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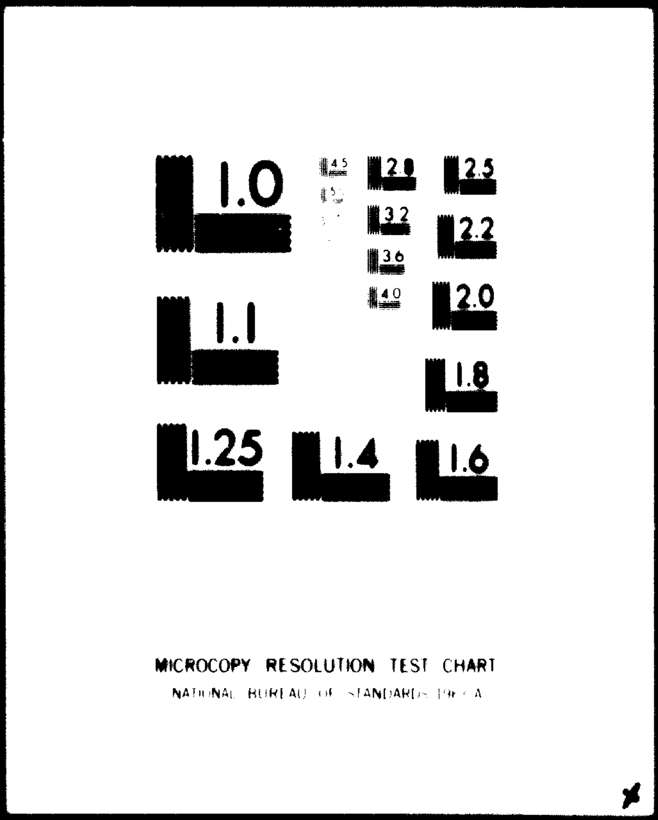
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RADIOISOTOPES AND RADIATION IN INDUSTRIAL DEVELOPMENT

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RADIOISOTOPES AND RADIATION IN INDUSTRIAL DEVELOPMENT

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1. INTRODUCTION

In the mid 1940's artificially produced radioactive isotopes became available in quantity. These materials, made in the first nuclear reactors, were eagerly awaited by rapidly growing groups of research workers which now had new tools to help solve long-existing problems. Because of their unique property of giving out radiation which could be detected and assessed remotely, radioactive isotopes were soon put to use as tracers, to simply follow the movement of objects or substances in such diverse fields as medicine, agriculture and industry. Crude electronic instrumentation based on simple Geiger-Müller counters was used to measure the radiation from these radioisotopes and new specialists, the nuclear chemist, the nuclear physicist and the nuclear engineer, evolved to verify the properties of their radiations. New discoveries were made and rapidly translated into practical applications.

The radioisotopes and their associated detection equipment were at this time largely in Government-controlled laboratories in a few countries, but the small groups of enthusiasts vigorously devoted themselves not only to understanding their new science, but also to educating and training other research workers. The general public on the other hand, largely through fear and ignorance by associating all things nuclear with the more dramatic and lethal aspects of atomic energy, was wary, critical and even obstructional of this new technology and to some extent this situation still pertains today. A great deal of time, effort and money was spent by Governments in educational campaigns and even now new films and publications appear which still attempt to explain to the layman the simplicity and safety involved in the correct use of the same radioisotope techniques which were developed 25 years ago.

Elaborate national and local regulations have been drawn up and implemented to ensure that the user of radioisotopes and radiation controls his "tools" in a responsible manner. These regulations are enforced by health authorities at both the national and local level. Scientists are now taught how to handle radioisotopes as part of their education and training. Internationally recommended regulations for the transport of radioisotopes exist as do regulations governing the exposure of radiation workers and the general public to the different types of radiation. All of these measures, designed after much consultation and with great care, operate successfully and effectively, with a minimum of interference to the user.

As a technology, the application of radioisotopes and radiation has experienced the benefit of Governmental support in both manpower and money since its inception. In diagnostic medicine and agriculture the techniques are well-established and rewarding. They are also in the hands of trained and experienced personnel. Industry, which has the most to gain from the use of these techniques, has not fully exploited them in spite of concerted attempts by those with vested interests to promote their advantages. Many theories have been expounded to explain this situation and many surveys and analyses have been made to assess the economic implications of the use of nuclear techniques in industry. There is no doubt that considerable savings in money, raw materials and time can be made through the introduction of some radioisotope techniques. Why then are these applications not more widespread?

