FINAL REPORT

Industrial Applications of Sealed Radiation Sources and Alternative Non Nuclear Technologies

Prepared by:

Trinity Engineering Associates
8832 Falmouth Drive
Cincinnati, Ohio 45231-5011

Under:

Contract 68-D-00-210
Work Assignment E210 1-16

Prepared for:

U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
Washington, DC 20460

Ms. Sally Hamlin
Work Assignment Manager

September 30, 2002

Table of Contents

1.0 Background

The energy emitted through the process of radioactive decay has been utilized for literally hundreds of applications. Owing to the variety of radioactive isotopes, the various decay modes (type of radiation emitted), and the range of energies associated with these various isotopes, diverse applications for the use of radioactive isotopes have been developed in the last few decades. These applications can be loosely divided into medical and industrial applications. Within the industrial applications, the use of radioactive materials can be broadly categorized into applications employing tracer technology and applications using radioactive materials encapsulated in a manner to prevent their release to the environment (i.e. sealed radioactive materials).

This report deals only with this last category, the applications of sealed radioactive materials in industry. The objective of this report is to describe the types of sealed sources used, the industries/applications in which they are used, and to identify the existence of feasible alternate technologies that perform the same functions without using radiological sources. Appendix A of this report describes some gauging technologies that do not use radioactive sealed sources.

2.0 Industrial Applications

A concise overview of the major industrial applications for radioactive materials is provided by the Uranium Information Center (UIC, 2001) and also by the US Nuclear Regulatory Commission (NRC, 2002). Table 1 provides a bibliographic-like listing of industries, applications, environment, and type of sealed source used.

Table 1. Industries Utilizing Radioactive Sealed Sources
Industry: Manufacturing Products / Services: Numerous thickness of metal components, thickness of coatings, moisture content in manufactured products Environment: Various but typically not hostile Gamma emitters such as Ba-133, Co-60, Cs-134, Cs-137, Sb-124,Se-75, Sr-90, Tm-170
Chemical Processing Various Process characteristics - density, thickness of coatings, specific gravity, level. Equipment parameters - pipe thickness, corrosion, wear. Temperatures and pressures vary widely depending upon process requirements; contact with corrosive environments not usually required Type of Sources: gamma emitters; neutron sources (for level measurement)
Industry: Construction

Table 1. Industries Utilizing Radioactive Sealed Sources

Products / Services:	Buildings, geophysical structures
Use of Sealed Sources:	Moisture content, location of reinforcing bar (rebar)
Environment:	Ambient
Type of Sources:	Gamma emitters, neutron sources - Am/Be, Pu/Be, Cf-252
Industry:	Mineral Processing
Products / Services:	measure levels of minerals in process streams
Use of Sealed Sources:	density gauges, spectroscopy
Environment:	Ambient
Type of Sources:	Gamma emitters such as Am-241, Co-57, Cs-137
Industry:	Coastal Engineering
Products / Services:	Measurement of environmental parameters
Use of Sealed Sources:	Levels of sediments in rivers and estuaries, mobilization ofsediment
Environment:	Ambient
Type of Sources:	Gamma emitters such as Am-241, Co-60, Cs-137
Industry:	Non Destructive Examination
Products / Services:	Radiography
Weld & weld overlays, castings, forgings, valves & components, machined parts, pressure vessels, structural steel, aircraft structures	
Environment:	Ambient, manufacturing environments
Type of Sources:	Co-60, Cs-137, Ir-192
Industry:	Oil Refining
Products / Services:	Refinery products
Use of Sealed Sources:	Column scanning, level measurement
Environment:	Elevated temperatures
Gamma emitters (column scanning); neutron sources (level measurement) especially Am/Be	
Industry:	Coal Fired Boilers
Products / Services:	Electricity generation
Use of Sealed Sources:	Level of ash in coal, moisture content of coal
Environment:	Ambient
Type of Sources:	Gamma sources such as Cs-137 with Am-241 (for ash content)
Industry:	Drilling
Environment:	Borehole Logging
Products / Services:	Geophysical investigations
Use of Sealed Sources:	Hydrogen content
Environment:	Ambient temperatures, ambient to high pressures
Type of Sources:	Gamma emitters, especially Co-60, and neutron - Am/Be
Industry:	Agriculture

Table 1. Industries Utilizing Radioactive Sealed Sources	
Products / Services:	Various crops
Use of Sealed Sources:	Soil moisture measurements
Environment:	Ambient
Type of Sources:	Neutron sources such as Am/Be, Pu/Be, and Cf-252
Industry:	Hydrology
Products / Services:	Environmental assessments
Use of Sealed Sources:	Soil moisture
Environment:	Ambient temperatures, elevated pressures
Type of Sources:	Neutron sources such as Am/Be, Pu/Be, and Cf-252
Industry:	Consumer Products
Products / Services:	Smoke Detectors
Use of Sealed Sources:	Produce an ionization current that is affected by the presence of smoke
Environment:	Ambient
Type of Sources:	Alpha emitter typically Am
Industry:	Medical Care
Syringes, surgical instruments, surgery consumables, pharmaceuticals	
Use of Sealed Sources:	Sterilization
Environment:	Ambient
Type of Sources:	Gamma emitters, especially Co-60
Industry:	Materials Processing
Blown Film, Cast film & sheet, Rubber, Vinyl, Coatings & Laminations, Nonwovens, Textiles, Composites, Paper, Plastic Pipe, film thickness, electroplating	
Measurement of thickness or weight, measurement of basis weight & consistency, moisture content	
Environment:	Ambient
Gamma emitters, e.g. Am-241; Beta emitters such as Pr-147, Kr-85, Sr-90	

Table 2 lists the specific type of sealed sources (e.g., Beta) and the various industries that routinely utilize that application.

Table 2. Summary of Radiation Type and Industries

Type of Source	Industries Using this Type of Source
Gamma	Radiography, mineral processing, oil refining, borehole logging
Beta	Material processing (thickness of materials), coatings, electroplating

Neutron	Chemical processing, refining, borehole logging, radiography

While there are some specific advantages to using sealed sources that are distinct to various industries, the major advantages are essentially the same across all the industries. Sealed sources provide the following advantages for use in industry:

- Portable energy source not requiring other sources of energy (e.g., electricity) for operation
- Range of energies
- Easily transportable
- Interacts with other media in well defined manner that facilitates various measurements
- Does not require contact with other material / media for use
- Devices are typically easy to use and do not require sophisticated operator training
- Commercially available from a large number of vendors in a variety of forms and energies
- Mature technology

There are a number of disadvantages to the use of radioactive sealed sources that are common to all industries. These include:

- Need for precautions to prevent exposure of individuals to harmful radiation
- Energy source is always “on”, thus requiring significant attention to storage
- Loss of the source can create an environmental and health hazard
- “Spent” sources require appropriate disposal

Advantages and limitations for the specific industries – gauging, well logging and radiography – are described in the sections that follow.

3.0 Alternatives to Radioactive Sealed Sources

3.1 Industrial Gauging

Well-established techniques utilizing radioisotopes encapsulated as sealed radiation sources are used in industrial gauging and analytical applications. Gauging devices are used to monitor and control the thickness of various manufactured products including: sheet metal, textiles, paper, newspaper, plastics, photographic film and rubber.

3.1.1 Current Viable Technologies

Fixed gauges (non-portable) are designed for measurement or control of material density, flow, level, thickness, or weight. The gauges contain sealed sources that radiate through the substance being measured to a readout or controlling device. Portable gauging devices are used in field applications for moisture density measurement and in the construction industry. These gauges contain a gamma-emitting sealed source, usually cesium-137, or a sealed neutron source, usually americium-241 combined with beryllium (Am-Be source).

