to the dental profession. . . . Our associates have been wholeheartedly welcomed by the Bureau. . . . The supervision of the work, the assumption of responsibility for the data, and the complete publication of all findings by the Bureau, have given us an authoritative position seldom possible in such fields of research."

11. World War II

During World II the Bureau found it necessary to curtail activity on many programs as it devoted about 90 percent of its work to problems of defense. It was declared a Restricted Area under the supervision of the Departments of War and Navy. The American Dental Association sent a prompt and patriotic request to the Bureau authorizing it to feel free to transfer its dental associates to Bureau military work as needed, salaries to be continued by the Association. Both, Bureau and Association scientists, filled assigned military positions with distinction. Dental research was restored to its full-time activity at the close of the war.

12. Rapprochements

Within 10 years after the previously mentioned oppositions were met, all dissenters had disappeared. The schools, societies, and manufacturers were joining in their commendations of the work. New and and better materials and techniques have been discovered. Perhaps the comment of one manufacturer can be used as a summary: "The research and specifications are our only effective protections against competitors trying to exploit inferior materials by glaring advertisements and personal endorsements".

13. An Unfinished Research

One project on the possible "Remineralization of Dentin", started by Schoonover and Souder, was dropped by reason of the more important war needs. The illustrations in the preliminary report [9] show a deposit of some material in the hardness indentations; the length of the indentation mark is shortened after exposure to a fluoride solution. The body's ability to repair a broken bone suggested the possibility of some such attempt to repair injury to dentin, under favorable conditions. Dr. von Buest of the University of Louisville Dental School was the only one to give us encouragement on the idea. Quotes from recent re-

ports on the effects of fluoride are given below: Bierman, M.D. [10] "the (cancerous) bone becomes harder and more durable". Hoffman, NDRI [11] "topical fluoride can reverse the dental caries process and may even heal incipient caries". A research [12] ". . . into the molecular basis of disease" has been announced. Even a TV puppet declares that fluoride makes a tooth stronger. Perhaps some budding researcher may decide to make an independent evaluation of these reports.

14. Fare Thee Well

With these scattered reminiscences my part in this program must close. These are no feelings of resentment toward anyone. Rewards and gestures of appreciation have been excessive. My response is, Thank You and Best Wishes for the Future.

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Dental Research at the National Bureau of Standards—History and Individuals

W. T. Sweeney*

Chief, Dental Research Section, NBS, 1953–1968

Dental research at NBS was initiated in 1919 by Dr. Wilmer Souder with work on dental amalgams. Dr. Souder built the Section on the principle of cooperation between research laboratories, manufacturers and the dental profession. In the 1920's research associates, first from the Weinstein Research Laboratory and later from the American Dental Association were added to the NBS dental research staff. Dr. N. O. Taylor and Dr. George C. Paffenbarger were the first ADA Research Associates. In 1945 while Dr. Irl C. Schoonover was Chief of the Section, the laboratory staff was further enlarged by the addition of Guest Workers from the Armed Services. Among the many important areas of research were precision casting, dental cements, polymers for dentures bases, composite restorative materials, high speed turbine handpieces, panoramic X-ray equipment, studies of natural tooth structure and development of standards and specifications.

Key words: Amalgam, dental; American Dental Association; casting, dental; dental research; Dental Research Section, NBS; guest workers; Paffenbarger, George C.; Schoonover, Irl C.; Souder, Wilmer; specifications, dental.

1. Introduction

The objective of this paper is to give a brief and concise report of the most outstanding events, personnel, and accomplishments of the dental research program at the National Bureau of Standards in order to set the stage for the symposium honoring the 50th Anniversary of the program. Only a few of the many persons and events can be discussed or even mentioned in the limited time allowed.

The name of Dr. Wilmer Souder is the most outstanding of all the scientific staff because he is responsible for setting the character and ideals of the program and was chief of the Section for the first half of its life. The merit of bringing good scientific measurements into the health field as an adjunct to better dental health care for the public was thereby established. He also realized that a cooperative effort was essential between the three groups, dental profession, manufacturers, and general public as represented by the government. While this sounds trite, looking back today, it was not a very popular idea when he first started in 1919, as there were very few who had the long-range vision to see the advantages of such cooperation.

