EGG-FM-5563

October 1981

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NONDESTRUCTIVE CHARACTERIZATION OF LOW-LEVEL TRANSURANIC WASTE

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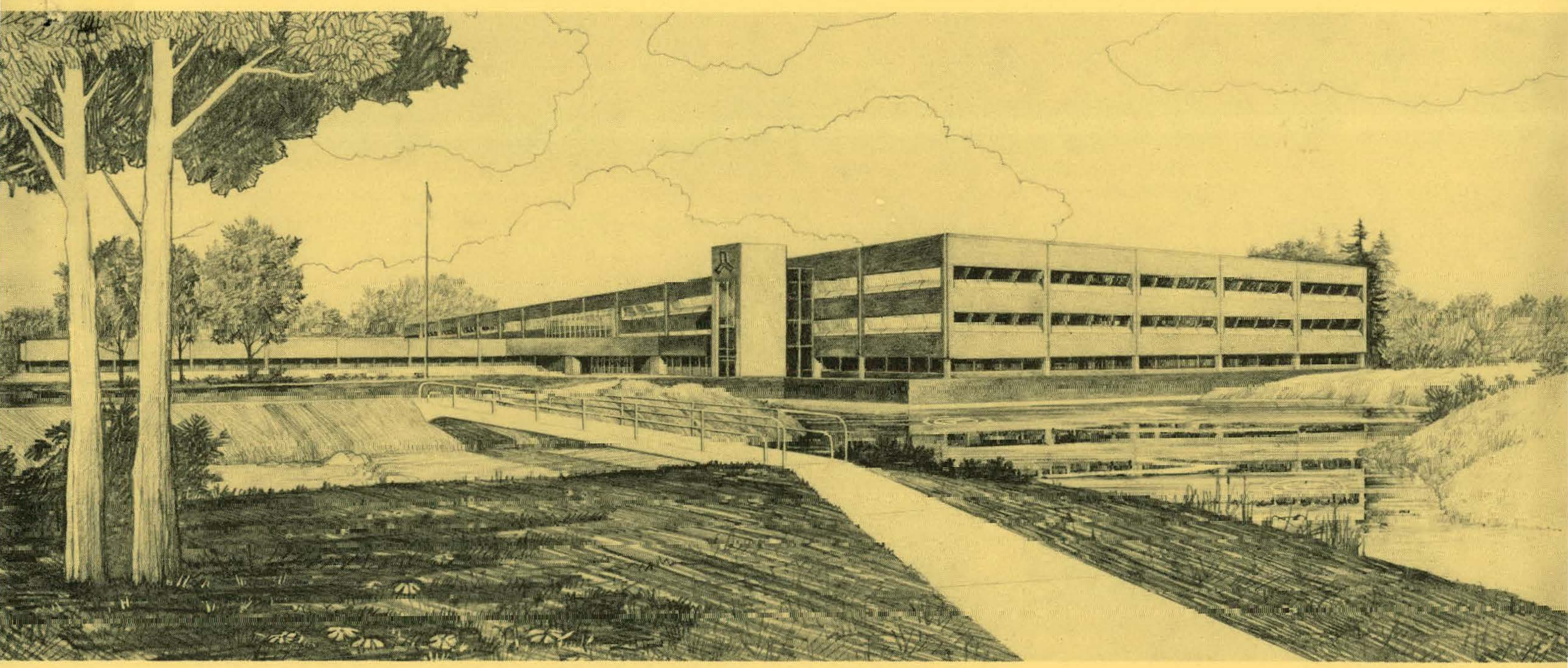
Idaho Operations Office • Idaho National Engineering Laboratory



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Prepared for the
U.S. Department of Energy
Idaho Operations Office
Under DOE Contract No. DE-AC07-76ID01570

EG&G Idaho

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EGG-FM-5563

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ABSTRACT

The use of nondestructive evaluation (NDE) methods is proposed for characterization of transuranic (TRU) waste stored at the Radioactive Waste Management Complex. These NDE methods include real-time X-ray radiography, real-time neutron radiography, X-ray and neutron computed tomography, thermal imaging, container weighing, visual examination, and acoustic measurements. An integrated NDE system is proposed for characterization and certification of TRU waste destined for eventual shipment to the Waste Isolation Pilot Plant in New Mexico. Methods for automating both the classification of waste and control of a complete nondestructive evaluation/nondestructive assay system are presented. Feasibility testing of the different NDE methods, including real-time X-ray radiography, and development of automated waste classification techniques are covered as part of a five year effort designed to yield a production waste characterization system.

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NONDESTRUCTIVE CHARACTERIZATION OF LOW-LEVEL TRANSURANIC WASTE

1. INTRODUCTION

Low-level transuranic (TRU) waste stored or buried at the Idaho National Engineering Laboratory (INEL) Radioactive Waste Management Complex (RWMC) which is to be shipped to the Waste Isolation Pilot Plant (WIPP) in New Mexico must first be characterized so that the waste can be certified to meet the WIPP waste acceptance criteria (WAC).[1] (Many of the types of waste stored or buried at the RWMC are not acceptable to WIPP.)

In order to characterize and certify the waste, the waste containers must either be opened or, more practically, be nondestructively examined; all examinations are to be performed in accordance with documented procedures approved by the WIPP Project Office and DOE-ID. Several different nondestructive evaluation (NDE) methods may be applicable to the characterization and certification of TRU waste. This study was performed to develop an approach for assessing the capabilities and limitations of these NDE methods and to develop an examination plan for characterizing waste on a production basis.