Radioisotope gauging is based on the principle that the radiation emitted from a radioisotope will be reduced in intensity by matter between the radioisotope and a detector. The amount of this reduction can be used to gauge the presence or absence of the material, or even to measure the quantity of material between the source and the detector. The advantage of this form of gauging is that there is no contact with the material being measured. A typical application is the manufacturing of plastic film. The film runs between a radioactive source and a detector and the detector signal strength is used to measure then control the thickness of the plastic film. A similar technique is used to measure the height of coal in hoppers. Another common use of radioactive sources in gauging is level measurement in tanks or other containers. The radiological methods have an advantage of being low maintenance and non-invasive, since typically the gauge uses gamma sources that can 'see' through the tank walls.

In addition to sealed sources, a variety of other technologies are also commercially available to perform many of the gauging applications. Table 3 summarizes both common technologies using sealed sources and the alternative technologies available.

Table 3 Technologies for Gauging Applications in Manufacturing

Gamma	
Primary Uses	Thickness, basis weight
Primary Advantages	Wide range of energies suitable to multiple materials and applications. No contact with piece required.
Primary Limitations	Radiation safety considerations; not appropriate for all materials; requires access to both sides of the material

Industries	Blown Film, Cast Film & Sheet, Rubber, Vinyl, Coatings & Laminations Nonwovens, Textiles, Composites, Paper, Plastic Pipe
Beta	
Primary Uses	Thickness, basis weight
Primary Advantages	High accuracy for thin materials, films or coatings. No contact with material required.
Primary Limitations	Not suitable for all materials; requires access to both sides of the material; radiation safety considerations.
Industries	Blown Film, Cast Film, Pipe and Tubing, Sheet , electroplating, thin film
Infra Red	
Primary Uses	Basis weight, film thickness, moisture content
Primary Advantages	No contact necessary; very accurate for applicable materials
Primary Limitations	Limited material thickness; affected by variations in texture and color of material
Industries	Cast film extrusion, Blown film extrusion, Sheet film extrusion, Coextruded films, Paper and board manufacture and converting, Nonwovens, Fiberglass pre-pregs, Tissue
X Ray	
Primary Uses	Thickness
Primary Advantages	No contact required; accommodates variety of materials and thicknesses; relative to other radiation sources the gauge is off when the machine is off.
Primary Limitations	Requires electrical energy; access to both sides of material required;
Industries	Metals, Plastic, Cast Film & Sheet, Rubber, Vinyl, Coatings & Laminations, Nonwovens, Textiles, Composites, Paper
Laser Technologies	
Primary Uses	Thickness
Primary Advantages	High Precision, Non-Contacting Measurement, Unaffected by Product Density, Insensitive to Changes in Color or Texture, Dynamic Compensation for Change in Gap or Roll Run-Out, Compact, Rugged and Easily Maintained

Primary Limitations	Use of the proper laser; frequent calibration; requires correct laser orientation relative to material; limited types of material and process speed
Industries	Cloth or material thickness, Foam products, Strip metal, Laminated films, Rubber sheet
Ultrasonic	
Primary Uses	Thickness
Primary Advantages	Gauges exist for many materials and thicknesses.
Primary Limitations	Most gauges require direct contact with the material; those that do not still need some coupling between the transducer and the material (e.g. liquid bath).
Industries	Metals, plastics, ceramics, composites, epoxies, and glass, in-process measurement of extruded plastics or rolled metal is often possible, as is measurement of layers or coatings in multilayer materials
Capacitance	
Primary Uses	Thickness
Primary Advantages	Non-contact, high speed, with high accuracy
Primary Limitations	Requires frequent calibration; affected by thermal expansion, improper positioning of test piece and alignment of sensors.
Industries	High volume OEM gauging applications such as automotive, semiconductors, rubber, etc.

Industrial gauging covers a broad range of specific applications for nuclear sealed sources and the alternative technologies. Table 3 describes industrial gauging in the broad sense and not the needs / applications of specific industries. While the type of measurement might be similar for different types of manufacturing (e.g., thickness of paper and sheet metal), the application, implementation, and attitude toward use of alternative technologies can vary widely in these distinct industries.

3.1.2 Abundance of Application

All of the technologies listed above are proven technologies that are currently in use. Each is commercially available from vendors manufacturing and marketing the various gauges. Examples for non-nuclear methods are Oryx Systems (www.oryxsystems.com), Automation Industries Corporation (www.automationindustriescorp.com), and GE Panametrics (www.panametrics.com). There are an abundance of applications for the alternative gauging technologies, and the vendors of the alternative technologies have viable businesses which include not only supply of the product but additional services such as data analysis software development, field maintenance, and consulting/training. Most suppliers of gauging and other NDT/NDE systems specialize in one or two methods; a comprehensive list of many suppliers and their offerings is available at http://www.globalspec.com/ProductFinder/Test_Measurement/Nondestructive_Test_Equipment.

From this source, it appears fairly uncommon for the vendors of NDE methods utilizing sealed sources to also offer devices utilizing an alternative technology such as ultrasonic or laser gauging.

Although commercial alternatives to nuclear sources are available, the wide range of requirements (e.g. accuracy, tolerances, etc.) in the application of the method means that in many cases the alternative technologies cannot directly replace the nuclear methods. For instance, level gauging is used in many manufacturing industries (see http://www.berthold.com.au/industrial_pages/level.html). Both nuclear and non-nuclear devices can be used for this measurement, but the method selection is driven by the specific requirements of the application. For this application, there are a variety of competing technologies including microwave gauges, ultrasonic gauges, capacitance gauges, and laser-based gauges.

One example of an industry that has long used nuclear gauges, but which could also increase adoption of non-nuclear methods, is the paper industry. In manufacturing paper, common measurements include thickness, basis weight and moisture content. For basis weight and moisture content, nuclear gauges are extensively used throughout the industry. They have been used for many years, are a well-known and accepted technology, and provide good results. Thickness measurements are also typically performed using the radiological methods, but could be performed using a variety of methods, including laser and ultrasonic techniques, in addition to nuclear methods.

3.1.3 Attitudes of Stakeholders

The attitude of stakeholders regarding use of alternative technologies is highly dependent upon the specific industry. A number of individuals and corporations were contacted to determine the attitudes of the user community towards the use of sealed sources and the alternative technologies available. Several general themes emerged:

- Sealed sources are used extensively with good results; manufacturing industries benefit from the use of these devices

- Radiation safety is an on-going concern

- Alternative technologies are well accepted in some industries but in others sealed source devices are the preferred technology

As mentioned previously, the paper industry is a good example where alternative technologies have made little inroad. For basis weight measurements, the industry uses nuclear devices extensively. Most individuals contacted had little knowledge of alternative technologies, and were not interested in using any alternative technologies. The phrase “fixing something that wasn’t broken” was mentioned by numerous contacts.

3.1.4 Implementation Considerations

Alternative technologies provide effective, economical gauging devices for many manufacturing applications. Barriers to use of alternative technologies include the long history of good service provided by sealed source devices and the expense of adopting new technologies when the current technology is working well.

Because the range of alternative gauge applications is so broad, it is not possible to detail all considerations for individual industries. The following are offered as examples of industry-specific considerations:

- For level gauging, it is highly likely that the use of nuclear devices could be eliminated in favor of other technologies. Barriers in this instance are the cost of replacing an existing capability and perhaps the training of an individual to maintain the new type of technology. A conscientious program to replace legacy devices when they reach the end of useful life could be quite successful for this manufacturing application.