As explained earlier, the design and development of industrial gauges, for example, was initially in the hands of research scientists, most of whom had little contact with industry and, as a result, little knowledge of real industrial conditions. The first radioisotope instruments installed in industry in 1949 were to measure the thickness of sheet material. These gauges were little more than laboratory instruments redesigned to meet a particular measuring problem and, as a result, they were prone to break down in the more exacting industrial environments. Gradually, the manufacture of these devices passed into the hands of more experienced engineers who constructed gauges which were reliable and which could be adapted to a particular process rather than vice versa. The presently available thickness gauges are reliable, accurate and, when necessary, sophisticated, employing the most advanced electronic and mechanical technology. As a result, their use is accepted as a routine method of thickness measurement and control in numerous industries. Other techniques have followed a similar pattern but some have suffered from the over-enthusiasm of their proponents and others have simply not been adapted to give the user the type of instrument he really requires.

On the industrial side, radioisotope usage is still treated largely as a specialist art instead of being just another technique at the disposal of the engineer. It is here that the developing countries have an advantage over the more industrially advanced nations. Large numbers of scientists and engineers of all disciplines have been given training in Universities and in Government-sponsored courses to enable them to judge the need for and advantages of radioisotope techniques when applied to a particular problem. Industry in these countries is in the hands of young technologists who do not have the traditional or inherited conservatism of some of their opposite numbers in the industrially developed countries. At the same time they have the benefit of being able to introduce well-proven and established techniques and instruments at an early stage.

As will be seen in the following chapters, some nuclear techniques are widespread in industrial practice. No attempt has been made to explain in depth the theory behind these techniques as this is well-documented elsewhere. Only those techniques which are routinely used and which are economically or technically viable are considered. Instruments and techniques which are still in the development stage or which are variations of a basic principle have been deliberately excluded as have those which are used only on a limited scale.

2. FUNCTIONS

2.1 Instrumentation

2.1.1 General.

Radioisotope instruments are used to determine:

(a) mass per unit area, or thickness of homogeneous materials such as steel, aluminium or copper or heterogeneous materials of constant composition such as plastics, paper or rubber;

(b) thickness of coatings on a dissimilar backing material such as zinc on steel;

(c) density of materials of constant thickness such as liquids or slurries in pipes;

(d) density of bulk materials such as concrete, rocks or soil;

(e) levels of fluids or solids in vessels or packages;

(f) elemental composition of some heterogeneous materials.

In addition, there are many applications where the same basic principles are applied, such as in flow meters, fire detectors, anemometers and position indicators.

All of these instruments consist of a source of radiation, a radiation detector and the associated electronics which make up the indicating unit. Radiation absorption, scattering, ionization or excitation phenomena are used to measure a range of physical properties. The radiation source and detector are either located on the same side of the material under investigation (backscatter) or on opposite sides (transmission), depending on the application.

The choice of radioisotope source and detector is determined by the particular application. Alpha and beta particle emitting sources and sources of electromagnetic (gamma or X-) radiation and neutrons are available in a very wide range of physical and chemical forms suitable for almost any application. Radiation detectors are Geiger-Müller counters, proportional counters, scintillation counters, ionization chambers and, in a few cases, solid state detectors made of Germanium (Li) or Silicon (Li). Detectors are selected because of their better response to the radiation being measured and radioisotope sources are chosen to meet the basic scientific requirements or measuring principle being used. Thus, whilst it is possible to use beta particle and electromagnetic radiation transmission to measure all the properties (a) to (f), gamma transmission is generally used for (c) and (e) and gamma backscatter for (d). Elemental analysis is accomplished mainly with low energy electromagnetic radiation but to a limited extent with beta particle absorption and backscatter. Coating thickness is measured by beta backscatter or X-ray fluorescence, the latter technique rapidly overtaking the former in most applications.

2.1.2 Mass per Unit Area or Thickness.

The measurement of mass per unit area of sheet materials is made by the transmission of alpha particles, beta particles and electromagnetic radiation and backscattering of beta particles and electromagnetic radiation. Alpha particles are used for thin materials (1-5 mg/cm^2), beta particles for most sheet materials (1-1000 mg/cm^2), bremsstrahlung radiation in the thickness range 0.05-5mm and gamma radiation on thick materials, such as steel, in the range 10-150 mm.

