FINAL REPORT

Task Order 1345
Feasibility of a Pilot Project, Gauging Devices

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Under:

GS-10F-0306P
Order Number 1345

Prepared for:

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

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June 30, 2006

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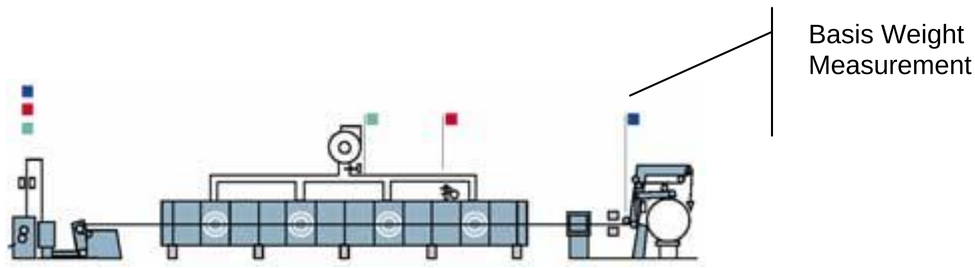
1 .0 Background and Rationale

In the pulp and paper industry (as well as plastics, film and rubber), weight of the sheet per unit area is an important characteristic. This is described by the term basis weight. It is very common to measure basis weight using fixed nuclear gauges based on interaction of beta particles with the material. These gauges make use of the fact that the range of β particles in a material depends on the energy of the electrons and the material density in which they move.

Frequently used commercially available β particle sources include Kr-85 (half-life of 10.73 y and maximum β energy of 672 keV) and Pm-147 (half-life of 2.62 y and maximum β energy of 225 keV). The detectors used are usually saturation ionization chambers filled with argon at 2 to 3 atmosphere pressure to increase their efficiency.

β particle backscatter is another nuclear technique used in the paper and film industry for this measurement. Assuming saturation thickness, the efficiency of β backscatter increases with the energy of the incident radiation and with the electron density of the material. Thus the best applications for these techniques are those in which a high atomic number material is laid on a much lower atomic number material. The radiation source in a backscatter gauge is a pure β emitter with an energy chosen to suit the application. Examples are Ni-63 (67 keV), Pm-147 (225 keV) and Tl-204 (763 keV).

In the paper industry, such devices are used to continuously monitor the paper as it travels at speeds up to 400 m/s. The output from these devices may be used to control the speed and inclination of the rollers and to ensure that the paper thickness always remains within the desired tolerance. In addition, microwave and infrared techniques are used to monitor and control the moisture level, thus ensuring that high quality paper is manufactured within tight tolerances, with a significant reduction of the use of materials and energy.



Schematic of paper mill

Regarding the number of nuclear devices in use; it is conceivable that every paper, plastic and film manufacturer uses fixed nuclear gauges in the production of these materials. The number of facilities numbers in the 1000's. The number of new gauges purchased each year by this industry segment is on the order of 100.

The objective of this Task Order was to identify relevant aspects of a potential partnership among the paper industry, gauge manufacturers, and a research institution involved in the pulp and paper industry, and provide recommendations for a pilot project that will facilitate the research and development, validation, and adaptation of alternative gauging devices for the determination of basis weight and thickness measurements in the pulp and paper industry.

2.0 Tasks

Trinity Engineering Associates conducted / participated in three tasks under this assignment to support the EPA. These tasks were: 1) Identify Potential Industry and Research Institution Partners; 2) Identify Technical Goals and Requirements; and 3) Contribute to an Implementation Plan for the EPA Pilot Project. In meeting the requirements of this Work Assignment, TEA was in a support role and was not involved in the development of (or decisions relative to) EPA policy, nor in any other activity that is an inherently Government function.

2.1 Identification of Potential Industry and Research Partners

TEA contacted a wide range of potential partners to determine appropriateness for collaboration and willingness to participate in the pilot project. Information regarding these contacts was coordinated with the Product Stewardship Institute (PSI) and the US EPA. PSI developed the final deliverable relative to partners for the collaboration.

Contacts made by TEA included the following.