By 1986, there will be an estimated 4.5 million cubic feet of stored and buried waste at the RWMC. Approximately 20,000 waste containers per year are to be characterized; those wastes which can be certified will be sent to WIPP for long-term storage beginning in 1989. Even at a rate of 20,000 containers per year, it may take 25 years or more to characterize all the stored and buried waste at the RWMC.

The use of NDE methods for waste characterization is attractive for two reasons, both related to cost of operation. First, it is doubtful that a production throughput of 20,000 containers per year could be attained based on opening and inspecting containers, without building large and expensive environmentally-controlled facilities. Secondly, the potential cost savings available through use of an integrated NDE/NDA system are large because of low labor costs associated with the operation of an automated or semi-automated system.

Several different NDE methods may be applicable for use in characterizing the waste with respect to WIPP-WAC on gas generation, immobilization (particulate), free liquids, sludges, pyrophoric material, explosives and compressed gases, and toxic and corrosive materials. The methods discussed in this report are real-time X-ray radiography, real-time neutron radiography, X-ray and neutron computed tomography, thermal imaging, visual examination, container weight, and acoustic (including ultrasonic) analysis.

The methods selected would be used in an integrated NDE waste characterization system; results from particular tests could be entered into a decision algorithm to separate certified and noncertifiable waste in the production waste characterization system. Two approaches may be used for the integrated NDE portion of the waste characterization system: automated container handling and data acquisition with NDE and data interpretation by trained system operators, or complete automation of the system including data interpretation and waste classification. The second system would be more expensive to fabricate because of development costs associated with the data interpretation (pattern recognition) and automated classification (decision analysis algorithm) portions of the system . The completely automated approach would be more reliable in classifying waste than an operator-controlled system due to both fewer problems with operator fatigue and boredom and the use of more objective, rigidly defined classification criteria with an automated system. It should be noted that interpretation by a trained individual may still be required on certain waste containers. The automated characterization system should be cheaper to operate due to lower labor costs and higher waste throughput.

2. BACKGROUND

In 1978 efforts were initiated to identify NDE techniques which could prove useful for evaluating the contents of 55-gallon drums packed with low-level TRU wastes. The first studies used newly developed in-motion real-time X-ray radiographic techniques for imaging drum contents. After discussions with possible equipment suppliers, a decision was made to fabricate some test drums with various loadings simulating the range of contents of drums stored at the RWMC. Five drums were put together containing such things as simulated sludge; laboratory glassware; compacted rags; plastic bottles; and assorted shop scrap such as wood, paint cans, boxes, and electrical items. These test drums were shipped first to Schonberg Radiation Corp. in Mountain View, CA, then to Science Applications, Inc. (SAI) in LaJolla, CA, for evaluation with their respective real-time X-ray radiography systems. With EG&G representatives in attendance, the drums were examined and the results videotaped for future evaluation. The test results were very encouraging with a high degree of accuracy demonstrated in identifying drum contents. Based on this initial feasibility study, it was decided to proceed with the procurement of a specialized real-time X-ray radiography system to be used for the examination of waste drums in 30-, 55-, and 83-gallon capacities and 4 x 4 x 7-foot plywood boxes. The system was to feature rotation of drums in order to obtain a psuedo 3-D image of the drum contents. A performance specification[2] for system procurement was developed and issued prior to the request for quote that went out to several potential suppliers. A vendor selection was made based on the quotations received and a contract was awarded to Schonberg Radiation Corp., however, only the design portion of the contract was completed before the contract was terminated.

In 1980, Schonberg Radiation received a contract from EG&G to perform real-time radiographic evaluation of seventy 55-gallon waste drums at the RWMC. This work was done using a simple turntable for drum rotation, a 300 kV constant potential X-ray machine, and a real-time fluoroscreen imaging system with all tests tape recorded for later evaluation and analysis. Thirty-five of the seventy tested drums were then shipped to

Rocky Flats, opened, and the contents evaluated. When the taped real-time video displays were carefully analyzed and the results compared with the "destructive" test results from Rocky Flats, it was found that the correlation was extremely good, on the order of 90% accurate. These tests demonstrated that the application of real-time X-ray radiography to waste drum content characterization was feasible.

Although several other techniques for waste characterization may ultimately prove feasible, the real-time X-ray approach is the only NDE method which, to date, has been demonstrated feasible for use for waste container content characterization. Many other complementary NDE techniques will be discussed in the body of this report.

3. NDE METHODS

Several different NDE methods which may be applicable to the characterization and certification of TRU waste are presented in this section. These methods have been selected after a thorough review of the waste characterization requirements and the fundamental physical principles involved. The methods discussed are real-time X-radiography, real-time neutron radiography, X-ray and neutron computed tomography, thermal imaging, visual examination, container weighing, and acoustic (including ultrasonic) methods.

3.1 Real-Time X-Ray Radiography

Real-time X-ray radiography has been carefully evaluated at EG&G and found to be useful for imaging the contents of waste containers. At this time, real-time X-ray radiography is probably the leading candidate NDE method for waste characterization.

