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Abstract
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THE IMPORTANCE OF NONDESTRUCTIVE EVALUATION TO FUTURE ENERGY SYSTEMS

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ABSTRACT

The Department of Energy conducts both applied and basic research on nondestructive evaluation. The importance of NDE is discussed with emphasis on future energy systems. Organization, needs, barriers and new developments are described.

The Nation is faced with an enormous task if it is to make the least painful transition from its current energy sources (chiefly petroleum and natural gas) to ones more abundant, and ultimately to those that are inexhaustible. This transition will require an unprecedentedly large and rapid shift to different, if not new, technologies.

In this transition, the role of nondestructive evaluation (NDE) is certainly clear to its practitioners, but unappreciated or ignored by almost everyone else. It will not be possible to rely on accumulated wisdom to predict the safety, reliability and lifetime of the new components that must be developed. Yet such knowledge can have a major effect on the cost of the new energy systems, as they are deployed industrially.

Within the Department of Energy, a variety of programs and projects are applying, and, in some cases, developing NDE techniques. I will discuss some of this work -- typical needs that have been identified, progress that is being made, barriers that have been encountered, and new developments, both in techniques and in quantitative understanding, that appear of special interest.

I will first describe the organizational framework in which the overall program is carried out.

The Department of Energy was formed on October 1, 1977. It operates with a budget of about $10 billion per year and has approximately 20,000 employees. It has consolidated under one cabinet level department the responsibilities and personnel from the former Energy Research and Development Administration, the Federal Energy Administration, and the Federal Power Commission as well as components previously under the Departments of Commerce, Defense and Interior.

Although the Department of Energy incorporates many programs and functions from other agencies, it is not an amalgamation of existing agencies with a new tier of leadership. Instead, many previous programs and functions have been reshaped to fit the national energy policy of the new department. The DOE organization and functions are represented in Fig. 1.

I especially wish to call to your attention the programs within Resource Applications, Conservation and Solar Applications, Energy Technology, Defense Programs and the Office of Energy Research. It is within these organizational units that most of the research and development programs are located. Except for the Defense Programs, a spectrum of research cuts across the Department, from the most basic in the Office of Energy Research, to technology development under Energy Technology to commercialization under Resource Applications, and under Conservation and Solar Applications. The structure of the Office of Energy Research is represented in Fig. 2.
The growing importance of NDE under the Materials Sciences, and in Engineering, Mathematics and Geosciences where fundamental research on NDE occurs or will occur in the near future. Additional programs are conducted elsewhere (universities, industry) based on submission of unsolicited proposals.

The DOE outlay for R&D programs in NDE for FY 1978 is approximately $5 million. Active NDE programs are being conducted under DOE sponsorship at a number of sites, primarily DOE laboratories and facilities. Essentially all the developmental effort is applications-oriented, with the principal thrust in most cases being the development of an NDE solution for specific components or problems. The broad scope of developmental activities includes all the more traditional methods of NDE (e.g., radiography, radiation attenuation, ultrasonics, eddy currents, acoustic emission, x-ray fluorescence and holography) and limited work in such areas as Mossbauer spectroscopy, positron annihilation, and neutron scattering. Interest is increasing in the use of computers for both signal processing and pattern recognition.

Some typical applied projects underway include:

- Development and application of NDE techniques to flaw detection in ceramic turbine materials and components - under the Power Systems Division of the Fossil Energy Program.
- NDE in-situ techniques for the examination of thin coatings used to protect interior surfaces of components - under the Coal Conversion Division of the Fossil Energy Program.
- NDE techniques applied to the detection of incipient failure of drill pipes - under the Geothermal Energy Division.
- In-service inspection of coarse-grain austenitic stainless steel welds in reactor components, ultrasonic examination of primary and secondary piping welds in the Fast Flux Test Facility and in-service inspection of primary system reactor piping - under the Reactor Technology Division of the Nuclear Energy Program.
- Adaptation of acoustic emission, ultrasonics, eddy currents, x-radiography, radiation attenuation, neutron radiography, and holography to problems of film thickness measurements and weld integrity, and computer applications for data analysis and presentation; and signal analysis of NDE techniques - under the Defense Programs.

Although many organizations are working in the same general field, the complex nature of the methods and the varying application requirements has minimized (or virtually eliminated) redundancy. More information on programs underway can be obtained from the various divisions supporting this work. A recent compilation of projects was carried out under the auspices of an internal coordinating committee and is contained in the report, "Survey and Analysis of Selected Topics Within the Energy Research and Development Administration's Materials Research and Development Programs," DOE/ET-0006, January, 1978 available from NTIS.