- For the manufacturers of thin films (paper, plastic, etc.) the barriers to implementation are much more extensive. In these industries, nuclear devices are used at many facilities and the alternative technologies are neither well known nor sought after. It will take years of education and advocacy at professional society meetings and trade shows for the alternative technologies to receive due consideration.

3.2 Well Logging

Well logging is a process used to determine the porosity of a formation and whether a well has the potential to produce oil. This process uses both byproduct or special nuclear material tracers and sealed sources in connection with the exploration for oil, gas, or minerals in wells. Basically, the source (a neutron or gamma source) is placed in a long, cylindrical tool designed to travel down the open hole (sometimes the hole has been cased, and this limits the utility of the technique). The source emits neutron or gamma radiation into the surrounding formation while the tool is being drawn up the hole. Sensors in another part of the tool record the response of the formation rock to the irradiation. Such tools can be designed to estimate formation porosity and a wide variety of other useful parameters. A typical application of this technology utilizes a probe containing a neutron source lowered into a bore hole where the radiation is scattered by collisions with surrounding soil. Since hydrogen (the major component of water) scatters neutrons very efficiently, the number of neutrons returning to a detector in the probe is a function of the density of the water in the soil. Soil density and water content are typically measured with an americium-beryllium-241 source that generates gamma rays and neutrons that pass through a sample of soil to a detector.

3.2.1 Current Viable Technologies

Geophysical logs employ a variety of measurement techniques that fall under the broad categories, including mechanical, electrical, acoustic/sonic , and radioactive measurement or response devices, the later of which may employ sealed radioactive sources. Measurement techniques of each category are summarized below:

- Mechanical or physical measurements include caliper and temperature logs. The caliper is a tool that measure the diameter of the uncased borehole and can be used, for example, to identify specific “soft” lithologies, zones “washed out” during drilling, etc. Temperature logs measure formation fluid temperature.

- Electrical measurements include those employing formation resistivity, conductivity, including spontaneous potential. The Spontaneous Potential (SP) log is a recording vs. depth of the difference between the electrical potential of a movable electrode in the borehole and the electrical potential of a fixed surface electrode. SP curves typically assists in lithology determination (i.e. shales or shaley material). The resistivity/conductivity tools also pass electrical currents through formations in various electrode or induction device configuration. These tools yield information that can be used for a variety of measurements, and is commonly used in conjunction with other measurements to assess the formation water saturation.

- Acoustic or sonic tools consist of a transmitter that emits a sound pulse and receiver that records the rock response (i.e. sound travel time/characteristics) through adjoining rock formations. Sonic tools are typically used to assess formation porosity, as sound travels more slowly through highly porous, water-filled rock that tight formations.

- Radioactive tools use either radioactive sources or natural rock gamma emissions to assess rock formation characteristics. Logs that use radioactive sources include 1) the Neutron Log which records formation response to exposure to neutron sources 2) the Formation Density Log, which determines formation density calculated from rock effects via exposure to gamma sources, and 3) Natural Gamma Log. Basically, the source (a neutron or gamma source) is placed in a long, cylindrical tool designed to travel down the open hole. The source emits neutron or gamma radiation into the surrounding formation while the tool is being drawn up the hole. Sensors in another part of the tool record the response of the formation rock to the irradiation. Radioactive tools include:

- Neutron tools measure the formation porosity (assuming 100% formation fluid saturation); since hydrogen (the major component of water) scatters neutrons very efficiently, the number of neutrons returning to a detector in the probe is a function of the “amount” of water in the rock pore space and hence a measure of formation porosity. Typical neutron sources are Cf-252, Pu/Be, Po/Be, Am/Be and Ra/Be.

- Density tools employ gamma emitters, with density being a function of the amount of Compton scattering associated with the emitted gamma radiation. Gamma ray sources, used with NaI scintillation detectors filtered to Compton Scattering energies, are calibrated in terms of bulk density of the material surrounding the borehole. Typical isotopes used are Co-60 and Cs-137.

- Natural Gamma Ray Logs measure the natural radioactivity of rock formations (i.e $K^{40)}$ which are preferentially concentrated in shaley formations; these logs do not require a radioactive source but do measure the natural radioactivity of the formations. (Schlumberger, 1989).

- Neutron and Density logs can be used to calculate formation porosity and formation lithology, and can also be indicators of other formation or formation fluid characteristics (i.e."bright spots" on neutron logs could indicate the presence of natural gas, wherein the pore space is filled with a loss-than-anticipated amount of hydrogen). In addition, neutron measurements can also be related to neutron activation of carbon and/or various metals present in the sediments and/or rocks surrounding the borehole.

In addition to and as part of these technologies, new/different applications and uses of geophysical logging techniques have been introduced to the mineral, oil and water well industries. Examples of new technologies being marketed today include but are not limited to:

· Magnetic Susceptibility tools, used for mineralogy logging of magnetically susceptible formations. The tool is useful for determining magnetite content and iron ores, and records natural gamma emissions and drilling deviations. It measure magnetic susceptibility and uses natural gamma radiation detectors.

· Gyroscopic deviation tools are used for determining borehole deviation and natural gamma mineralogy of magnetically anomalous formations. It employs an axis magnetometer and inclinometer and gyroscope, as well as natural gamma detectors.

· Acoustic televiewers are used for geotechnical observations, whereby a viewer is used to take an oriented acoustic picture of the borehole wall using high resolution sound waves. Information from this tool is used to assess formation fractures, rock strength, etc.

- Spectral Gamma Ray Logs are used to measure the amounts and types of radioactive material in formations and consists of four curves showing standard Gamma Ray in API units, Potassium in percentage uranium in ppm and thorium in ppm. The log is used for clay typing or to identify specific natural or artificial isotopes.

- Ion Beam Analysis (IBA) uses a particle accelerator to inject the nuclei of light atoms such as hydrogen or helium, resulting emitted nuclei, gamma rays or x-rays characteristic of the elemental composition of material being tested. Apparently this technology, however, has not yet been adapted for use downhole..

A number of specific well-log types fall under the broad well log categories discussed above, and examples are shown in Table 4.

Table 4 Common Borehole Logging Technologies

Electrical/Resistivity	Sonic	Nuclear	Physical/Mechanical and Other
Spontaneous Potential	Sonic	Ion Beam Analysis	Temperature Log and Caliper log
Normal Resistivity, microresistivity	Acoustic televiewer s	Formation Density	Caliper
Guard Logs and Lateral Logs	Hole to Hole P and Shear wave data	Neutron Porosity	Flowmeter (spinner)
Induction Logs	Wellbore Seismic, Vertical Seismic profiling	Passive/na tural Gamma	Borehole Televiewer
Fluid Resistivity Production	Vertical Seismic Profiling	Spectral Gamma	Gyroscopic Deviation and GPR

Schlumberger, 1989, also
http://www.welenco.com/;
http://www.Imdex.com,
http://www.technos-inc.com

Table 5 compares the use of radioactivity-related tools (sealed sources and natural gamma) to other major categories of well log types showing general uses, advantages, and industries.

Table 5 Comparison of Radioactivity and Other Logging Technologies

Technology	Examples of Primary Uses	Major Advantages	Major Limitations	Industries
Gamma sources	bulk density, lithology, porosity	Portable, mature technology	Radiation safety	oil, water, environmental
Neutron sources	porosity, fluid content	Portable, mature technology, cased hole	Radiation safety	oil, water, environmental
Natural Gamma	lithology	Portable mature technology, cased hole	limited use	oil, water, environmental
Sonic	porosity, lithology	Portable, mature technology	Open hole only	oil, water, environmental
Electric	fluid type/content, water/oil saturation	Portable, mature technology	Not used for lithology	oil, water, environmental
Other	fracture analysis, borehole deviation, fluid flow	Use in difficult geologic conditions, etc.	method-specific uses	oil, water, environmental

The vast majority of technologies presented above are very mature, and have been used in the oil and water industries for literally decades. Application of these technologies to the environmental industry is relatively new, and must be adopted to the specific conditions of this industry. For example, many electrical well log techniques rely on water-filled boreholes to aid in signal generation/transmission, but environmental boreholes are often shallow (above the water table), thus limiting the use of these technologies. However, many can and have been adapted for use in the environmental industry, including neutron tools whereby the specific hydrogen content of soils can be assessed (hydrogen being a constituent in many hazardous organic constituents).