The attenuation of beta particles and electromagnetic radiation by material is a function of the thickness and density of the material, i.e. mass per unit area. If the density of the material is constant, the thickness can be measured directly after calibration. Measurement accuracy is usually better than 1% when using beta particle transmission except for very light weight (<1 mg/cm^2) materials when accuracies are about 2%. The most commonly used detectors for these systems are ionization chambers which have a continuous current output of about 10^{-10} amp. Presentation of the detector signal, after amplification, is usually done on a recorder or a deviation meter showing variations from a target thickness.

"C"and "O" frames which support source and detector on opposite sides of the sheet can be made sufficiently rigid to cover widths up to several metres. The movement of the source and detector can be programmed to scan the width of the sheet material continuously and to follow a pre-determined pattern with the facility of over-riding this programme to make measurements at any position across the sheet. Beta particle transmission gauges are the most commonly used for light-weight sheet material. However, many modern paper machines are more than 10 metres wide and to overcome the errors introduced by the distortion which occurs in long frames supporting the source and detector beta backscatter is used to measure mass per unit area. Source and detector are mounted side by side in an integral, light-weight measuring head which rides on the paper, also eliminating pass-line errors.

Similar mechanical systems are used in bremsstrahlung or gamma radiation transmission gauges which are used routinely to measure the thicknesses of metal sheets, either cold- or hot-rolled. A wide range of radioisotope sources of electromagnetic radiation is available, making it relatively easy to select the optimum radiation energy for a particular application. When only one side of the material is accessible, such as when inspecting pipe or vessel walls, gamma backscatter is used to measure thickness. The measuring head of simple, portable instruments is held against the surface of the material to be measured so that constant geometry is assured.

Prices for these instruments range from $ 500,- for a portable wall-thickness gauge to up to $ 500,000,- for a sophisticated transmission gauge capable of controlling a paper making machine. The majority of beta- and gamma-transmission measuring instruments, which simply indicate deviations from a target thickness, are in the $ 5,000,- to $ 20,000,- range, depending upon their origin, the use of modern electronic components and their reliability. The latter implies the attention given to design and quality control during manufacture.

2.1.3 Coating Thickness or Weight.

Beta-particle backscatter and radioisotope X-ray fluorescence are the preferred methods for measuring coating thickness. In some applications, dual beta particle transmission systems are used, measuring before and after application of the coating and obtaining the desired measurement by signal subtraction. For "light" or low Atomic Number materials, typical measuring problems are associated with adhesive or chemical coatings applied to paper. Beta-particle backscatter is used for these measurements providing there is a considerable difference in the Atomic Numbers of the backing and coating materials. Saturation backscatter must be obtained from the base material so that any change in beta-backscatter is due solely to change in coating thickness. For this reason these measurements are best performed against a backing of material of similar Atomic Number to the base. The mass per unit area range covered by this type of measuring system is 1-10 mg/cm^2 and instrument costs range between $ 2,000,- and $ 20,000,-.

The same principle has been widely used for measuring thin metal coatings on a steel base, such as electroplated tin or zinc on steel but it is rapidly being superceeded by the more practical X-ray fluorescence technique. Virtually mono-energetic radioisotope sources of low energy electromagnetic radiation are now commercially available and this allows the selection of a source just sufficiently energetic enough to excite characteristic radiation from the element to be measured. Thus, for zinc coatings on steel, it is possible to excite zinc X-rays and separate these either electronically or mechanically from those of iron. The intensity of fluorescent X-radiation increases with increasing concentration of an element and hence coating weight or thickness can be determined. For tin, paint or aluminium coatings on steel the absorption of iron X-rays in the coating layer is used to measure the coating thickness. This technique is an excellent example of radioisotope instrumentation solving a previously difficult on-line measuring problem and it has led to the development of a new generation of sophisticated thickness gauges. Costs range from $ 8,000,- for a laboratory instrument to $ 250,000,- for a double-sided on-line system suitable for process control.

2.1.4 Density.

Most density measurements are made on materials in pipes or other containers and the gamma transmission technique is most suitable for this purpose. The radioactive source, in a lead or heavy metal container, is mounted on the outside of the pipe with the radiation detector diametrically opposite. The detector is most commonly an ionization chamber and the radiation energy is usually chosen to be of sufficiently high energy so that its absorption by the material is a function of electron density only. Since source-detector separation is fixed, the resulting signal from the detector is a measure of the physical density of the material in the pipe, providing that the pipe is full. Application areas are numerous ranging from oil and slurries in pipelines to ice cream and other edible products in concentrating vessels. Installations in the $ 2,500,- to $ 10,000,- range are used to indicate deviations from a target density with an accuracy of ±0.1%.