2. Early or Formative Period, 1919–22

This period was the most important as it is the germ from which the Section grew. The original request from the War Department to the National Bureau of Standards for assistance in evaluating dental products purchased for the Federal services was referred to Dr. Souder for a routine reply. Amalgam was the material of interest. Souder, as a young physicist fresh from his Ph.D. studies at the University of Chicago, naturally looked at the problem scientifically. The more he examined the basis for selection of dental materials, the more he was convinced that the science of measurement could make a contribution to the dental profession and the dental treatment of the public. He, in short, visioned the substitution of quantitative measurements of properties for the art of personal skill and personal recommendations. He had the zeal and forethought to advocate and demonstrate that physical science had a great many things to offer the health professions.

A few people, notably G. V. Black, a dentist, had carried out some very basic investigations but the precision of a physicist was almost unknown to the science of materials used by the dentist. Souder first turned his attention to dental amalgams and in 1919 published his report on the measurement of such properties as dimensional setting changes, strength, and flow. His results and methods are good today even after 50 years and have led to much improvement of alloys and techniques for dental application. He held the theory that the best way to evaluate any material is to measure the properties that are important for its application. He meant to obtain numerical evaluations by measurement and then delineate his procedures so that any competent scientist could repeat and check his results. This was a unique point of view in the field of dental materials. He was told that it was impossible to

*Present address: School of Dentistry, University of Alabama, Birmingham, Alabama 35233.

determine the elements in certain alloys, as the analytical methods were too crude. As a matter of fact this was correct, in some cases at least, but he answered this by saying that if we obtained a scientifically trained staff, we could overcome this and he certainly proved it.

Souder, realizing in this early period that a working together of the research laboratories, manufacturers, and profession was required if the public were to receive maximum dental service, tried to interest the dental profession through their national organization to join in a cooperative program. While certain individuals gave moral support to the idea, the organization was not yet willing to put financial support into the research program. When this failed he was fortunate to secure financial assistance from Weinstein Research Laboratories, who provided substantial support from 1922 to 1928.

3. Expansion of the Program Via Research Associates, 1922–28

This period was most productive as it represents the first expansion of the dental work by the addition of research associates to the group. The research associates were directed by NBS and supported by the Weinstein Research Laboratory. The first research associate, R. L. Coleman, an engineer, was selected from the NBS Staff, a member of the Weights and Measures Division. His work on measurements of properties of gold alloys and precision casting techniques is classical in that it set the standard for precision casting, not only in the dental field but later in industry, such as in the casting of blades for turbines. During this period the first dental specification for amalgam alloys was promulgated, based on the original work of Souder; and the properties of accessory materials used in dental casting, such as waxes, investments, and orthodontic wires were studied, and standard measuring techniques were developed so that specifications could be written later.

The chemical analysis of alloys of gold and the platinum group metals by the joint efforts of Raleigh Gilchrist, an NBS chemist, and William Swanger, a research associate, was an example of how the cooperative effort produced worthwhile scientific results. Their reports justify Souder's prediction that well trained chemists could determine accurately the composition of dental alloys. After these reports, it was obvious that secret formulas would be secret only until someone was willing to spend the time and money to do precision chemical analysis. This work created many controversial problems for NBS on the policy of publication of analyses of trade brand alloys or materials. These problems have not yet completely disappeared because it is a moot question as to how far a tax-supported institution should go in publishing trade secrets that individual companies have spent much in developing. In general, the dental profession argued that it should know exactly what it uses and the manufacturer thought he needed protection because he spent a lot of money to advance his product. The principle has been to use trade names in publications if they are necessary for understanding by the reader. Details of methods of analysis were given in scientific reports so anyone competent could evaluate properties versus composition.

Verbal reports and many articles by the staff of the Section during this period created such a demand by the dental profession for more scientific evaluations that by 1928 the profession was willing to support the research program and give official recognition to it by formal agreement between the American Dental Association and NBS. This arrangement made for a much broader base of operation and the liaison has proven most profitable to all concerned.

4. Cooperative Program With American Dental Association, 1928–45

In April 1928 the cooperative program between the American Dental Association and the National Bureau of Standards was initiated. The first ADA research associate was Dr. N. O. Taylor, a chemist, who was followed in 1929 by Dr. George C. Paffenbarger, the first dentist to work full time in the Section. The period of the late 1920's and 1930's witnessed a great expansion of the research program through the addition of both NBS and ADA personnel. Basic research on the physical and chemical reactions of many materials was undertaken. This period was productive and an improved understanding was obtained of the properties of practically all the materials used in restorative dentistry from amalgam alloys to denture resins. The approach was basically the same for all materials. First a study was made of the properties of the available materials and how they were affected by composition and by techniques used in practice. Typical examples were studies of the effect of heat treatment on gold alloys and how the mechanical properties were changed by cooling rates in the dental laboratory; how the method of mixing cements could drastically change the useful properties of the material; and how exposure to light affected the color stability of pink denture base resins.