3.2.2 Abundance of Applications

Well logging is performed, to some degree, in probably every oil well drilled. While full log suites may not be conducted in, for example, well field "infill" wells where field porosity, fluid content, etc. are already defined, usually some type of log (i.e. natural gamma, SP) is run to locate specific lithological zones and to facilitate well completion activities. Use of these tools, however, in the water and environmental industries is not as abundant, as the shallow nature of many of these boreholes is more amenable to well bore lithological logging, sample collection and sample analysis to obtain needed information.

3.2.3 Attitudes of Stakeholders

Those surveyed who performed exploratory drilling indicated a high degree of satisfaction with sealed source devices and a lack of knowledge of the alternative technologies. Those surveyed who provide the well logging technologies were well aware of both the nuclear devices and the alternative technologies. Those providing the services and technologies (companies such as Haliburton and Baker Atlas) understood the advantages and limitations of the technologies. Typically, clients will specify the type of log (technology) they want performed for their project. In many (most) cases, clients specify nuclear devices because of their long history of use and their quality of service. There is ongoing consideration of radiation safety issues with loss of a nuclear device. However, most users of logging services select radioactivity-related logs despite this concern because these logs provide high quality lithologic information (i.e. porosity, etc) that can be obtained using other tools. For example, sonic must be run in open rather than cased holes and is generally not used to determine specific lithologies, only velocity of sound in those lithologies and related porosity. Also, SP logs typically do not present as detailed lithologic boundaries as natural gamma logs.

3.2.4 Implementation Considerations

New technologies have not focused on specifically replacing the information obtained by neutron, gamma, and natural gamma tools. For example, new technologies such as down-hole video can be used to examine lithologies and fracture orientation, but would not be used to replace a neutron tool for formation fluid and porosity determinations. Continued research is warranted to identify robust technologies that can provide equivalent service at comparable prices. The Natural Resources Ministry of Canada, Borehole Geophysics and Petrophysics Section, is one good source of research and development in the area of alternative technologies. See http://borehole.gsc.nrcan.gc.ca/index_e.html.

3.3 Non Destructive Examination

Nondestructive examination (NDE) and Non-Destructive Testing (NDT) is a branch of the materials sciences that is concerned with the uniformity, quality and serviceability of materials and structures. The science of nondestructive evaluation utilizes a variety of technologies for detection and measurement of material properties, including discontinuities, in items ranging from research specimens to finished components. These nondestructive techniques are the means by which materials and structures may be inspected without damaging or impairing the functionality of a part or component.

One common method of non-destructive examination is radiography that uses gamma radiation. The necessary equipment is highly portable and ideally suited to the sometimes remote and often difficult working conditions on construction sites.

3.3.1 Current Viable Technologies

Iridium-192 is ideal for many types of radiography but other radionuclides can be used depending on the characteristics of the object material. Table 6 provides information on common sources and applications in gamma radiography.

Table 6 Gamma Radiography Sources

Radionuclide	Gamma energies (MeV)	Optimum steel thickness(mm)
Cobalt-60	High (1.17 and 1.33)	50-150
Cesium-137	High (0.662)	50-100
Iridium-192	Med (0.2-1.4)	10-70
Ytterbium-169	Low (0.008-0.31)	2.5-15
Thulium-170	Low (0.08)	2.5-12.5

A particular source is chosen so that the radiation has enough energy to penetrate through the material but with sufficiently reduced attenuation when passing through a defect. The increased transmission through a flaw results in a darker image on the developed film. The activity of the source is a critical characteristic since the quality of the measurement is affected by it. Too high of an activity adds fog to the film, darkening it overall and reducing the likelihood of identifying the flaw. It also requires safety precautions over a wider area.

It should be pointed out that radiography is performed both with sealed gamma sources and with machines that generate x-rays. The applications overlap but the gamma techniques are able to test thicker materials better than x-ray radiography, because of the higher energy and thus higher penetrating ability of the gamma photons. Sealed gamma sources also do not require external power sources to operate, while x-ray generators do.

There are a variety of alternative technologies available for non-destructive evaluation. The National Materials Advisory Board (NMAB) Ad Hoc Committee on Nondestructive Evaluation adopted a system that classified NDE/NDT methods into six major categories:

- Visual
- Penetrating Radiation
- Magnetic-Electrical
- Mechanical Vibration
- Thermal
- Chemical-Electrical

The American Society of Nondestructive Testing version of this classification system is shown in Table 7 below (from http://www.asnt.org/ndt/primer4.htm).

Table 7. Categorization of Alternative NDE Technologies

Method	Characteristics Measured
Mechanical and optical	color, cracks, dimensions, film thickness, gaging, reflectivity, strain distribution and magnitude, surface finish, surface flaws, through-cracks
Penetrating radiation	cracks, density and chemistry variations, elemental distribution, foreign objects, inclusions, microporosity, misalignment, missing parts, segregation, service degradation, shrinkage, thickness, voids
Electromagnetic and electronic	alloy content, anisotropy, cavities, cold work, local strain, hardness, composition, contamination, corrosion, cracks, crack depth, crystal structure, electrical and thermal conductivities, flakes, heat treatment, hot tears, inclusions, ion concentrations, laps, lattice strain, layer thickness, moisture content, polarization, seams, segregation, shrinkage, state of cure, tensile strength, thickness, disbands
Sonic and ultrasonic	crack initiation and propagation, cracks, voids, damping factor, degree of cure, degree of impregnation, degree of sintering, delaminations, density, dimensions, elastic moduli, grain size, inclusions, mechanical degradation, misalignment, porosity, radiation degradation, structure of composites, surface stress, tensile, shear and compressive strength, disbonds, wear
Thermal and infrared	bonding, composition, emissivity, heat contours, plating thickness, porosity, reflectivity, stress, thermal conductivity, thickness, voids
Chemical and analytical	alloy identification, composition, cracks, elemental analysis and distribution, grain size, inclusions, macrostructure, porosity, segregation, surface anomalies

These technologies are commercially available and are manufactured and marketed widely. Table 8 summarizes the advantages and limitations of the technologies used for non destructive evaluation.