The more fundamental NDE work within DOE, and that concerned with quantitative NDE in particular, occurs in the Office of Basic Energy Sciences. The major NDE interest here will be divided between the two Divisions - Engineering, Mathematics and Geosciences, and Materials Sciences. Research on detection systems and computer interfacing will be within the purview of our new program in Engineering Sciences that will commence on October 1, 1978. Work concerned with materials studies, especially quantitative predictive behavior and new techniques applied to the determination of remaining safe useful lifetime of materials in service, will fall within the scope of the Materials Sciences program.

Importance of NDE - The growing importance of NDE to future energy systems is based on sound and sophisticated awareness of factors such as economics, reliability, environmental effects and safety. Nondestructive evaluation takes on an especially important role in technology when the capital costs of an operating facility are large. For example, in the case of a forced shutdown of a 1000 MWe nuclear power unit, one day's outage costs approximately $0.6 million (estimate by EPRI, 1975), and 36% of the down time is due to forced outages. If only a small percentage of these forced outages could be prevented by proper...
monitoring and repaired during normal down times, a tremendous saving would result. The same general argument can be made for other capital intensive base load facilities. The growing awareness of the public in the areas of environment and safety further heightens the importance of NDE. In many cases, a technology could not survive the sociological consequences of a severe accident. Not only do facilities such as liquid natural gas storage tanks, nuclear plants and coal liquefaction plants have to be well designed and the materials carefully tested, but a monitoring system that nondestructively monitors significant flaw initiation and growth would help alleviate both perceived and actual fears. There are new systems also which must be monitored in addition to being carefully tested in view of the unknowns. Fusion reactors will be very large and expensive, and the technology would be set back years in the event of a disastrous surprise.

Underground power transmission systems are under development that would carry ever increasing blocks of power, the ultimate being superconducting transmission lines. The dielectric breakdown behavior of insulators is still quite difficult to predict, but would be catastrophic for the transmission line if it occurred. Some methods for evaluating and monitoring these new systems must be developed before they can be confidently utilized.

Institutional Problems - In view of the increasing importance of NDE, one question that arises is: Are there satisfactory university programs set up to advance the science and to train future scientists in this area? At the present time, the NDE area is a multidisciplinary field drawing from materials science, mechanical engineering, electrical engineering, chemical engineering, physics and increasingly others such as mathematics and computer science. This makes the academic training process more difficult and time consuming, leaving much of it to on-the-job training. Some experiments should be tried to break down the departmental barriers in order to see if benefits could derive from a more coherent curriculum. Another institutional problem facing the NDE area is the problem of design philosophy that emphasizes initial design and construction of the facility rather than lifetime considerations. As our understanding of failure prevention increases and our ability to detect the onset of property deterioration increases, the systems designers should take advantage of this new understanding and build detection systems into the design. More cooperation between code formulating bodies, designers and the NDE community is needed to accomplish this.

Needs - For the field of energy technology, in addition to the more general needs such as trained personnel, there are many areas of need specific to particular energy systems. Safety and reliability are important criteria for fossil and nuclear electric baseload facilities. A more quantitative understanding between flaw detection and failure prediction is needed. This requires both a greater ability to detect flaws of a critical size and defects of a subcritical size together with a greater understanding of their effect on properties. The ability to continuously monitor sub-critical defects in situ, under service requirements of temperature, stress, radiation, etc., and to use such data to quantitatively predict the remaining safe lifetime of critical components prior to failure would provide a significant economic saving.

There continues to be a need to better evaluate welds in all applications, and to quantitatively relate NDE to the parameters of fracture mechanics. The area of radioactive waste disposal is currently receiving much attention. Monitoring of waste canisters for failure may assist in solving this crucial problem for the nuclear industry. Coal liquefaction and gasification plants will contain materials which have to operate in highly aggressive environments containing sulfur, hydrogen, carbon, oxygen and other elements. Monitoring of these systems for stress corrosion cracking, hydrogen attack and corrosion will be essential to prevent catastrophic shutdowns. With the push to higher temperatures in turbines and heat exchangers, there will be a need to monitor the effects of thermal excursions, thermal structural stability and a need to predict remaining life to fatigue failure. In the solar photovoltaic area, there is a need to monitor semiconductor junction behavior as a function of time. The heating and cooling cyclic behavior of solar collectors will have to be monitored for fatigue and property deterioration. Overriding all of these needs is the requirement for objective and accurate interpretation of the failure detecting signals, and for increasing the signal to noise ratio under realistic service conditions. Certainly more research is needed in the way of instrumentation and computerization to take the human interpretation out of the system. Of course this cannot be done without sufficient understanding of the role of defects and their influence on properties, especially a quantitative understanding.