Real-time X-ray radiography systems typically have X-ray sources ranging from 100 kV up to several million volts, a detector made of a fluorescent screen which produces light photons under X-ray photon bombardment, a fiber-optics-coupled image intensifier to boost light levels, and a low light level TV camera to produce signals for viewing on a TV monitor. The fluorescent screen and other components are fitted into a portable lighttight shielded box. In use, the X-ray beam passes through the object being examined and is then picked up by the detector which converts the transmitted X-rays to light for TV monitoring. With this system, images of in-motion objects can be produced. Low voltage X-rays up to 300 kV are useful for inspection of waste container contents when the waste is not highly attenuating to X-rays. For sludge-filled drums or larger containers, such as 4 x 4 x 7-foot plywood boxes, it may be necessary to use an X-ray source of several million volts (a LINAC, for example) to obtain a sufficient level of transmitted radiation to perform in-motion radiography.

As discussed in Section 2, real-time X-ray radiography has been used to evaluate the contents of 55-gallon TRU waste drums with excellent results.

While the 300 kV constant potential X-ray machine used was sufficient for most drums examined, it was inadequate for complete examination of the Rocky Flats' sludge drums. Since sludge drums might contain things other than sludge, such as a lead "pig" containing a discarded radioactive isotope source or sources, higher energy X-ray sources are needed for adequate penetration. The use of a 420 kV constant potential X-ray source would give improved results on large boxes, but would probably still be inadequate for examining most sludge-filled drums. Drums filled with metal or similar highly attenuating material could probably be imaged with the 420 kV source.

A "production" real-time system will likely use a 420 kV machine for evaluating most waste containers, with a 3 or 4 MeV machine available for evaluating sludge drums or containers filled with large amounts of metal. High voltage sources would be a poor choice for evaluating containers filled with low Z material, such as combustible waste, because the lack of available image contrast would seriously compromise image quality and thereby render the low Z materials almost invisible. The high voltage LINAC sources are not as readily adjustable for output as the lower voltage X-ray generators; two separate X-ray sources are therefore required.

3.2 Real-Time Neutron Radiography

Neutron radiography may be a viable supplement to X-ray radiography for TRU waste characterization. The relationship between neutron absorption or the neutron cross-section of a material is not directly dependent on a material's atomic number (in contrast to X-rays and gamma rays which show a monotonically increasing absorption with increasing atomic number). Since neutrons are greatly influenced by hydrogenous materials while X-rays are not, a real-time neutron system should show excellent sensitivity to rags, plastics, water, organic materials, etc. Unfortunately, the waste drums are usually equipped with a 2.3-mm (0.090-in.) thick polyethylene drum liner which would be very attenuating to the thermal neutrons (0.01 to 0.3 eV) used in conventional neutron radiography. Either epithermal (0.3 eV to 10 keV) or fast (>10 keV) neutrons would have to be used for waste examination because of their increased penetration and reduced sensitivity to hydrogenous materials. (Epithermal neutrons may show an increased penetration for hydrogenous materials of as much as a factor of 40 in comparison with thermal neutrons.) Unfortunately, as with X-rays, the higher the energy of the neutrons used, the poorer is the available contrast between materials being examined. Experiments would be required to define the lowest energy neutrons which might be used for adequate penetration without losing too much contrast in imaging.

Another approach which might be used to identify, or increase the detectability of, specific materials is the use of resonance neutrons. In this procedure a beam of monoenergetic neutrons is selected using a crystal monochromator to exploit cross-section resonances in the range of 0.02 to 2 eV to offer possible improvements in radiographic contrast. This technique has been demonstrated in the laboratory, but is not known to have been applied in a practical case.

With suitable conversion screens to convert neutrons to electrons for imaging (screens such gadolinium oxysulfide), the real-time X-ray detector system could be used for real-time neutron imaging. Neutrons may be supplied by a reactor, a portable accelerator-based source, or an isotope source (^{252}Cf). Neutron fluxes available from these different sources after collimation run from 10^4 to 10^5 $cm^{-2}s^{-1}$ for accelerator-based or ^{252}Cf isotopic sources up to 10^6 to 10^8 $cm^{-2}s^{-1}$ for reactor sources. Presently available real-time imaging systems require a neutron flux of about 10^6 $cm^{-2}s^{-1}$ for acceptable imaging.[3] For levels lower than this, electronic signal enhancement equipment is needed to yield acceptable video displays. Reactors are the preferred choice for thermal neutron radiography because of their high neutron yield, while accelerator-based or isotopic sources work well in the epithermal and fast neutron regime. The price of a neutron generator ranges from about $200,000 for isotope sources up to $1,000,000 for a small reactor source.

3.3 X-Ray and Neutron Computed Tomography

Tomographic techniques can provide detailed images that are much more sensitive than conventional X-ray or neutron radiography to small absorption differences in the contents of the waste containers.

Conventional X-ray and neutron images are essentially shadowgraphs that project a three-dimensional object into a two-dimensional plane image. Tomography, on the other hand, constructs a detailed image of a slice through an object. There is no doubt that this would provide a high resolution image for content evaluation, but there are some drawbacks to the technique.

It would be difficult to identify waste container contents from an image of a single tomographic slice through the container. In-motion radiography has a distinct advantage in this respect in that more information is being presented for evaluation even if that information is distorted by the projection of a 3-dimensional object onto a 2-dimensional imaging plane. Because of this, tomography would probably be most useful if it was applied as an extension of in-motion radiography, or if numerous tomographic slices were used to create a 3-dimensional imaging space. The first idea would be applied when an in-motion radiograph had an area that was difficult to identify. By generating a tomographic image of a slice through the area, enough additional information might be gained to allow identification of the contents. In this approach tomography would not routinely be applied to each container, but only to those for which additional information was required for classification. The second concept of using numerous tomographic planes to create an imaging space is attractive from a standpoint of optimum high resolution image construction, but is potentially time consuming and complex. In theory, several tomographic slices would be generated and then combined (via computer) into a 3-dimensional representation of the container and its contents. It would then be possible to manipulate the image by rotation about any axis or to view a slice through any part of the imaging space. This capability added to the high resolution of the tomographs would give the most flexible type of image for content evaluation.