Table 8 Characterization of NDE Technologies

Radiography (gamma and x-ray)	
Uses	Identification of defects due to change in density, inclusions and variations in material properties. Identification of foreign objects and

	placement of parts internal to a structure. In-service inspection for degradation (generally changes in thickness).
Major Advantages	Useful for a wide range of materials and thicknesses; versatile; permanent record generated.
Major Limitations	Radiation safety precautions; expensive; orientation of defect is a factor. The radiographs show discontinuities in two dimensions only. Access to both sides of the subject material is required. Subject material thickness can also preclude the use of radiography. In X-Ray radiography the limit of material penetration is dependent upon the energy of the X-Ray generator.
Industries	Power generation; aerospace; petrochemical; medicine / pharmaceuticals; nonmetals; law enforcement; food; evaluation of art / historic objects.
Ultrasonic	
Uses	Identification of defects through changes of acoustic impedance – cracks, inclusions, interface problems, lack of bonding. Typical applications include structural weldments, ship hull thickness, corrosion surveys, weld quality, aircraft wing and tail attach fittings, wheel rim and bead seat areas, gears and shafts, forgings, and some castings
Major Advantages	Effective for thick materials; excellent for crack detection.
Major Limitations	Requires a probe be coupled to the material to be tested; orientation of defect is a factor. Proper surface is essential. The geometry of the item being inspected may preclude the use of ultrasonics. The reliability of an ultrasonic inspection depends greatly on the skill and experience of the technician performing the inspection. Temperatures in excess of approximately 1000°F for thickness readings, and 400°F for weld scan, in the material to be tested may affect the ultrasonic sound waves, which may affect the inspection results.
Industries	Component fabrication, aerospace, chemical
Eddy Current	
Uses	Identification of defects though changes in electrical conductivity – cracks, voids, inclusions and changes in material properties.
Major Advantages	Moderate cost; easily automated.
Major Limitations	Only useful for magnetically conductive materials; limited on thickness of material. Extremely dependent on operator proficiency. Adequate access to the item is required.
Industries	Aerospace, automotive, component fabrication, nuclear steam generators
Magnetic Particle	

Uses	Identification of surface defects or near surface defects through leakage of magnetic flux – cracks, voids, inclusions, material or geometry changes. Typical applications include large shafts, rods, gears, forging, castings, broaches, machinery ways, landing gear struts
Major Advantages	Moderate cost
Major Limitations	Limited to ferromagnetic material; surface preparation required; de-magnetization may be required.
Industries	Petrochemical; construction; aerospace; automotive; defense; nuclear; transportation; marine.
Liquid Penetrant	
Uses	Identification of surface defects through liquid seeping into crack – cracks, porous regions, seams, or folds. Typical applications include weldments, castings, forgings, turbine housings, airplane parts, and many non-ferrous metallic materials
Major Advantages	Inexpensive; easy to use; portable.
Major Limitations	Limited to surface defects; not useful with porous materials or on rough surfaces. Normally performed at a temperature range of 40°F to 125°F, unless special procedures and penetrants are used. The surface must be accessible and capable of being satisfactorily cleaned. Easily affected by surface contaminants or conditions
Industries	Power generation; petrochemical; marine; aerospace; metalworking; welding.

3.3.2 Abundance of Applications

As noted in Table 8 above, each of the methods is used in multiple industries. Similar to gauging applications, the selection of a specific method will be subject to the exact requirements of the test being performed. Method selection is performed by trained engineers and certified technicians, taking into account the various advantages and disadvantages of each technique.

3.3.3 Attitudes of Stakeholders

Practitioners in the field of NDE use gamma radiography extensively and cite the portability of this technology and the ability to measure thick material as two significant advantages of this technology. Another significant advantage is that radiography generates a permanent record. While other technologies can generate a permanent record, it is not as straight forward as with radiography. Radiography produces a film record that is easily archived and simple to interpret even after long periods of time have elapsed since the test was performed. This is very valuable in applications where safety is a concern, since Quality Assurance programs and regulatory bodies involved with overseeing these applications will audit these records over the course of years. By contrast, an ultrasonic or eddy current test may generate only an electronic signal that is more subject to degradation or obsolescence, and a dye penetrant test may not leave any permanent auditable record other than an inspector's notes.

NDE professionals tend to use a variety of technologies depending upon the size and geometry of the part and the material. It is typical to use more that one NDE technology on a single item. In many instances, a customer will specify to a manufacturer which methods they expect to be used.

Radiation safety concerns are present for gamma radiography and a number of those surveyed had experienced problems with sources inadvertantly coming out of the device or with lack of care by the device operators, either of which can lead to unnecessary radiation exposures.

In general, the personnel interviewed believed that alternative technologies could replace gamma radiography, although this would take some time given the history of service provided by this technology. Table 9 provides a useful reference for determining when a particular non-destructive evaluation technology is indicated. As can be seen in Table 9, there are very few instances when an alternative to radiography would not be a viable inspection method.

Table 9: Preferred NDE Methods

Type of Defect	NDE Method
Bursts (wrought metal)	Ultrasonic Testing
	Magnetic Particle Inspection
Cold Shuts (casts)	Liquid Penetrant Inspection
	Radiography
Fillet cracks (bolts)	Ultrasonic testing
	Liquid Penetrant Inspection
Grinding Cracks	Liquid Penetrant Inspection
	Magnetic Particle Inspection
Convolution Cracks	*Radiography*
Heat-affected Zone Cracking	Magnetic Particle Inspection
	Liquid Penetrant Inspection
Heat Treat Cracks	Magnetic Particle Inspection
	Liquid Penetrant Inspection
Surface Shrink Cracks	Liquid Penetrant Inspection

Type of Defect	NDE Method
	Magnetic Particle Inspection
	Eddy Current
Thread Cracks (wrought metal)	Liquid Penetrant Inspection
	Magnetic Particle Inspection
Tubing Cracks (nonferrous)	Eddy Current
	Ultrasonic Testing
Hydrogen Flake (ferrous)	Ultrasonic Testing
	Magnetic Particle Inspection
Hydrogen Embrittlement	Magnetic Particle Inspection
Inclusions (welds)	*Radiography*
	Eddy Current
Inclusions (wrought metal)	Ultrasonic Testing
	Eddy Current
	Magnetic Particle Inspection
Lack of Penetration (welds)	*Radiography*
	Ultrasonic Testing
	Eddy Current
	Magnetic Particle Inspection
	Liquid Penetrant Inspection
Laminations (wrought metal)	Ultrasonic Testing
	Magnetic Particle Inspection
	Liquid Penetrant Inspection
Laps and Seams (rolled metals)	Liquid Penetrant Inspection
	Magnetic Particle Inspection
Laps and Seams (wrought metals)	Magnetic Particle Inspection
	Liquid Penetrant Inspection
	Ultrasonic Testing
	Eddy Current
Microshrinkage (magnesium castings)	*Radiography*
	Liquid Penetrant Inspection
Gas Porosity (welds)	Radiography
	Ultrasonic Testing
	Eddy Current
Unfused Porosity (aluminum)	Ultrasonic Testing
	Liquid Penetrant Inspection

Type of Defect	NDE Method
Stress-corrosion Cracking	Liquid Penetrant Inspection
Hot Tears (ferrous coatings)	*Radiography*
	Magnetic Particle Inspection
Intergranular Corrosion	Liquid Penetrant Inspection
	Radiography

3.3.4 Implementation Considerations

Radiography is used extensively, is considered a valuable tool in NDE, and provides a permanent record of the examination. For alternative technologies to completely replace gamma radiography, practitioners must be convinced that the alternative technologies provide as accurate and as reliable a measurement. With continued improvements in the currently available alternative technologies, some experts expect the use of gamma radiography to decline in many applications, though not all.

4.0 Conclusions

Radioactive sealed sources are used by a wide variety of industries in a very large number of applications. This report focused on the use of these sources for gauging and nondestructive examination applications. Technologically viable alternatives to radioactive sealed sources were found for essentially all applications where radioactive sealed sources are currently used, however, many barriers exist to fully replacing radioactive sealed sources. These barriers include:

- Overcoming reluctance to replace a method that has proven itself rugged and reliable
- Costs of implementing new methods, including training and startup costs
- Lack of understanding of alternatives in some industries
- Job specific standards and requirements that promote using sealed source methods

Institutional and regulatory barriers to adopting alternative technologies exist in some cases. Specifically, radiography using sealed sources is a method that could likely be almost entirely phased out, except that the quality of the permanent record that is generated by radiography make it a very useful choice in applications where quality assurance or regulatory compliance programs are involved.