Beta-particle transmission gauges are used on less dense and thinner materials and the absorption of this type of radiation is a function of electron density of the material. One of the largest application areas for radioisotope gauging is in cigarette manufacture and here beta transmission gauges are standard equipment, measuring tobacco packing density to better than the 0.25% deviation normally allowed in the mean cigarette weight. The small radioactive source and ionization chamber detector are built into modern cigarette-making machinery and costs are therefore difficult to ascertain, but $ 2,000,- to $ 5,000,- is an estimated range.

For bulk materials such as sugar, soil or coal a single probe instrument is preferred in which the radioactive source and radiation detector are mounted together. The probe can be inserted into the material to be measured either by simply pushing or by first drilling a bore-hole. When surrounded by sufficient material, gamma radiation from the source is scattered back to the detector to give a measure of density. These instruments, when used to measure compaction in road construction for example, are usually combined with a neutron gauge in which, under favourable conditions, fast neutrons are moderated by hydrogenous material to give a measure of moisture content. Prices of these portable instruments range from $ 1,500,- to $ 5,000,.

2.1.5 Level

The most widespread use of radioisotope instrumentation is the relatively simple level control or switch. In their simplest form these devices consist of a radioisotope source (usually a gamma emitter) and a radiation detector (either a Geiger-Müller counter or scintillation counter) which actuates a control relay when the radiation level either increases or decreases.

Their main use is to detect levels in large containers or vessels without contact with the material in the vessel and for this purpose gamma transmission techniques are almost exclusively employed. The gamma source and detector are arranged on the outside of thick-walled vessels so that the beam of radiation is interrupted when the material inside the vessel rises above a pre-determined level, as in coal bunkers or petroleum tanks for example. Source and detector arrangements can be varied to meet the requirements of particular applications and multiple source-detector systems are used to give continuous level indication over a limited range.

A package monitor is a special type of switch which is used to inspect the level of contents in packages moving along a conveyor belt. Beta-particle emitting sources are normally used for this application where the packages, such as beer cans or soap powder cartons, pass between the source and Geiger tube detector set at the lowest acceptable level for the contents. Packages with contents below this level allow more radiation to reach the detector, actuating a relay and thus rejecting the faulty package.

Prices range from $ 500,- for a simple on-off device to around $ 5,000,- for sophisticated continuous level control and package monitoring.

2.1.6 Analysis

All of the known radioisotope techniques have been applied to problems of analysis with varying degrees of success. Although alpha-, beta- and gamma backscattering are used routinely for a few applications, activation analysis and radioisotope X-ray fluorescence are the most significant techniques. Even neutron activation analysis, which is very widely used when access to a nuclear reactor is possible, has yet to be fully utilized in industrial systems but the development of sealed neutron tubes and the availability of more suitable radioisotope neutron sources promises to change this situation.

Radioisotope X-ray fluorescence is probably the most widespread radiation technique used for rapid non-destructive analysis, in spite of its late development. In theory it is possible to excite characteristic X-rays from each component of a multi-element system and so obtain a complete analysis since the intensity of the characteristic X-rays excited is proportional to the weight fraction of the element present. In practice, the technique is best suited to the analysis of simple systems such as alloys although ore assessment is the most widespread single application.

Simple portable instruments are available for $ 3,500,- but more stable and sophisticated laboratory instruments giving a direct reading of elemental concentration in times as short as 8 seconds cost from $ 8,000,- upwards.

2.2 Radiography

Radiography, using X- or gamma radiation is probably the most widespread non-destructive testing method. Other techniques, such as ultrasonic and magnetic flaw detection, are less specific and more difficult to use because the results obtained are significantly influenced by the experience of the operator. Whilst radiography is also dependent on operator technique, the end result is a record on film which, with relatively little training, can be rapidly interpreted.

Simply, the technique consists of interposing the object to be inspected between a source of X- or gamma radiation and a radiographic film to detect inhomogeneities. These nearly always consist of holes filled with air or gas such as cracks, cavities, porosities, laminations, etc. The amount of radiation passing through the object is a function of its mass per unit area so that thin sections or homogeneities show up as darker areas on the developed film. Sharp definition is obtained by mounting the radiation source at some distance from the object and the film close to the other side of the object.