While the tomographic techniques are attractive, additional development and study would be required to determine their suitability to this application. Questions need to be answered in several areas; i.e., what is the effect of sharp density changes on the reconstruction algorithms, can X-ray or neutron intensity data taken from the real-time viewing system serve as an input to the tomographic system, and can the reconstruction and imaging be conducted in a timely manner for the application?

3.4 Thermal Imaging

Investigators at Westinghouse Hanford[4] performed thermal tests on simulated waste containers (55-gallon drums) and found that free liquid (water) could be detected quite accurately. Unfortunately, this approach may be difficult to use on a production basis for the examination of every drum because of the time involved in running each test (on the order of 5 minutes per drum for each measurement). The investigators also found that solids, liquids, and air inside sealed waste drums could be distinguished from each other by their respective thermal characteristics. Water on either the top surface or in surface-exposed cracks of the waste solids was readily detected.

Thermal imaging is based on applying heat to the surface of a steel drum for a short time period. When the heat source is removed, the surface temperature of the drum increases, then decreases. When the inside surface of the drum wall is in contact with air, its temperature falls more slowly than if it is in contact with water. Solid wastes show a temperature drop rate faster than air, but slower than water. The surface temperature drop rates are then mapped.

This technique may not work well on many of the stored waste drums because of drum liners and various internal plastic bags which contain the waste. However, a limited study should be performed to determine the feasibility of applying this technique to stored waste, especially for detecting free liquids since they would not normally be detectable with the real-time X-ray radiographic system although they may be with the real-time neutron radiographic approach. Some of the older drums may not contain drum liners; for these drums, thermal imaging may be a viable technique.

3.5 Visual Examination

Since drums and boxes must remain sealed, it would be impossible to perform a visual inspection of the waste drum contents without boring or punching a hole through the drum or box wall and inserting a borescope or similar device. However, visual examination can be useful for such things as determining (for Rocky Flats material) the drum contents based on container identification markings. This could serve as a crude initial screening technique. Also, the condition of the container, including its outside surface, could be ascertained to determine if there may be breaks or corrosion in the walls.

3.6 Container Weighing

Each container should be weighed accurately prior to other characterization operations since container weight may offer insight into the contents of a particular container. Some correlation work will have to be performed to see if container weights can be used to predict contents. This method would be used for initial screening.

3.7 Acoustic and Ultrasonic Methods

Acoustic methods would include such widely varying techniques as measurement of drum skin resonant frequency to ascertain the presence of gas at pressures higher than ambient, vibration analysis of container contents using a shaker table and appropriate electronic monitoring, and ultrasonic measurement of drum wall thickness (to check for corrosion problems).

The resonance measurements would be made on the top drum head using currently available measurement techniques. The resonance of the drum head should be controlled by the elastic modulus of the head material; any material (for example, waste) in contact with the drum head; the boundary conditions; specifically differences in atmospheric pressure on the outside and inside surfaces of the drum head; and the thickness of the particular drum head. In addition, residual stresses in the material and any changes in configuration such as denting will likely affect the results. A study should be performed to determine if variables other than gas pressure affect resonances to any significant degree.

Different container contents, for example sludge versus compacted combustible waste versus metallic components, should give much different acoustic signatures. Vibration analysis equipment would include a variable frequency shaker table system on which the container would be mounted. Testing of many containers should give a data base for screening of container contents as a function of acoustic response.

Ultrasonic measurement of drum wall thickness (with an automated system) could yield indications of internal corrosion in drums. Measurements of the time required for a high frequency sound wave to travel through the wall of the drum would be useful for screening for drums which may contain free liquids, high internal humidity, or corrosive materials inside.

4. COMBINED METHODS AND DECISION ALGORITHM

From the discussions of the various NDE methods in Section 3, it is obvious that each technique provides some unique information. The most accurate assessment of container contents would be based on an evaluation of all applicable data rather than on a single test result. This suggests an NDE system that would obtain and analyze data using several different methods. For example, drum weight may indicate the presence of sludge or scrap metal in a particular container. Acoustic data and/or imaging information could be then used to differentiate between the two possibilities.

This type of analysis easily lends itself to the development of a decision algorithm which would use the available information to assign a contents code that is derived from a set of known content possibilities. Data input to the algorithm could include: X-ray image information, neutron image information, original container content listing, container weight and distribution, acoustic and ultrasonic analysis, thermal image information, and visual examination. Evaluation of this data would provide a statistical basis for characterizing waste.

As experience is gained during the development of the system and a statistical base is established to link all test results to container contents a high confidence level for waste characterization should be attained. The statistical base is necessary because there will undoubtably be scatter in the data for a given type of waste; however, the scatter should not be so severe as to preclude an accurate probabilistic determination of contents.

An attractive feature of this approach is that the algorithm can use simple or complex information as desired while still providing systematic criteria for certifying waste. If desired, X-ray or neutron image information can be in the form of human interpretation of the real-time images or contrastingly, as output from a pattern recognition program that operates on a digitized version of the images. In either case, the algorithm would be designed to ensure that any waste containers which do not fit a pattern for identification would be flagged for additional evaluation.