This work assignment included a significant effort to identify technologies, developers of the technologies, and practitioners in the various fields. For all industries investigated, a number of contacts were identified and inquiries made to numerous individuals. While some individuals were interviewed successfully, many more did not respond or were unwilling to contribute meaningful information. All requested anonymity. The information collected thus represented a less robust cross section of practitioners than was desired.

To gain greater information on the attitudes of stakeholders and the barriers to implementing alternative technologies, we suggest participation at professional society meetings and trade shows. By carefully selecting the appropriate venue, the quantity of useful information that could be gathered would be significantly greater than has been possible through this work.

5.0 References and Bibliography

ASNT 2002, Introduction to Nondestructive Testing, American Society for Nondestructive Testing, 2002, Available at www.asnt.org/ndt/primer1.htm

Baker Atlas, 2002, www.bakerhughes.com/bakeratlas/

Bray, D.E., and R. K. Stanley, 1989, Nondestructive Evaluation, McGraw-Hill Book Company

Cartz, L., 1995, Nondestructive Testing: Radiography, Ultrasonics, Liquid Penetrant, Magnetic Particle, Eddy Current, ASM International, Materials Park, OH

Halliburton Energy Services, 2001, www.haliburton.com/news/archive/2001/

Hellier, C.J., 2001, Handbook of Nondestructive Evaluation, McGraw-Hill Companies

Johnson, D.E., & K.E. Pile, 2002, Well Logging in Non-technical Language, Penn Well Publishing, Company, Tulsa, OK

Kohl, J., R. Zentner, and H. Lukens, 1961, Radioisotope Applications Engineering, Von Nostrand Company

Labo, J., 1986, A Practical Introduction to Borehole Geophysics, Society of Exploration Geophysics, Tulsa, OK.

Lowenthal, G.C., and P.L. Airey, 2001, Practical Applications of Radioactivity and Nuclear Radiations, Cambridge University Press

ORNL 2002, Radioactive Sealed Sources and Devices, Oak Ridge National Laboratory, 2002, Available at www.hsrd.ornl.gov/sources/index.cfm

Sharma, P.V., 1997, Environmental and Engineering Geophysics, Cambridge University Press, Cambridge, UK.

Schlumberger 1989, Log Interpretation Principles and Applications, Schlumberger Educational Services, 1989

USNRC 2002, Industrial Uses of Nuclear Materials, US Nuclear Regulatory Commission, 2002, Available at http://www.nrc.gov/materials/miau/industrial.html

UIC 2001, Radioisotopes in Industry, Nuclear Issues Briefing Paper, Uranium Information Center, November 2001, Available at http://www.uic.com.au/nip27.htm

Appendix A
Description of Some Non-Nuclear Gauging Technologies

Non-Radiological Thickness Gauges

Electronic Gauges (Information From Oryx Systems Corporation, www.oryxsystems.com)

Electronic thickness gauges operate on the principle of measuring the capacitance formed between the face of the capacitance probe sensing element and the target surface. The interruption of this field by a dielectric material predictably changes this capacitance based upon the dielectric constant of the material. This change is recorded as a direct voltage change. The sensors and signal processing capture and convert this voltage change into thickness or mass units of measure.   Figure A1 shows a diagram of an electronic system

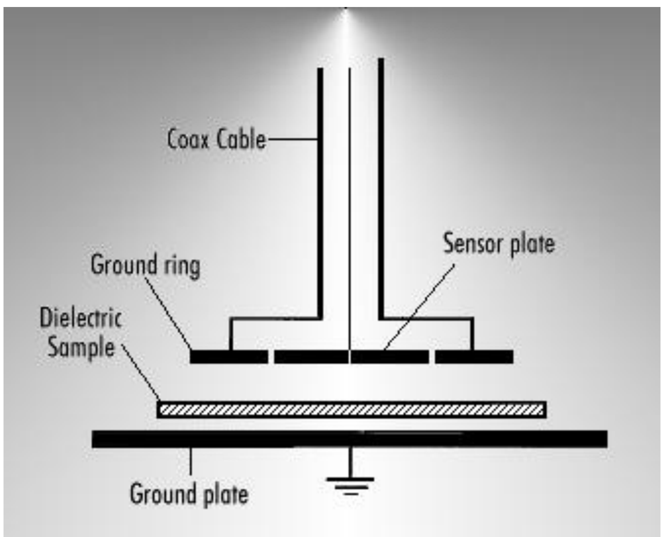


Figure A1: Electronic Gauge System Diagram

Laser Gauges (Information From Oryx Systems Corporation)

Lasers offer an extremely accurate thickness and 'displacement' measurement technique. However, to work properly, particular attention must be given to laser selection, signal processing, calibration, linearization, mounting, the material you are measuring, and process speed, if applicable. They are designed for measuring the thickness of:

- opaque and clear plastic
- battery materials
- paper
- rubber
- steel
- ceramic film & chips
- copper foil
- foam
- fabric
- and many other materials.

Figure A2 depicts a typical laser gauge system.

Figure A2: Laser Gauge System

Ultrasonic Gauging Methods (Information from GE Panametrics)

Ultrasonic nondestructive testing (NDT)--characterizing material thickness, integrity, or other physical properties by means of high-frequency sound waves--has become a widely used technique for quality control. In thickness gauging, ultrasonic techniques permit quick and reliable measurement of thickness without requiring access to both sides of a part. Accuracies as high as ±1 micron or ±0.0001 inch are achievable in some applications. Most engineering materials can be measured ultrasonically, including metals, plastic, ceramics, composites, epoxies, and glass, as well as liquid levels and the thickness of certain biological specimens. On-line or in-process measurement of extruded plastics or rolled metal is often possible, as is measurement of single layers or coatings in multilayer materials. Modern hand held gauges are simple to use and highly reliable.

Precision ultrasonic thickness gauges usually operate at frequencies between 500 KHz and 100 MHZ, using piezoelectric transducers to generate bursts of sound waves when excited by electrical pulses. A wide variety of transducers with various acoustic characteristics have been developed to meet the needs of industrial applications. Typically, lower frequencies will be used to optimize penetration when measuring thick, highly attenuating, or highly scattering materials, while higher frequencies will be recommended to optimize resolution in thinner, non-attenuating, non-scattering materials.

A pulse-echo ultrasonic thickness gauge determines the thickness of a part or structure by accurately measuring the time required for a short ultrasonic pulse generated by a transducer to travel through the thickness of the material, reflect from the back or inside surface, and be returned to the transducer. In most applications this time interval is only a few microseconds or less. The measured two-way transit time is divided by two to account for the down-and-back travel path, and then multiplied by the velocity of sound in the test material. The result is expressed in the well-known relationship:

$d=Vt/2$

where d = the thickness of the test piece

V = the velocity of sound waves in the material

t = the measured round-trip transit time

Additionally, in actual practice, a zero offset is usually subtracted from the measured time interval to account for certain fixed electronic and mechanical delays. In the common case of measurements involving direct contact transducers, the zero offset compensates for the transit time of the sound pulse through the transducer's wearplate and the couplant layer, as well as any electronic switching time or cable delays. This zero offset is set as part of instrument calibration procedures and is necessary for highest accuracy and linearity.