Industry experts included:

Department of Paper Science and Engineering
Miami University

Department of Paper Engineering, Chemical Engineering, and Imaging
Western Michigan University

Institute of Paper Science and Technology www.ipst.edu/

Pulp and Paper Manufacturers' Association www.ppmausa.com/

Mohawk Paper www.mohawkpaper.com
Explanation of paper making process and use of quality sensors in the process

Review of industry information included these sources:

Globalspec http://sensors-transducers.globalspec.com
Web sensing & scanning systems. List of vendors of web (e.g. paper) measurement systems.

Polysort www.polysort.com
Listing of laboratory, test and measurement equipment (including basis weight gauges)

Honeywell www.acs.honeywell.com

Measurement products and sensors for the pulp and paper industries, including basis weight measurement

ADVANZ www.advanzgauge.com/
Manufacturer of measurement control systems for continuous web applications, including basis weight measurement

ATI Adaptive Technologies www.atigauge.com/
Gauges for measurement solutions, including beta and gamma gauges

Electronic Systems SPA www.electronicsystems.it
Manufacturer and supplier of quality control systems, including basis weight measurement

Invensys Process Systems www.invensysips.com
Process automation and advanced technologies, including non-nuclear basis weight measurement

NDC Infrared www.ndcinfrared.com/
Manufacturer and supplier of quality control sensors, including basis weight sensors

Oryx Systems www.oryxsystems.com/
Thickness gauges for measurement control

GE Panametrics www.gepower.com/dhtml/panametrics/en_us/index.jsp
Ultrasonic testing and measurement equipment, including thickness gauges

Analytical Technologies, LLC www.filmthickness.com/index.html
Non-contact, non-destructive thickness measurement (optics)

Paper Mills contacted included:

- Appleton Coated LLC
- Atlas Paper Mills
- Badger Paper Mills
- Burrows Paper Corporation
- Fox River Paper Company
- Georgia-Pacific Corporation
- International Paper
- Marcal Paper Mills, Inc.
- Mohawk Paper Mills
- Fraser Papers Inc
- Wausau Mosinee Paper Corporation
- Weyerhaeuser Company

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.

2.2 Identification of Technical Goals and Requirements

TEA supported the EPA in the determination of technical goals and requirements for a pilot project to develop alternative devices. TEA also provided support in the selection of alternative technologies that received further consideration for the pilot project.

Requirements were established relative to the following:

- the efficacy of the technology (i.e., its ability to perform successfully and reliably), with emphasis on innovation and extent of use for a particular application
- the expertise and experience of project team and the project plan with regards to the proposed technological innovation
- relative benefits and risks of the proposed technology compared with industrial gauges that utilize sealed radioactive sources
- the potential broader applicability of the proposed technology to in a variety of applications and industries

These were submitted to the EPA TOPO per the work order.

The following technologies were reviewed and evaluated to support the pilot project:

- Infrared
- X-Ray Backscatter and Transmission
- Low activity beta
- Laser caliper

Evaluation of the technologies was provided to the EPA TOPO per the work order.

2.3 Contribute to Implementation Plan for Pilot Project

TEA has contributed to the demonstration and validation of alternative gauges for the pulp and paper industry as directed by the TOPO. Specific activities and deliverables included in this task are enumerated below.

Activity	Deliverable	Date Provided
Evaluation of proposals for pilot project	Correspondence with TOPO	June 2005
Recommendations on outreach strategy	Correspondence with TOPO	November 2005
Development of advisory panel for pilot project – scope of responsibilities and composition of panel	Correspondence with TOPO	October 2005
Site visit to support pilot project	Letter evaluation	December 2005
Participate in Advisory Panel Discussions	Presentation materials for discussions	March 2006 and June 2006
Develop report on alternatives to radioactive devices	Report to TOPO	April 2006
Support presentation to NAS	Letter report to TOPO	June 2006

A copy of the report on alternatives to industrial gauging is provided in Appendix A.

3.0 Discussion on Pilot Project

Radioactive sealed sources are used by a wide variety of industries in a very large number of applications. This project focused on the identification of alternative technologies for the pulp and paper industry and the implementation of a pilot project to evaluate the potential for affecting change in use of gauges using sealed radioactive sources in that industry. The pilot project was intended to facilitate research and development, validation and adoption of alternative technologies. The pilot project has been fairly successful at facilitating R & D and validation of alternative technologies. Two distinct efforts are currently on-going that are proving successful in these phases of the project.