The quality of radiographs from a well-focussed beam of mono-energetic X-rays is usually superior to that from a radioisotope source but for compactness and ease of operation radioisotope sources are indispensible. Whilst compact X-ray units are available, they need auxiliary power supplies if they are to be used with the convenience of radioisotope sources transported and used in shielding containers. Fairly specific application areas have now emerged for each technique with gamma radiography being used primarily in remote areas, small and inaccessible places and for the simultaneous exposure of a number of components. For these reasons X- and gamma radiography should not be compared but should more properly be considered complementary.

Although a number of artificially produced radioisotope sources are suitable for radiography, in practice three are used for most applications. These are Cobalt-60, Iridium-192 and Caesium-137. The first two can be used to cover steel thicknesses from 1 to 15 cm with the added advantage that they can be made with high specific activities so that the radiation source is very small. The advantage of Caesium-137 is its long half-life and medium radiation energy, making it economical for those applications where sharp definition is not the primary consideration.

$ 5,000,- to $ 15,000,- is sufficient to set up a modest gamma-radiography unit which could be utilized for a wide range of inspection purposes from pipelines to pressure vessels.

2.3 Radiation Processing

The interaction of radiation with matter results in the transfer of energy to the material. This energy manifests itself in the form of heat, in effecting changes in molecular structure or, in the case of living organisms, as an antimicrobial characteristic. The large quantities of artificially produced radioisotopes necessary to translate these effects into commercial processes are now available and several economically viable techniques have emerged. In some of these processes, where high dose rates are required and thin specimens have to be irradiated, particle accelerators are used. Because of their independence from external power supplies and the high penetration of their gamma radiation, Cobalt-60 and Caesium-137 are preferred for the majority of applications.

2.3.1 Radiation Sterilization.

Modern manufacturing techniques allow rapid and automated production of most medical devices. In most cases, when clean factory conditions are available, these techniques can be extended to include hermetic sealing of the product in foil or plastic. Under these conditions, a sterilizing process which is capable of reducing any bacteriological contamination on the pre-packed article is essential and radiation offers the only solution.

Simply, a radiation sterilization facility comprises a thick concrete shield inside which packages of medical products are conveyed past a high activity radioisotope source. The source is usually arranged in the form of rods making up a vertical plaque and the monorail conveyor carries sealed boxes about one cubic foot in volume on multiple horizontal passes around this source. After receiving a previously determined radiation dose which is guaranteed to eliminate or reduce to an acceptable level any bacterial contamination, the medical products remain "sterile" until their hermetic seal is broken.

Radiation sterilization is the most successful application of large radiation sources and it has led to the development of medical products, such as syringes, which can be used once and then disposed of, so reducing or even eliminating cross-infection.

A typical plant, capable of continuously processing 1.5×10^6 pounds per year of medical products costs about $ 500,000,-. Smaller batch facilities which can handle 200,000 pounds per year cost about $ 100,000,-.

2.3.2 Wood Plastic Composites.

Wood can be stabilized by replacing the water in the cell walls with a non-volatile, insoluble material so that the cell walls remain permanently swollen and shrinkage of the wood is reduced considerably. The molecular size of the impregnating material must be sufficiently small to allow penetration into the wood substance. For this reason, low molecular weight materials are essential for impregnating wood, which is not always highly permeable and varies in permeability both within and between species. Ideally, the requirement is for an impregnating material which will penetrate uniformly into the voids of the wood and which can then be made to harden and, if possible, form a chemical link with the cellulose in the fibres. One means of achieving this is by using radiation. Wood is impregnated with a variety of monomers which are subsequently polymerized with gamma radiation from a radioisotope source.

The specific properties obtained in wood-polymers depend upon the wood, the polymer and the loading (percent weight increase due to the polymer). A general division of physical properties which are better or worse in wood plastic composites than in the untreated wood is given below.

Better Than Original Wood	Worse Than Original Wood
Static bending	Nailability
Shear	
Hardness	
Flame retardancy	
Dimensional stability	
Decay resistance	
Compression strength	
Weatherability	
Machinability	
Aesthetic characteristics	
Abrasion resistance	
Acid resistance	
Insect resistance	
Impact strength.	

The cost of producing wood plastic composites varies considerably since timber and labour costs vary and it is extremely difficult to give accurate figures which can be generally applied. In Europe, one cubic metre of a soft wood treated with a vinylchloride/vinylacetate mixture costs less than, say, Japanese oak or Bangkok teak but has equal, or better, properties.

Other similar techniques are rapidly being developed although they have not yet reached commercial maturity. For example, plastic impregnated concrete can be made with a factor of 2.5 improvement in compression strength and reduced permeability by 98%.