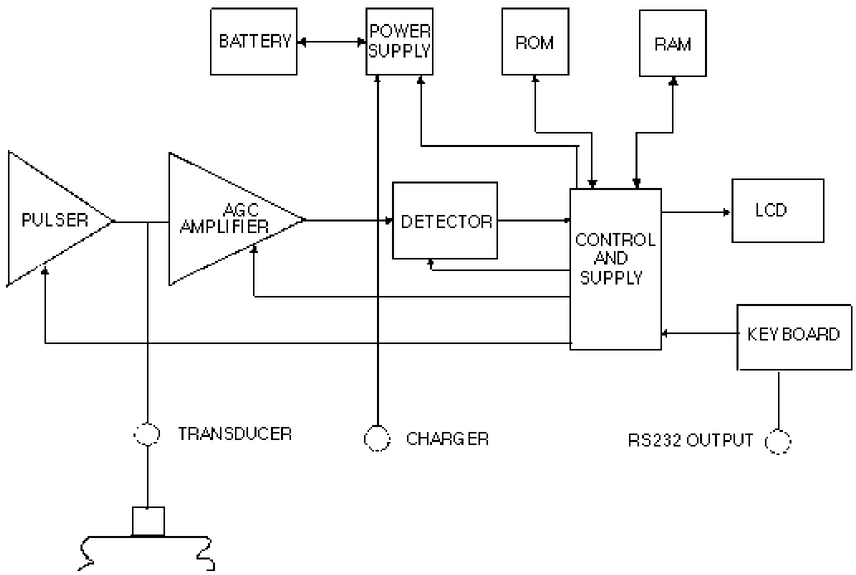


Figure A3: Ultrasonic Gauge Block Diagram

Figure A3 represents a generalized block diagram of a modern microprocessor-controlled ultrasonic gauge. The pulser, under control of the microprocessor, provides a unidirectional broadband voltage impulse to a heavily damped broadband ultrasonic transducer. The broadband ultrasonic pulse generated by the transducer is coupled into the test piece, normally with the aid of a liquid coupling medium. Returning echoes are received by the transducer and converted back into electrical pulses, which in turn are fed to the receiver Automatic Gain Control (AGC) amplifier. The microprocessor-based control and timing logic circuits both synchronize the pulser and select the appropriate echo signals to be used for time interval measurement.

If echoes are not detected during a given measurement period, the gauge will shut down to save power until a new measurement cycle is required. If echoes are detected, the timing circuit will precisely measure an interval appropriate for the selected measurement mode, and then repeat this process a number of times to obtain a stable, averaged reading. The microprocessor then uses this time interval measurement, along with the sound velocity and zero offset information stored in the Random Access Memory (RAM), to calculate thickness. This thickness measurement is then displayed on the Liquid Crystal Display (LCD) and updated at a selected rate.

Many modern gauges incorporate an internal datalogger and are capable of storing several thousand thickness measurements along with identification codes and setup information in RAM. These stored readings may be recalled to the gauge's display or uploaded to a printer or computer for further analysis

Ultrasonic Weld Examination (Information from GE Panametrics)

Welding, in its various processes and methods, can produce a number of different types of discontinuities. These discontinuities can result from material inconsistencies, operator error, or from uncontrollable factors. Regardless of the discontinuity's source, detection is critical. An unsatisfactory weld will seriously reduce the strength of the bond between two materials.
Using ultrasonic transducers and powerful standard software, inspectors equipped with flaw detectors can accurately locate discontinuities within a weld and the heat-affected zone surrounding the weld. These might include toe cracks, root cracks, porosity, slag inclusions, incomplete penetration, and lack of fusion (See

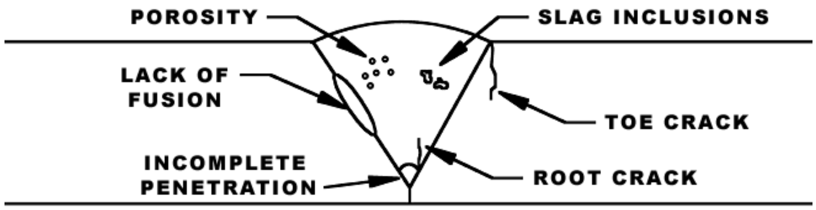


Figure A4). A trained inspector can not only detect these discontinuities, but in some cases also pinpoint their location and dimensions within the material.
Figure A4: Typical Weld Flaws
Ultrasonic weld inspections are typically performed using a straight beam transducer in conjunction with an angle beam transducer and wedge. A straight beam transducer, producing a longitudinal wave at normal incidence into the test piece, is first used to locate any laminations in or near the heat-affected zone. This is important, as an angle beam transducer may not be able to provide a return signal from a laminar flaw, as depicted in Figures A5 and A6.

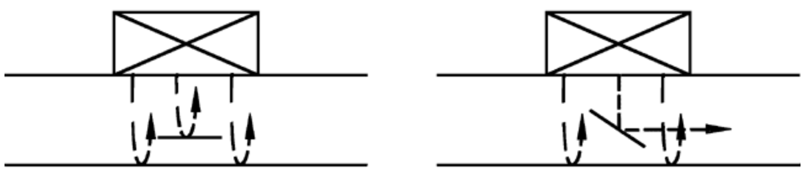


Figure A5: Straight Beam Lamination Inspection

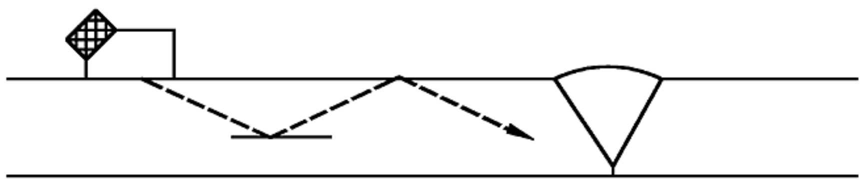
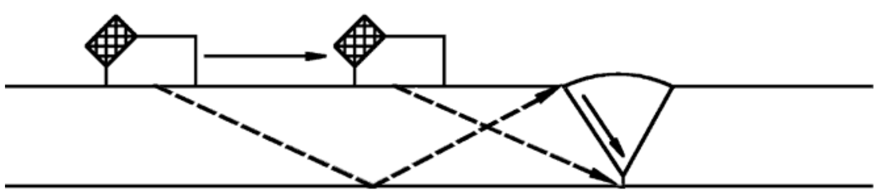


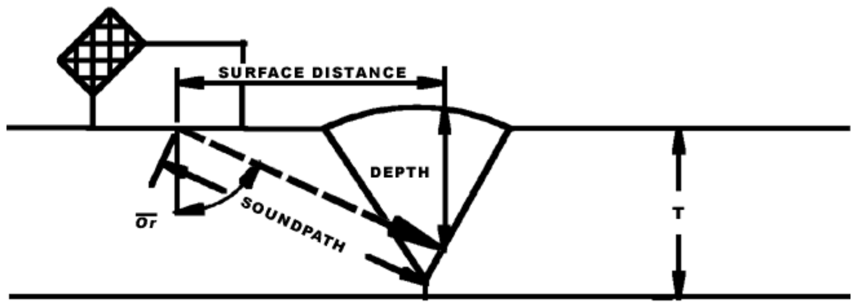
Figure A6: Angle Beam Lamination Inspection

The second step in the inspection involves using an angle beam transducer to inspect the actual weld. Angle beam transducers use the principles of refraction and mode conversion to produce refracted shear or longitudinal waves in the test material. [Note: Many AWS inspections are performed using refracted shear waves. However, material having a large grain structure, such as stainless steel may require refracted longitudinal waves for successful inspections.] This inspection may include the root, sidewall, crown, and heat- affected zones of a weld. The process involves scanning the surface of the material around the weldment with the transducer (See Figure A7). This refracted sound wave will bounce off a reflector (discontinuity) in the path of the sound beam. With proper angle beam techniques, echoes returned from the weld zone may allow the operator to determine the location and type of discontinuity.