The time frame of the project has been insufficient to affect adoption of alternative technologies. A mature industry is not going to change practices over a one or two year period in less there are economic or regulatory drivers that necessitate such a change. Some of the reasons for not adopting new technologies include:

- 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
- Product standards and requirements that promote using sealed source methods

The process established by the EPA for broad participation in the pilot project will pay dividends over time. From the perspective of a technical consultant, the characteristics listed below have been beneficial to the goals of the project:

- Engaging a broad number of stakeholders in the discussion of specific applications appropriate for alternative technologies
- Conducting an open request for proposals for alternative technologies on very specific applications
- In-depth discussions with users of the technologies to identify barriers and opportunities
- Use of an advisory panel composed of individuals with diverse experience and expertise

The pilot project could be strengthened by:

1. Fuller engagement of professional groups and trade organizations relevant to the specific application (to better understand industry issues and opportunities)
2. Additional site visits to users of the applications (to better understand specificity of the application, characteristics of the application that make it more or less amenable to adoption of alternative technologies, and potential for success of alternative technology)
3. Implementing a long-term approach to the project (will not necessarily require more funds)

4.0 Recommendations for Future Efforts

Well logging is widely used in the oil industry for determining the composition of the area around a borehole. In nuclear well logging, a tool consisting of a neutron or gamma-ray source and one or more detectors is lowered into the borehole. The response of the instruments to radiation returning from around the borehole is an indication of the lithology, porosity, and fluid characteristics of the surrounding materials.

Through discussions with industry experts – both producers and support services companies – it is clear that there is a significant opportunity for alternative technologies in this industry. Specific reasons for this include:

- The amount of exploration is significant and is expected to be significant for some time
- While the nuclear devices work well, there exists a limited supply of these devices and the US is currently dependent on an unstable foreign supplier
- The regulatory climate is burdensome such that a coordinated effort that included broad stakeholder participation could result in a significantly improved environment of alternative technologies

Appendix A
Update on Alternative Technologies

Update on Use of Radioactive Materials for Commercial and Industrial Purposes

Background – Current Use of Radioactive Materials

The energy emitted through the process of radioactive decay has been utilized for literally hundreds of applications. Because of 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). In some instances, material that is naturally occurring is used to facilitate measurements.

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:

- Robust – are amenable to a variety of environments
- Reliable – while the detection of the emitted radiation can be sophisticated, the energy source is simple and can not fail
- 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

Advances in radioactive gauge technologies and measurement systems have mostly come about due to improvements in detector capabilities and increased sophistication of the processing of information gathered about the measurement parameter. Modern computer systems are able to use a measurement (density for example) and associated process parameters and provide significantly more information about the manufacture or production of an item than has been available until recently.

Common Applications of Radioactive Materials in Industry

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: Products / Services: Use of Sealed Sources: Environment: Type of Sources:	Manufacturing Numerous thickness of metal components, thickness of coatings, moisture content in manufactured products 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
Industry: Products / Services: Use of Sealed Sources: Environment: Type of Sources:	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 Gamma emitters; neutron sources (for level measurement)
Industry: Products / Services: Use of Sealed Sources: Environment: Type of Sources:	Construction Buildings, geophysical structures Moisture content, location of reinforcing bar (rebar) Ambient Gamma emitters, neutron sources - Am/Be, Pu/Be, Cf-252
Industry: Products / Services: Use of Sealed Sources: Environment: Type of Sources:	Mineral Processing measure levels of minerals in process streams density gauges, spectroscopy Ambient Gamma emitters such as Am-241, Co-57, Cs-137
Industry: Products / Services: Use of Sealed Sources: Environment: Type of Sources:	Coastal Engineering Measurement of environmental parameters Levels of sediments in rivers and estuaries, mobilization of sediment Ambient Gamma emitters such as Am-241, Co-60, Cs-137

Table 1. Industries Utilizing Radioactive Sealed Sources	
Industry:	Non Destructive Examination
Products / Services:	Radiography
Use of Sealed Sources:	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
Type of Sources:	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 / 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
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

Table 1. Industries Utilizing Radioactive Sealed Sources	
Industry: Products / Services: Use of Sealed Sources: Environment: Type of Sources:	Medical Care Syringes, surgical instruments, surgery consumables, pharmaceuticals Sterilization Ambient Gamma emitters, especially Co-60
Industry: Products / Services: Use of Sealed Sources: Environment: Type of Sources:	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 Ambient Gamma emitters, e.g. Am-241; Beta emitters such as Pr-147, Kr-85, Sr-90

Other Significant Uses of Radioactive Materials
Power Sources - Radioisotopes are used as power sources for applications requiring small amounts of portable energy, such as for remote weather stations and weather balloons, and navigation beacons and buoys.
Dust and static control – in recording industries and for labels applied to products

Table 2 provides a listing of the radioisotopes that are most commonly used along with the common uses of that isotope.