2.3.3 Curing of Paints.

Polyester paints, when properly cured, give an excellent finish and are extremely durable. Unfortunately, these paints have been difficult to cure, have a limited shelf-life and have a "tacky" surface. Radiation curing eliminates all of these problems and several major paint companies have produced formulations that can be cured with low doses of radiation. Electron beams from particle accelerators are used in this process because of the thin paint films and the speed required to cure painted surfaces moving along production lines.

Compared to heat curing, where large ovens are required, painted plywood can be cured almost instantaneously in air at ambient temperatures. Since a chemical catalyst is not required, the paints can be stored and handled more easily and heat sensitive substrates can be coated without damage to the base material. Acrylic paints can be treated in a similar fashion and for plain surfaces the process competes most favourably with heat and chemical curing.

Electron beam machines for treating widths of flat sheet up to 1.5 metres can be purchased for less than $ 50,000,- but the process will really come into its own when complicated shapes, such as motor cars, can be painted and cured in this manner.

2.3.4 Textiles.

Cotton fabrics or mixtures of natural and synthetic fibres normally go through one or more finishing processes to modify their bulk or surface properties. The most common of these processes are crease recovery, flammability, dyeability, shrink resistance, stain and soil release and static dissipation. High energy radiation from either particle accelerators or radioisotope sources can be used to effect these changes either by crosslinking the polymer chains which make up the fibre or by graft copolymerization of monomers to these chains.

The two areas which have received the most attention by research workers are soil release and crease recovery or permanent-press and the latter process has operated commercially for at least four years using electron beam accelerators. Cotton fabrics have been treated chemically for a number of years to impart crease recovery but the chemical processes weaken the cotton fibres in the fabric so much that they have to be reinforced with synthetic fibres. The radiation processes on the other hand can be used to treat pure cotton fabrics by crosslinking the fibres after treatment with a monomer. Whilst the techniques involved in the radiation processes are well documented, very little is known about the process and economic details of the existing commercial facilities. Widely varying cost estimates have been made however and these range from $ 0.0001 and $ 0.01 per yard of material. Accelerators suitable for fabric treatment are available at a cost of $ 40,000,- upwards and a detailed cost estimate for a particular plant should be easily obtained.

2.4 Radioactive Tracers

The problem areas to which radioactive tracers can be applied are numerous and the techniques employed are almost equally numerous when considered in detail. Basically, however, tracing consists of labelling an object, substance, element or phase with an agent which behaves in the same manner as the matter being studied throughout its transport or transformation. Salts and dyes, for example, have been used for many years to follow water movement but radioisotopes, through their emission of radiation, offer several characteristics which make them eminently suitable as tracers.

The measurement of radiation can be made with extreme sensitivity so that the amount of tracer added to the process under investigation is so small that it does not interfere with the process. Furthermore, the measurement is absolutely specific if the tracer is the only radiation emitter in the system. In industrial systems, the radioisotope of choice is normally a gamma-emitter which means that instrumentation entirely outside pipes or vessels can be used. The basic instrumentation required is relatively inexpensive and the cost of the radioactive tracer is not normally a deterent. The fact that radioactively labelled compounds and objects are readily available to suit almost any process investigation makes the radioactive tracer a powerful tool in process investigations.

3. PRESENT WORLD STATUS

3.1 Instrumentation

Absolute information on the number of installations or applications of different techniques is difficult to obtain. However, by putting together details supplied by manufacturers of industrial nucleonic instrumentation and annual statistics compiled by national health or atomic energy authorities it is possible to make reliable estimates of the extent to which nuclear techniques have penetrated into industry.

There has been only one attempt to assess the world-wide use of radioisotope and radiation techniques in industry.(1) A survey instigated by the International Atomic Energy Agency in 1963 resulted in 25 countries submitting detailed information on the number of applications within different industries and, when possible, the economic advantages resulting from these applications. Of the countries participating in this survey, Japan is the only one which still collects and publishes an annual report of the number of radioisotope and radiation installations by both technique and industry (2). During the same period Japan's industrial growth has continued and the figures could represent a typical, balanced approach to the extent to which nuclear techniques might rationally be used in industry. However, it should be pointed out that for historical reasons, the laws governing the use of radioisotopes and radiation in Japan have been particularly stringent, so in considering the figures they should be perhaps more accurately viewed as minimum numbers which might be expected. They should therefore represent installations made only after careful consideration of economic and technical benefits. A comparison of the number of radioisotope gauging installations in March 1963 and March 1970 is given below:

	Thickness Gauges	Density Gauges	Level Gauges	Other	TOTAL
No.of devices 1963	124	28	146	72	370
No.of devices 1970	654	227	739	428	2,048

The figures for 1963 include the number of instruments permitted to be used for trial or adjustment by instrument manufacturers, so the increase in usage is actually more pronounced. Of the 428 unspecified types of instruments in 1970, more than half are either moisture gauges or gauges to measure the sulphur content of hydrocarbons.