Figure A7: Weld Scanning Techniques



To determine the proper scanning area for the weld, the inspector must first calculate the location of the sound beam in the test material. Using the refracted angle, beam index point and material thickness, the V-path and skip distance of the sound beam is found. These values are illustrated in Figure A8. Once they have been calculated, the inspector can identify the transducer locations on the surface of the material corresponding to the crown, sidewall, and root of the weld.



Surface Distance = Sin θ_R x Soundpath
Depth (1st Leg) = Cos θ_R x Soundpath
Depth (2nd Leg) = 2T - [Cos θ_R x Soundpath]

Figure A8: Angle Beam Setup Components

When a discontinuity is indicated by an echo returned from within the weld zone, it can then be analyzed for its surface distance and depth using angle beam inspection techniques. These values are illustrated in Figure A9. By thorough inspection, the size and type of discontinuity can be determined. A decision can then be made whether the weld is acceptable or unsatisfactory according to inspection codes or a manufacturer's minimum flaw size requirement.

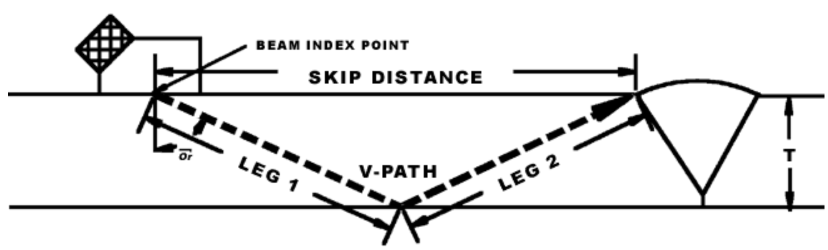
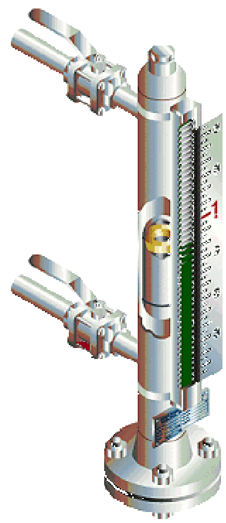


Figure A9: Reflector Components

Magnetic Liquid Level Gauge (Information from Kenco Engineering, www.kenco-eng.com)

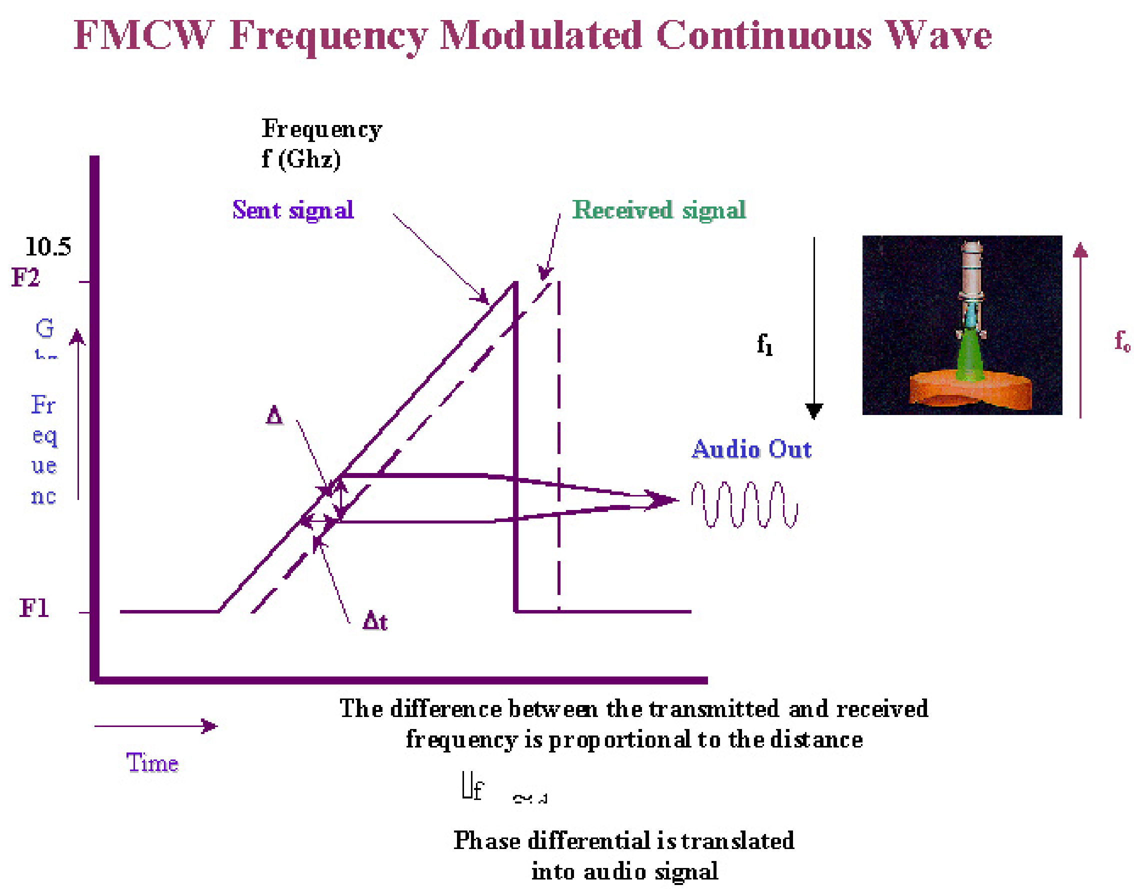
Magnetic liquid level indicators are used to determine the volume of liquid contained within a vessel. Magnetic level indicators eliminate the need for glass, so high pressure applications and hazardous locations are protected from the danger of a chemical spill due to glass failure.The Kenco Engineering magnetic level gauge utilizes three major components: the gauge housing chamber, the magnetic float and the magnetic flag assembly.The gauge housing chamber is mounted adjacent to the side of the vessel. It is constructed to withstand the same temperatures and pressures as the tank itself. It is equipped with the appropriate tank mounting connections for easy installation and to allow equalization of liquid level in tank and gauge.Inside the gauge housing chamber is the magnetic float, which contains radially-positioned magnets to provide a 360 degree magnetic-flux field. Each float is internally weighted based on specific gravity so that the liquid level in the gauge coincides with the location of the magnets inside the float.Attached to the gauge housing chamber is the magnetic flag assembly This is the visual means of liquid level indication. The assembly is made up a of a series of bi-colored fluorescent flags. As the magnetic float rises and falls with the liquid level in the gauge housing chamber, a magnet embedded in each flag reacts to the 360 degree magnetic flux of the float. This repelling magnetic force causes each flag to rotate 180 degrees. The flags below the magnetic flux of the float will flip to fluorescent green, while those flags above the float level remain steel gray.



θ_R = Refracted Angle
T = Materials Thickness

LEG = T/(Cos θ_R)
V-Path 2T/(Cos θ_R)
Skip Distance = 2T X Tan θ_R

Radar Level Gauges (Information from Thermo Measure Tech, www.thermo.com)
Radar level gauges use FMCW (Frequency Modulated Continuous Wave) technology. The radar instrument is placed inside a vessel at the apex. A microwave beam is continuously emitted with a modulating or changing frequency. The frequency range usually occurs between 9 Ghz and 11 Ghz. When the beam hits a liquid material it then bounces back to the instrument. The differential in frequency is directly proportional to the distance traveled. This



information is converted into a level of the liquid in the tank.
Advantages of Radar:

- Greater accuracy
- Electromagnetic waves aren't affected by temperature or atmosphere
- Tolerates higher pressure
- Non-intrusive sensor with isolation seal for sanitized and corrosive environments