A prime advantage of this decision algorithm approach is that it lends itself to an automation of the entire process. It should be noted that equipment for automated classification involves computerized pattern recognition techniques which are not commercially available, therefore this portion of an automated characterization system would require a development program. This system could eventually be used to assist or replace a trained operator and would have particular application in analyzing images from real-time radiography or computed tomography systems. The potential cost savings in terms of labor and the improved reliability of container certification are strong arguments for such a system.

5. COMBINED NDE/NDA/WASTE CERTIFICATION SYSTEM

With a large number of waste containers to certify, it is important to consider automating as much of the process as possible. A nucleus for this automation is the NDE waste identification algorithm discussed in the previous section. Since implementation of this algorithm requires all the basic information available about the container contents, it would be logical to computerize the identification process and use this to generate a data base for processing the waste containers. A production system of this nature would provide efficient, reliable data retrieval as well as the computing power to manage, and possibly automate, the NDE and NDA of the waste containers.

If such a system were implemented, the entire data package could be sent to WIPP for approval before shipping. The data would include the following information:

1. Identification number
2. Waste generation site
3. Date of packaging (or repackaging)
4. Radiation levels at the container surface
5. Weight (net and tare)
6. Accurate physical description of waste (from NDE tests)
7. Type of container
8. Nondestructive assay information
9. Hazardous material (if any)
10. Estimated gas production (moles)
11. Measured or calculated thermal power (decay heat)
12. Certification statement (how certified, i.e., administrative controls or actual testing performed)
13. Date of shipment
14. Carrier identification
15. Other relevant information

For uncertifiable (to WIPP-WAC) TRU wastes, the additional following information would be retrievable.

1. Waste generator content code
2. Comparison between NDE results and waste generator content code
3. Location of waste container
4. Categorization of uncertifiable waste containers as follows:
    a. Combustible
    b. Noncombustible
        (1) Metals
        (2) Sludges (classified, if possible)
        (3) Hazardous (toxic, pyrophoric, gas cylinders, etc.)
        (4) Other
5. Results of container pressure test.

With this certification system, a waste container entering the system would be tagged and "logged on" to a computer tracking system. As the container goes through successive evaluation steps, additional information would be added to the record either automatically or by a system operator. After the NDE and NDA examinations have been completed, identifying labels would be computer printed for both container identification and as a shipping record.

The level of automation of such a system is flexible; one alternative would be to use a computerized data base to track containers and generate archival records, with all of the input data being operator-generated. As the correlations between inspection data and container contents are developed, however, all or some of the data can be added automatically rather than through human input. Obvious first candidates for this process are relatively simple measurements such as weight or surface radiation levels. In a fully automated system pattern recognition techniques could be applied to the real-time images to classify waste into one of several predetermined categories; this data could also be automatically input to the system. The NDE waste identification algorithm can be implemented with any level of the system and only requires additional development work that can statistically group the results of the various tests described in Section 3.

As with any automated system, checks and balances must be designed to prevent erroneous data handling and container labeling. Techniques for establishing this range from redundant measurements to applying classification criteria that allow very little statistical spread in the NDE data. Redundancy can be accomplished through repeated and/or complementary measurements. Classification criteria would be developed from an analysis of the spread of data values for a given type of contents. By allowing only small deviations for a given content classification, it will be possible to have a high degree of confidence in the content code that is finally assigned. Waste being processed by the system would then separate into two groups: those that can be automatically classified and those that require further examination. Calculating the exact proportions for these two categories is impossible without further development work, but it can be reasonably expected from initial results with real-time radiography that most of the waste can be accurately characterized from container weight and image information.

A computerized NDE/NDA/waste characterization system is probably the only rational approach to certifying and sorting large amounts of waste. If the system were dependent on the repeated day-to-day interpretations of human operators looking at radiographic images, assay results, and other test information, the element of fatigue caused by the tedious nature of the job might seriously compromise the accuracy of test results unless many system operators are used. Unfortunately, duplication of resources (people and equipment) raises costs and lowers the consistency of results. An automated system on the other hand, will be consistent and immune to fatigue. The costs involved will be primarily in development of the pattern recognition and classification algorithms plus the NDE/NDA equipment costs.

It does not appear necessary at this time to make a full commitment to a totally automated system. The necessary development work can continue by initially implementing a first level system with real-time X-ray radiography to gather the statistical data base necessary for development of the automated approach. This support should also provide for the investigation of the other NDE techniques and their integration into a single system. The results of this suggested work should provide the basis for accurate cost estimates and capabilities. Details of this development plan are discussed in Section 7, Feasibility Studies.

6. ANALYSIS OF SPECIFIC WASTE CHARACTERIZATION PROBLEMS

This section suggests how specific waste characterization problems might be solved using various NDE methods. It should be noted that, since feasibility tests have not yet been performed except for some X-ray radiography, these recommendations are based on best engineering judgement.

6.1 Gas Generation

Because of storage requirements, a maximum gas generation value of 5 mole/year/drum has been established by WIPP-WAC. This is equivalent to a permissible organic content for 55-gallon drums of 224 kg/m^3 (14 lb/ft^3) and 96 kg/m^3 (6 lb/ft^3) for rectangular boxes. (EG&G believes these limits for the permissible organic content of containers is too low and should be raised for individual containers.[5] This would require WIPP to institute administrative controls to insure that no more than a certain percentage of drums or boxes in a given storage room contain cellulosics.)

Methods need to be devised to both determine the amount of combustible waste in a container and to measure drum pressurization. The first step would be to determine which waste containers may be susceptible to gas generation problems, the second part is the application of an NDE method for measuring gas overpressures (pressures higher than 1 atmosphere).