Table 2 Common Radioisotopes Used in Industry
(from US NRC "The Regulation and Use of Radioisotopes in Today's World)

Americum-241
Used in many smoke detectors for homes and businesses to measure levels of toxic lead in dried paint samples, to ensure uniform thickness in rolling processes like steel and paper production, and to help determine where oil wells should be drilled.

Cadmium-109
Used to analyze metal alloys for checking stock and scrap sorting.

Calcium-47
Important aid to biomedical researchers studying the cellular functions of bone formation in mammals.

Californium-252
Used to inspect airline luggage for hidden explosives, to gauge moisture content of soil in the road construction and building industries, and to measure the moisture of materials stored in soils.

Carbon-14
Major research tool. Helps in research to ensure that potential drugs are metabolized without forming harmful by-products. Used in biological research, agriculture, pollution control, and archeology.

Cesium-137
Used to treat cancerous tumors, to measure correct patient dosages of radioactive pharmaceuticals, to measure and control the liquid flow in oil pipelines, to tell researchers whether oil wells are plugged by sand, and to ensure the right fill level for packages of food, drugs, and other products. (The products in these packages do not become radioactive)

Chromium-51
Used in research in red blood cell survival studies.

Cobalt-57
Used as a tracer to diagnose pernicious anemia.

Cobalt-60
Used to sterilize surgical instruments, and to improve the safety and reliability of industrial fuel oil burners. Used in cancer treatment, food irradiation, gauges, and radiography.

Copper-67
When injected with monoclonal antibodies into a cancer patient, helps the antibodies bind to and destroy the tumor.

Curium-244
Used in mining to analyze material excavated from pits and slurries from drilling operations.

Gallium-67
Used in medical diagnosis.

Iodine-123
Widely used to diagnose thyroid disorders and other metabolic disorders including brain function.

Iodine-125
Major diagnostic tool used in clinical tests and to diagnose thyroid disorders. Also used in biomedical research.

Iodine-129
Used to check some radioactivity counters in in-vitro diagnostic testing laboratories.

Iodine-131
Used to treat thyroid disorders. (Former President George Bush and Mrs. Bush were both successfully treated for Graves' disease, a thyroid disease, with iodine-131).

Iridium-192
Used to test the integrity of pipeline welds, boilers and aircraft parts and in brachytherapy/tumor irradiation.

Iron-55
Used to analyze electroplating solutions and to detect the presence of sulphur in the air. Used in metabolism research.

Krypton-85
Used in indicator lights in appliances such as clothes washers and dryers, stereos, and coffee makers; used to gauge the thickness of thin plastics and sheet metal, rubber, textiles and paper, and to measure dust and pollutant levels.

Nickel-63
Used to detect explosives, and in voltage regulators and current surge protectors in electronic devices, and in electron capture detectors for gas chromatographs.

Phosphorus-32
Used in molecular biology and genetics research.

Phosphorus-33
Used in molecular biology and genetics research.

Plutonium-238
Has powered more than 20 NASA spacecraft since 1972.

Polonium-210
Reduces the static charge in production of photographic film and other matierals.

Promethium-147
Used in electric blanket thermostats, and to gauge thickness of thin plastics, thin sheet metal, rubber, textile and paper.

Radium-226
Makes lighting rods more effective.

Selenium-75
Used in protein studies in life science research.

Sodium-24
Used to locate leaks in industrial pipelines, and in oil well studies.

Strontium-85
Used to study bone formation and metabolism.

Sulphur-35
Used in survey meters by schools, the military and emergency management authorities. Also used in cigarette manufacturing sensors and medical treatment.