Many special methods were developed for measuring properties of these different materials. The fact that dentistry uses small specimens in comparison to those commonly employed in industry makes it necessary to use unique test methods. Special tests were developed to more closely simulate dental use. The fact that the oral cavity has a varied atmosphere with a variety of temperatures and humidity, makes it necessary that materials be evaluated under conditions which are found in clinical use. Biological requirements put many restrictions on otherwise suitable materials.

The specification program was a major development as it made the results of research useful to the general dentist and the public. The history of the research program during this period followed a consistent pattern of sufficient research on a type of material to understand the basic reactions and properties of dental significance followed by a survey of the existing materials to ascertain what could be reasonably supplied and to determine the range of properties of the satisfactory materials. A specification was then written using the information obtained to place numerical limits on the properties thought to be important. This was reviewed by a Specification Committee consisting of representatives from the profession, the manufacturers, and the government (representing the public). Following the recommendation of this Committee the specification was adopted as an official specification of the American Dental Association. Producers were asked to voluntarily guarantee their products to comply by signing a formal document of agreement. Specimens were purchased on the open market and tested for compliance at NBS by the ADA research associates. Materials which complied were listed in the ADA journal.

Specifications developed for the Federal Government and advice provided in writing purchase descriptions are among the many benefits of the Section's program to the government.

The series of reports on dental casting and accessory materials by Taylor, Paffenbarger, and Sweeney made it routinely possible to make clinically acceptable castings. This is in contrast to an early investigation where only 2 of 25 leading dentists were able to make an inlay casting that would fit even reasonably well a standard die furnished them by NBS.

The very excellent work on analytical methods for dental materials by Caul and Schoonover added new and precise information to the scientific literature on such a wide variety of materials as chrome-cobalt alloy, mercury-containing alloys, resins, denture rubber, impression materials, etc. and made it possible for manufacturers to improve and better control their production. These methods are used also to define composition limits of elements in many modern specifications such as those for amalgam alloy, and gold alloys.

5. Expansion of the Research Program to Include Guest Workers From Federal Dental Services and Foreign Countries, 1945–69

The period immediately following the end of World War II saw a major expansion in the program. As a result of the large scale procurement and utilization of dental materials by the Armed Services, persons directly knowledgeable in dental materials research and clinical practice had first hand experiences which emphasized the great need for more technical information. This made it possible for a very valuable liaison to be initiated.

Schoonover, with the help of Fischer (USAF) and Paffenbarger (USN), cooperated to set up working arrangements with the Federal dental services that added great strength to the Section by increasing both personnel and funds. This made it possible for NBS to equip a clinical unit and correlate many laboratory findings with clinical practices. These arrangements also made it possible for personnel from the Federal dental services to work in the NBS Dental Research Section as Guest Workers for periods of one to several years. The guest workers included not only dentists with much clinical experience but also scientifically trained enlisted personnel (chemists, physicists, engineers, etc.). In addition to the research accomplished, this program resulted in providing the services a number of dental officers trained in materials research. Also to the benefit of NBS, several of the enlisted guest workers remained after their tours of duty in service to become permanent members of the NBS staff.

It has been the policy to draw no sharp distinction between NBS staff members, ADA research associates and guest workers in the operation of the Section. A spirit of cooperation has prevailed with the result that many are the reports coauthored by representatives of each of the three groups. Guest workers have been encouraged to take advanced study and frequently the research carried out in connection with such studies involved collaboration with a Bureau senior scientist.

This period was characterized by many sharp contrasts of opinions on the relative amount of effort that should be put on basic in contrast to applied research. It is my strong conviction that in an area such as dental materials and clinical dentistry the most return will be obtained by conducting, as we have at NBS, the two side by side. Each is an asset and a source of strength to the other.

In 1950 a very thorough review and bibliography was published by Schoonover and Souder [1] to which the reader is referred for many details about the Section's work up to that time.