Gas generation problems are most likely to occur in containers which are filled with substantial amounts of combustible waste (specifically cellulose) or organic materials. A combination of real-time X-ray radiography and real-time neutron radiography should yield a clear picture of the percent combustible waste in a given container. In conjunction with container weight, contents in kg/m^3 (pounds/ft^3) could be estimated. Neutron radiographic methods, having a high sensitivity to hydrogenous materials such as cellulose, plastics, and other organic materials, will be quite useful if cellulose can be nondestructively separated from the other materials. In conjunction with an X-ray scan, this may be feasible. It may be that container atmospheres high in hydrogen (potentially explosive mixtures) can be detected with neutron radiography. The feasibility of this approach must be determined. Neutron interrogation should be useful for determining total organic material content.

Gas overpressures (irrespective of gas concentration or specific gases) might be detected through the application of sonic or ultrasonic resonance measurements. Measurements of gas pressures in Rocky Flats waste drums which were opened for correlation between drum contents and labeled drum content codes showed 4 of the 70 drums to have H_2 concentrations above the level considered explosive; the highest drum pressure was approximately 1.33 atmospheres (enough to cause a noticable bulge in the drum head). Elevated gas pressure should affect drum head resonance behavior. If feasibility testing shows this to be a correct supposition, drum head resonant frequency behavior or dampening response could be quickly measured using relatively inexpensive equipment. If data scatter bands are not excessively broad, it may be possible to obtain some relatively quantitative gas pressure measurements.

If gas generation is a problem in large 4 x 4 x 7-foot boxes, it is not known if the resonance approach would be applicable because of the possible severe variation in response inherent in the materials used (plywood and fiberglass reinforced plastic).

6.2 Immobilization (Particulate)

Particulate waste materials must be immobilized if more than 1 wt% is in the form of particles below 10 μm in diameter or if more than 15 wt% is in the form of particles below 200 μm in diameter. The waste must also be durable so that waste particles do not abrade into smaller particles during handling and transportation. Each of the different container content codes should be evaluated for waste forms that could contain particulate material.

This may be the most difficult waste problem to define nondestructively because neither X-ray nor neutron radiography has the resolution capability to identify respirable fines below 10 μm in diameter. Free particles below 200 μm in diameter may be detectable at more than 15 wt% if real-time X-ray or neutron radiography is used in conjunction with a relatively large amplitude shaker table and/or combined with container inversion to disperse particles through the waste package. Migration of the particles may be observable. Feasibility testing would be definitely needed to determine if NDE approaches are even applicable. There may be some chance of finding particulates if drum contents are adequately identified through waste records already in existence. If the approaches already discussed prove unusable a concerted research and development effort may be required to solve this problem.

6.3 Free Liquids

Certified TRU waste is not allowed to contain any free liquid to prevent radionuclide leakage in the event of a waste container failure. Solidified liquids must be demonstrated to be free of, or resistant to the formation of, free liquids. Methods need to be developed to identify waste containers which might have free liquid present.

Neutron radiography appears to be the leading candidate method for free liquid detection. Neutrons are significantly attenuated/absorbed by water or organic liquids. Mercury metal (which may or may not be included in the free liquid category) would not be as attenuating as the other liquids. (With sludge eliminated from certifiable waste in accordance with WIPP-WAC, most of the possibility of finding free liquid is probably eliminated.) Containers would have to be moved around in conjunction with real-time neutron imaging in order to see liquid motion, although liquids may be apparent in waste surface cracks even without motion.

Another NDE method which may be applicable is thermal imaging, although the technique would probably be relatively insensitive to liquid which is not in direct contact with the waste container wall. For example, a flask of liquid in a waste package would probably be nearly impossible to detect thermally but could probably be detected using neutron imaging.

6.4 Sludges

Certified TRU waste may not contain sludge since compliance with water desorption and respirable fine requirements cannot be ensured. Examination methods need to be employed to verify that the container content code is consistent with the actual container contents. (Methods also need to be developed to locate lead "pigs" and other items mixed in sludge.)

A real-time X-ray radiography system should easily identify sludge-filled containers. If there is interest in trying to locate objects within concrete sludge, such as electric motors, radioactive sources, etc., a high voltage X-ray source will be needed for the real-time X-ray radiography system.

Real time neutron radiography used in conjunction with X-ray radiography should be useful in separating concrete-filled and evaporator-salt-filled containers from those containing organic wastes, based on the selective absorption of neutrons by hydrogenous materials.

In addition to the penetrating radiation approaches, acoustic methods may be applicable to identification of sludge-filled drums. It may be possible to separate dried evaporator salts from the other sludge forms.

6.5 Pyrophoric Material

Pyrophoric material is not normally allowed in certified waste. These materials must either be mixed with chemically stable materials or processed to remove their hazardous properties, i.e., oxidized. However, up to 1% by weight of the waste in each package may be pyrophoric forms of radionuclide metals if they are dispersed through the waste. RWMC stored waste may contain small amounts of ^{238}U metal from retrieval projects.[6,7] Methods may need to be developed to distinguish between low, middle, and high Z metals.

Detection of pyrophoric materials will be extremely difficult. The only method which may possibly work is identification of metals using the absorption of X-rays as a function of atomic number. Since any measurements would be much influenced by the container contents, detection of pyrophoric materials will be one of the most difficult waste problems to solve.