(1) Industrial Radioisotope Economics, Technical Report Series No.40, IAEA, Vienna, 1965.

(2) Statistics on the Use of Radiation in Japan, Published by Japan Radioisotope Association, Tokyo.

Only older official figures are available for three other highly industrialized countries; France, the United Kingdom and the USSR.

	Thickness Gauges	Density Gauges	Level Gauges and Relays	Other	TOTAL
FRANCE (1961)	374	48	858	74	1,354
FRANCE (1966)	662	172	1,577	107	2,518
U.K. (1961)	718	982	300	30	2,030
U.K. (1966)	-	-	-	-	(4,000)*
USSR 1961-65	1,054	1,314	18,000	64	20,432

* Estimate.

More than 30 factories are producing nucleonic instruments for industrial purposes. By totalling the number of gauges produced by those companies prepared to release the information and comparing it with the old, but official, statistics from different countries, it is possible to deduce with reasonable certainty the minimum number at least of different classes of instruments.

There are certainly more than 40,000 thickness gauges in use in the manufacturing industries. The largest single user is the paper industry, followed by the plastics and metal industries. These gauges are now installed as a routine within these and other industries and the trend is towards more sophisticated systems with computer interpretation of the detector output with subsequent automatic process control. This figure includes coating thickness gauges which number only a few thousand, but the introduction of radioisotope X-ray fluorescence has opened up a large new market in the metal coating industries. The majority of these measurements were previously only possible through the use of destructive techniques and the next few years will see hundreds and possibly thousands of these new gauges in use in either a portable or an on-line form.

More than 20,000 density gauges are installed, principally in the tobacco, chemical, petroleum or construction industries. Beta transmission gauges are used almost exclusively in cigarette manufacture and are an integral part of the manufacturing machinery. Gamma transmission density gauges are normally mounted externally on pipelines or vessels to monitor and control liquid products or slurries. A large number of portable density gauges, operating on the principle of backscattered electromagnetic radiation, is used to measure the bulk density of soil when compaction in road or dam construction is necessary.

Close to 50,000 level gauges and switches can be accounted for. The main uses are on large vessels or hoppers where internally mounted devices would soon be damaged, and gamma transmission is exclusively employed. Level controls using beta particle absorption are widely used to monitor the contents of packaged materials such as drugs, foodstuffs, beverages and soap powders.

Elemental analysis by the preferential absorption of bremsstrahlung radiation is confined to the measurement of sulphur or lead in hydrocarbons. Radioisotope X-ray fluorescence is used primarily in mineral analysis, especially in ore assessment. Although these techniques are spreading, only about 1,500 instruments of these types are known to be routinely used.

3.2 Radiography

Gamma radiography is a widespread and accepted method in non-destructive testing. The technique is used almost exclusively for the examination of metal castings, machined metal parts and welds on pipelines or pressure vessels. It is therefore employed in circumstances where the future use of the object under inspection could be hazardous if flaws are present and it is almost always accompanied by a certificate of testing. In the mechanical engineering industry, where large numbers of parts are produced, it is an impossible task to inspect every product. Spot-checks or statistically applied schemes are used to maintain quality and gamma radiography is the standard test method.

The great majority of radiography sources are either Iridium-192 or Cobalt-60. The former has a half-life of only 70 days but the energy of its radiation makes it suitable for the examination of pipes and pressure vessels and it is the most favoured source. Cobalt-60 has a longer half-life, 5.3 years, and it is most suitable for thicker metal sections. Because of the need to replenish these sources after 2 or 3 half-lives, it is difficult to arrive at a figure for the total number in use at any one time. Neither the number of radiography sources produced nor the number of containers manufactured for these sources gives an accurate indication.