Exciting New Areas - The entire field of NDE has come alive with new ideas in the past few years. Some of the energy-related areas do not require new ideas as much as they require the application of current knowledge to practical engineering systems. Significant progress has been made and should continue in the areas of instrument miniaturization for field applications, high frequency systems and circuit designs for optimum signal to noise ratio, computerization, theory of defect scattering of various probing signals, and the relationship between materials characterization and predictive behavior. However, I would like to close by mentioning a few new techniques (positrons, high intensity x-rays, neutrons) which may not be carried over directly into the NDE field, but will no doubt contribute to our understanding in a quantitative way.

Positrons injected into a material eventually annihilate together with an electron giving off a detectable gamma ray. Measurements such as the positron lifetime and Doppler line broadening give information on the structure of the material. Recent progress in instrumentation and theory has led to an ability to observe phenomena such as vacancy concentrations and dislocation pile-ups that are precursors to fatigue hardening. Positron annihilation has been shown to be sensitive
to the detection of hydrogen embrittlement in certain materials. Hydrogen-dislocation interactions and localized high concentrations of hydrogen are revealed through changes in the Doppler shape factor. A U.S. patent (#4064438) has recently been issued on the hydrogen embrittlement detection method.

With the advent of modern high energy electron storage rings, the possibility of very high flux sources of x-rays and vacuum ultraviolet radiation has opened new vistas in materials characterization. The radiation is emitted as high energy electrons are accelerated with a magnetic field. A number of facilities are now available, one not very far from here, at the Stanford synchrotron radiation project. The radiation emitted is inherently collimated, pulsed, plane polarized, has a continuous energy spectrum, and exceeds the intensity of other broadband sources by factors of $10^4$ to $10^5$. The Department of Energy has under construction a dedicated facility as an x-ray and ultraviolet radiation source at Brookhaven National Laboratory called the National Synchrotron Light Source. Synchrotron radiation has been used to produce x-ray pictures of thin samples with greatly improved resolution compared to the details in familiar radiographs. This x-ray lithography technique uses a thin plastic film (photo-resist) which is sensitive to x-rays to replace the usual x-ray photographic film. After exposure to radiation, the photo-resist is placed in a solvent where the parts receiving the most radiation are preferentially dissolved. The resultant "radiograph" can be studied with an electron microscope to reveal detail as fine as 10 nm (100Å). Topography is another technique where x-rays are used to image structure - in this case the x-rays are scattered rather than absorbed. The exciting feature of synchrotron radiation for topography is the marked reduction in exposure times made possible by the intense radiation. Experiments have been performed showing magnetic domain wall movements in materials, and the new and more intense synchrotron radiation sources being built open the possibility of x-ray motion pictures of dynamic events at the dislocation level.

The availability of high fluxes of cold neutrons (long wavelength) offers another possibility for examining and characterizing defects in materials. Cold neutrons can be used in either the absorption mode or the scattering mode. In the absorption mode, long wavelength neutrons can greatly improve contrast and resolution over normal radiographic methods. This improvement will be especially evident for hydrogenous materials (e.g., 1 mm of plexiglas contained within two 7 cm sections of steel). Small angle neutron scattering with cold neutrons is a new technique based on scattering of neutrons. It can be used to detect heterogeneities (10 - 1000Å) imbedded within a matrix of different neutron scattering power. The scattering technique has a much finer resolution than the radiography method. Although applications of the cold neutron methods are limited by the need to utilize the few nuclear reactor sources available, they offer the possibility of examining bulk specimens at resolutions never before attained.

Summary - The subject of nondestructive evaluation is one which will receive increasing attention in future energy systems because of the greatly increased public awareness of economic, reliability, safety and environmental issues. Some institutional problems such as the training of scientists and engineers and design philosophy need to be addressed for the proper utilization of NDE in these systems. Quantitative predictive NDE, the subject of this meeting, is, of course, the key to effective deployment of NDE.