6.6 Explosives and Compressed Gases

TRU certified waste shall contain no explosives or compressed gases. With the exception of ion exchange resins there are no known potentially explosive mixtures in any of the RWMC stored waste. Most explosive mixtures contain large amounts of hydrogenous materials; because of this, neutron radiography is probably the most applicable candidate technique. Tomography may be useful in evaluating shapes of possibly explosive materials.

Compressed gases, assuming they are in pressure containers, could probably be located using the standard real-time X-ray radiography system. However, a high voltage X-ray source would be required if pressure containers happened to be stored in sludge drums. The only way NDE methods could be used to determine if a gas container were depressurized would be to search for a hole in the gas container wall which would show that the container would not be capable of holding internal pressure.

6.7 Toxic and Corrosive Materials

Certified TRU waste may not contain toxic substances unless they exist as co-contaminants with transuranics. Corrosive TRU wastes must either be neutralized or packaged to ensure package integrity throughout the package design life. Toxic and corrosive materials must be packaged in color-coded containers. WIPP may allow shipment of waste if the material receives prior approval. Methods such as administrative control will be needed to determine the probability of toxic or corrosive waste being present in particular content code containers because without particular distinguishing characteristics the material could probably not be identified nondestructively.

6.8 Drum Wall Thickness

The thickness of waste drum walls should be evaluated because of possible internal drum corrosion from free liquids or a highly humid environment if a drum liner has been breached. This measurement could be done using an automated ultrasonic thickness measurement as one of the NDE methods used in the waste container characterization/certification system.

Another technique which could be used is computed X-ray tomography. This is a slower, more costly approach than ultrasonics, but it might be preferable for the area on a drum where the bottom head is attached (which may be difficult to examine ultrasonically). Neutron radiography may also be applied by using an approach based on identifying corrosion product residue (normally hydroxides) on the inside of a metal drum. Neutron radiography has, in the past, been found capable of being used to detect corrosion products in many materials.

6.9 Data Package

All TRU waste which is certified must be accompanied by a complete data package covering required details on waste containers, waste forms, and the waste package. The data package will be stored in a computerized data retrieval system for ready accessibility. The information will be transmitted to WIPP for approval before shipments are made.

7. FEASIBILITY TESTING

This discussion will be restricted to the feasibility tests required for the development and qualification of nondestructive methods for classifying TRU waste. The nondestructive methods development does include development of a decision algorithm and automated classification techniques.

In order to gain needed experience in TRU waste characterization, a 420 kV real-time "production" X-ray system should be procured and made operational early in FY 82 to gain experience in waste characterization under production conditions. This lower powered X-ray system could be put together and made operational for under $300,000 (including shielding, handling equipment, controls, signal enhancement electronics, etc.), while a higher energy LINAC alone might cost nearly $500,000. The demonstration/production system should include commercially available digital image processing equipment for signal enhancement and contrast improvement (especially important when examining highly attenuating material). The use of this equipment is mandatory for obtaining good quality video images and clear, noise-free tape recording and playback. This equipment (with the exception of the X-ray source) is also required for any real-time neutron radiography work in order to obtain acceptable signal to noise ratios and contrast in the video images.

It appears that real-time X-ray radiography will be the primary NDE method used for certification of TRU waste containers, supplemented by other NDE methods for greater characterization accuracy and reliability. The X-ray method has been shown to be feasible for waste characterization, and because of this, development and refinement of this method should proceed as rapidly as possible.

ANL-West is currently modifying their neutron radiography (NRAD) facility to provide the capability of radiographing objects at least as large as 55-gallon waste drums. This reactor source could be used for evaluating the real-time neutron radiography of nuclear waste drums in conjunction with the imaging system from the real-time X-radiography system, which should be available early in FY 82. The basic imaging system would be used with the addition of appropriate neutron converter screens. The digital signal processing equipment needed for video display and video taping of signals should also be available early in FY 82. If the real-time neutron radiographic approach proves feasible using a reactor neutron source, the feasibility (and cost) of using isotope or accelerator-based sources should be investigated.

Since there are approximately 60 waste container content codes, a large number of standard waste containers must be fabricated. These containers would include examples of the waste characterization problems which, based on both demonstrated results and engineering judgement, could be expected to be solved using the various nondestructive methods previously discussed. It may be necessary in some instances to open certain waste containers, accurately determine the contents, and then use these as standards. The standard drums would be used to evaluate real-time X-ray radiography, real-time neutron radiography, computed X-ray and neutron tomography, thermal imaging techniques, acoustic signature analysis, and container weighing. Special pressurized 55-gallon drums would be used for evaluating the feasibility of acoustic resonance methods for drum pressure measurement. To obtain a definitive rating of the correlation between waste container weight and waste contents a statistical study using a large number of actual waste containers which have been characterized by other NDE methods will be performed. A small number of "standard" samples would not be sufficient in this particular instance.

Development of a decision algorithm using combined NDE methods would have to await feasibility testing of the individual NDE techniques to determine which methods may be applicable. The initial feasibility of using automated waste classification methods would be restricted to a study designed to gather suitable background information in appropriate pattern recognition techniques. Assuming the method appears feasible in a production NDE system, videotaped images from the real-time X-ray radiography system will be computer analyzed. If this approach is successful, then neutron radiography and computed tomographic images will also be evaluated. Results of the pattern recognition work would then be incorporated with the decision algorithm work to develop the automated classification system.