Technetium-99m
Used in genetics and molecular biology research. The most widely used radioactive pharmaceutical for diagnostic studies in nuclear medicine. Different chemical forms are used for brain, bone, liver, spleen, and kidney imaging and also for blood flow studies.

Thallium-201
Used in nuclear medicine from nuclear cardiology and tumor detection.

Thallium-204
Measures the dust and pollutant levels on filter paper, and gauges the thickness of plastics, sheet metal, rubber, textiles, and paper.

Thoriated Tungsten
Used in electric arc welding rods in construction, aircraft, petrochemical and food processing equipment industries. They produce easier starting, greater arc stability and less metal contamination.

Thorium-229
Helps fluorescent lights last longer.

Throium-230
Provides coloring and fluorescence in colored glazes and glassware.

Tritium
Major tool for biomedical research. Used in life science and drug metabolism studies to ensure the safety of potential new drugs, for self-luminous aircraft and commercial exit signs, for luminous dials, gauges and wrist watches, to produce luminous paint, and for geological prospecting and hydrology.

Uranium-234
Used in dental fixtures like crowns and dentures to provide a natural color and brightness.

Uranium-235
Fuel for nuclear power plants and naval nuclear propulsion systems, and used to produce fluorescent glassware, a variety of colored glazes, and wall tiles.

Xenon-133
Used in nuclear medicine for lung ventilation and blood flow studies.

Alternatives to Radioactive Sealed Sources

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.

Current Viable Technologies

Fixed gauges (non-portable) are designed for measurement or control of material density, flow, level, thickness, or weight. Nuclear 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).

In addition to nuclear gauges, 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.
Eddy Current	
Primary Uses	Thickness of metals; thickness of conductive coatings
Primary Advantages	Non-contact; not sensitive to environmental factors; does not need to be calibrated fro different metals / alloys
Primary Limitations	
Industries	
Optical (in addition to IR)	
Primary Uses	Thickness and color measurements
Primary Advantages	Non-contact; in-line or portable
Primary Limitations	
Industries	Coatings, thin films, laminating and extrusion

Well Logging

Well logging is a process used to determine the porosity of a formation and to assess whether a well has the potential to produce oil. This process uses both byproduct or special nuclear material tracers and sealed sources in 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.

Current Viable Technologies

Geophysical logs employ a variety of measurement techniques that fall under 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 in Table 4.

Table 4 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
Nuclear Magnetic Resonance	Porosity, permeability, reservoir quantification	Robust data generated	Costly, operator training to understand data	Oil, water

Technology	Examples of Primary Uses	Major Advantages	Major Limitations	Industries
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 adapted 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).

Industrial Radiography

Industrial radiography is a method of nondestructive inspection of materials for flaws and defects. It utilizes short wavelength electromagnetic radiation to penetrate various materials. Typically, a high energy X-ray machine or a gamma radiation source (e.g. Ir-192 and Co-60) is used as a source of photons, but neutrons can also be used. Radiation is supplied to one side of a material and the radiation emerging from the opposite side is detected and measured. Variations in the quantity and energy of radiation are used to determine thickness or composition.

Radiography is often used for the inspection of welds; both in a controlled setting and in the field. The measurement typically is in the form of a two-dimensional projection of the part onto the film. The image produced has varying densities according to the amount of radiation reaching each area of the film.

Radiography is one type of nondestructive examination. There are a wide range of technologies that are commercially available and used extensively. Radiography has the capability of being used as a portable inspection methodology without the need for an external power source. Other technologies have not been used as extensively in applications needing a portable measuring devise.

Current Viable Technologies
Table 5 summarizes the advantages and limitations of the technologies used for non destructive evaluation.

Alternatives to Portable Radiography
There are several technologies that have been used and that are being developed to perform the same function as a portable radiography camera. These technologies include:

- Ultrasound
- Portable x-ray
- Computer assisted tomography using x-ray sources

Table 5 Common Non-Destructive Examination Technologies

Radiography (gamma and x-ray)	
Uses	Identification of defects due to change in density, inclusions and variations in material properties.
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.
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.
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.
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.
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.
Major Advantages	Inexpensive; easy to use; portable.
Major Limitations	Limited to surface defects; not useful with porous materials or on rough surfaces. Easily affected by surface contaminants or conditions
Industries	Power generation; petrochemical; marine; aerospace; metalworking; welding.