6. Summary—Résume of History and Individuals

One cannot help but be impressed by reviewing, such as I have, the programs since my first contact on August 3, 1922. At that time the Section consisted of three scientists, Dr. Souder, Dr. Hidnert, and Mr. Coleman. This is in contrast with today's staff of thirty-five. About 175 individuals have been associated with the Section during the past 50 years.

Space to even mention all the major projects is not available but items that come to my mind as being specially noteworthy will be recorded with

[1] NBS Circ. 497, 14 (1950).

the individuals connected with them. In doing this it is realized that others may have different ideas but it is certain that these items have been an influence on dental practice.

1. The development of standards for dental materials based on measurements of properties of dental significance. This is probably the most used and productive effort of the Section. It covered many types of materials, in fact, most of the materials widely used in dentistry. The adoption of specifications and the publication of a list of certified products by trade names added to the practical usefulness of the program. The combination of professional approval and the scientific integrity of NBS combined to make a most reliable buyers' guide for dentistry. Also, the specification program served the manufacturers well, as it made available a standard to compare the quality of products without any reference to selling price. The success of this program has spread to many countries of the world and standards developed here are used as models for others.

A survey a few years ago showed that only 0.1 percent of the items on the published certified lists did not in fact meet all the requirements. This is proof that the production control by American manufacturers is very good. These results are based on tests of materials bought in the open market.

2. One item which is not usually emphasized when discussing the Dental Research Section is the effect the training of research personnel has had on teaching of dental materials in the schools and, in fact, on many techniques taught in restorative dentistry. The Federal dental services have sent many of their best officers to the Section for training and many have received advanced degrees using the research training in the Section for credit. The cooperative program with Georgetown University has resulted in 16 master's degrees and two doctor's degrees. Eleven foreign guest workers, for the most part representing dental schools, have been trained and returned to teaching and research.

3. The publication of scientific data and the explanation of the physical-chemical reactions of materials, for example, the setting mechanism of cements, the oral environmental effects on surfaces, and the effects of particle shapes of alloys used for amalgam have lead to many material developments and to superior techniques for using materials. The explanation of the cause of delayed expansion of zinc-containing alloys resulted in the elimination of the long used, undesirable, palming technique for mixing.

4. In addition to publication, a much used method of communication was the production of motion pictures on the properties and techniques for using many materials such as amalgam, cements, resins, gold alloys, etc. These pictures are in constant use in schools for explaining the basic properties of materials and the effect handling has on the clinical results.

5. The research reports and communications have been very productive in introducing new materials and equipment ideas in the fields of both clinical dentistry and dental research. The early work of Souder produced the dental interferometer which has been adopted as standard around the world for measuring the setting changes in amalgam. The NBS standard MOD steel die is probably the widest used device for evaluating precision casting. This was the result of the precision casting work of Coleman. The fused-quartz tube method of measuring the thermal expansion of solids, first developed by Hidnert and Sweeney in 1928, probably has been used more than any other equipment for expansion measurement of solids and especially for dental investments.

The panoramic x-ray equipment now in universal use in many clinics, was perfected by Hudson, Kumpula, and Dickson and is now commercially available with continuing expanding uses in dentistry for recording the condition of teeth and oral structures. This item has resulted in great savings to the Federal dental services, more than enough to repay the total cost of the whole Research Section's expenditure of public funds.

The turbine contra-angle high-speed handpiece developed by Nelsen and Kumpula is probably the most important advancement in dental equipment in this century. It has inspired manufacturers to use the principle to develop very sophisticated clinical turbines and has revolutionized the practice of operative dentistry. It not only makes the work of cavity preparation and tooth reduction faster and easier for the dentist, but more important it is much more comfortable to the patient, so much so that no modern dentist today can operate without high-speed handpieces. The number of these instruments in use, both in this country and foreign countries, is estimated to be in the hundreds of thousands.

The many instruments modified, or new, developed for use in specification tests are too numerous to mention, but the method developed by Paffenbarger for testing standard consistency of cements made it possible to compare on an equal basis the properties of different brands of both zinc phosphate and silicate cements. The use by Sweeney of cross index marks or pin inserts on dentures as reference points for measurement of microscopic dimensional changes, served to evaluate the accuracy and stability of a wide variety of denture base materials from vulcanite to methyl methacrylate resins under clinical conditions. The technique has been used to study the effect of curing and repairing processes on stability or warpage of dentures in service.

The early discovery of cristobalite for use as an investment material by Paffenbarger and Sweeney was rewarding even though the patent was finally