Feasibility testing should commence in FY 82 in order to obtain enough lead time to develop an operational system by 1986 or 1987. Initial work should begin with the real-time X-ray radiography system which must be obtained before any work can be done on real-time neutron radiography or computed tomography because many parts of the real-time X-ray system are needed in order to evaluate feasibility of these other approaches. The 420 kV real-time X-ray system should be fabricated and made operational as soon as practical because the feasibility testing of many other methods are dependent on having this system available. The X-ray system would be used for intensive demonstration testing.

8. CONCLUSIONS AND RECOMMENDATIONS

1. Real-time X-ray radiography has been identified as the primary NDE method for immediate waste characterization applications.

2. Several NDE methods including real-time neutron tomography, X-ray and neutron computed tomography, thermal imaging, visual examination, waste container weights, and acoustic (including ultrasonic) methods may be useful to supplement real-time X-ray radiography for improved waste characterization and reliability.

3. Automation of the NDE/NDA system should result in better waste classification reliability, greater waste throughput, and lower operating costs as compared with a manually controlled or semi-automated system.

4. Development of a comprehensive certification and tracking system should proceed as shown in Figure 1. The plan depicted in this figure shows a step by step approach to developing a fully automated system. It is important to note that this plan starts with the real-time radiography forming a first level system in early FY 83 which can then be expanded based on management evaluation of the ongoing development work. A second level system that includes a computer-based data management scheme can be implemented in 1984 if the necessary development work is undertaken in FY 82 and FY 84. The final phase automated system can be implemented in FY 87, again if the prerequisite development work is supported. Note that an alternative to a fully automated system is shown in dashed lines in FY 85. The choice of systems would be dependent on the outcome of the conceptual design and cost benefit analysis that are scheduled for 1984.

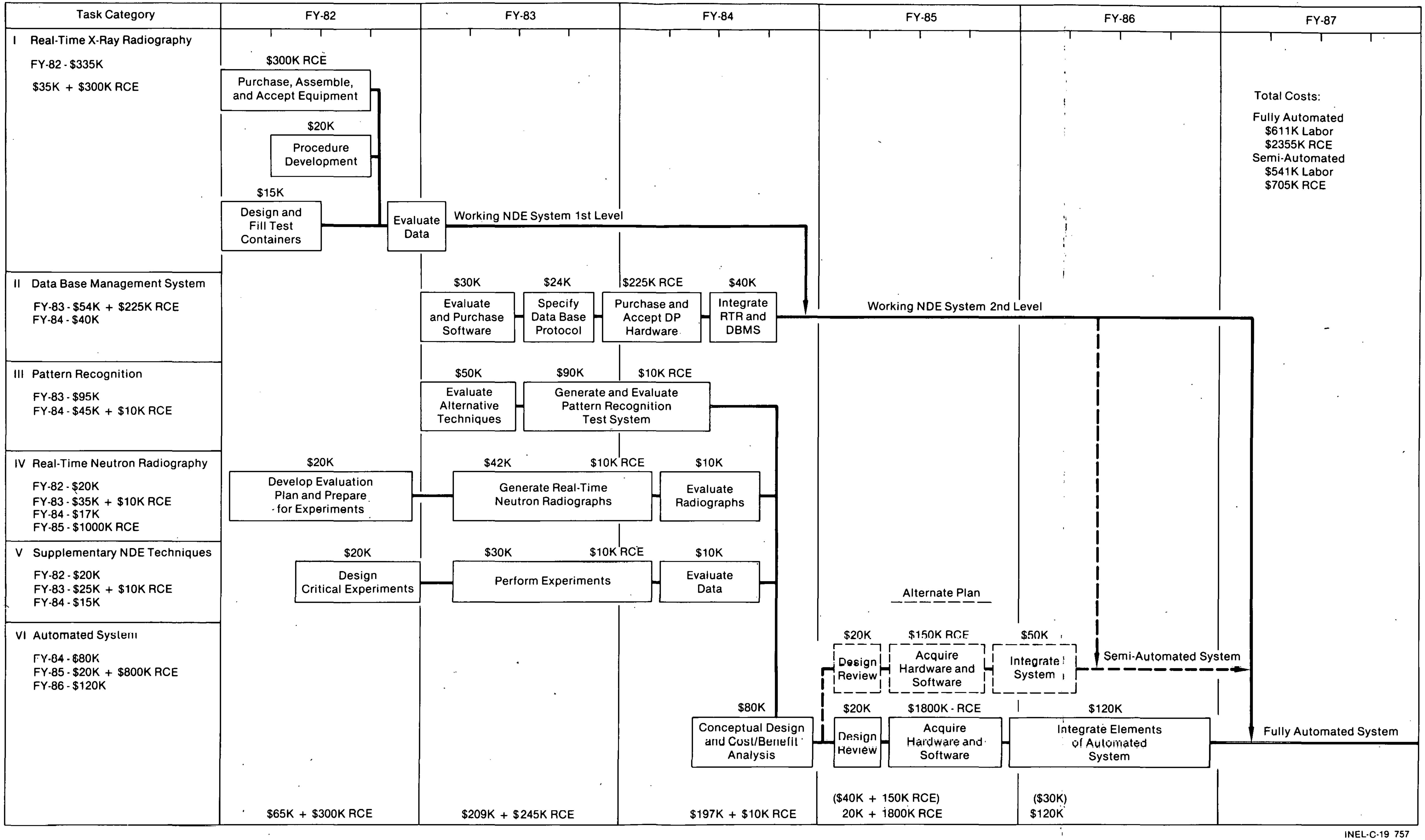

Figure 1. Proposed schedule for development of an automated NDE waste characterization system.

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