There are numerous private service companies carrying out contractual inspection of pipelines, vessels, etc., where an independent check is desirable. Central Governmental or semi-Governmental institutes perform a similar function. These organizations usually possess large numbers of radiographic sources which they use together with other non-destructive methods. On the other hand, there is an equally large number of single users; inspecting their own products. The extent of usage of the technique continues to expand, particularly as innovations are introduced, such as the crawler which moves remotely through pipelines making radiographs at each welded joint. For example, Japan reported that 168 radioisotope sources were used for radiography in 1963. This figure had increased to 514 in 1970. It seems reasonable, on the evidence available, to estimate that about 15,000 radiographic sources are currently in use.

3.3 Radiation Processing

Although several processes employ high doses of radiation from either radioisotopes or particle accelerators, only the radiation sterilization of medical products has won universal acceptance. Nearly 40 plants, ranging from little more than laboratory systems to very large facilities are treating packaged medical supplies for commercial purposes. The convenience of this technique and its economic justification have resulted in its acceptance as the method of sterilization for a wide range of products, particularly heat-sensitive articles, and the number of large plants is growing at a rate of about 10 per year. In countries such as Australia, the U.K. and the U.S.A., almost 100% of sutures and disposable syringes are sterilized in this manner and the technique is beginning to gain acceptance in developing countries. Little or no research is needed before applying this well-known technology to established manufacturing processes.

Large commercial facilities for the routine production of wood-plastic composites number only six, but there are many service facilities producing specific items on request. The commercial application of this technique is not straightforward as it depends on the raw materials available. Whilst the radiation part of the process is not difficult to handle, the impregnation techniques employed for different species of timber vary considerably and product uniformity is sometimes difficult to achieve. The range of suitable monomers is quite restricted and well-known but their availability and cost is an inhibiting factor in the exploitation of wood plastic composites. Even when locally produced monomers are used in the U.S.A., for example, they account for more than half the cost of the product. However, a combination of the use of fillers and pre-irradiation of the monomer promise to make the technique very attractive in the near future and its importance in the developing countries to produce construction materials should not be ignored.

Similarly, there are only three known commercial installations of particle accelerators to cure paint coatings on such things as wood, plastics and steel. The resulting product has a much tougher bond between the paint and the base material and this makes painted wood, say, ideally suited as an outdoor construction material. Rapidly cured paints on flat metal surfaces for household appliances such as refrigerators and washing machines certainly have advantages over the more usual heat curing techniques whilst the bonding achieved between acrylic paints and plastic substrates is unique to radiation processing. Commercial exploitation has been held back by the slow development of suitable paints and accelerators but several countries are looking to this technique as a means of leap-frogging traditional methods.

Table 3.3.1, although not complete, gives some idea of the range of radiation techniques already in use and in different stages of development. The up-grading of fabrics is done at the present time only in the U.S.A. although several other countries have developed similar techniques. The doping of semi-conductors is carried out routinely by about six of the major manufacturers and a variety of plastic films and foams in everyday use are given their enhanced properties by means of radiation. Numerous other techniques are in the pilot-plant stage and their ease of operation promises to make them attractive in the near future.

TABLE 3.3.1

SOME INDUSTRIAL CHEMICAL PROCESSES USING RADIATION

Chemical process	Location	Status	Source
Modification of polymer			
Polyethylene tape	General Electric (USA)	Commercial	Accelerator
	Sumitomo Electric (Japan) and several others	Commercial	Accelerator
Polyethylene film	W.R. Grace (USA) and several others	Commercial	Accelerator
Polyethylene oxide	Union Carbide (USA)	Designing plant	Co-60
Plastic molded parts	Raychem (USA)	Commercial	Accelerator
Polyethylene foam	Toyo Rayon	Commercial	Accelerator
	Sekisui Chemical (Japan)	Commercial	Accelerator
Polyethylene wire covering	Several (USA, France, Japan, USSR, etc.)	Commercial	Accelerator
Natural rubber latex	Saclay (France)	Pilot	Accelerator

TABLE 3.3.1 (cont'd)

Chemical process	Location	Status	Source
Graft copolymerization			
Polyethylene with acrylic acid	Dow Chemical (USA)	Pilot	Accelerator
Polyethylene with butadiene	Electrical Communication Laboratory (Japan)	Pilot	Co-60
Polyethylene with butadiene and styrene	Takasaki Research Establishment (Japan)	Pilot	Co-60
Polyvinylchloride with butadiene	Takasaki Research Establishment (Japan)	Pilot	Co-60
Polyvinylchloride with styrene	Dow Chemical (USA)	Pilot	Co-60
Polyester and cotton blend fabric with vinyl monomer	Deering-Milliken(USA)	Commercial	Accelerator
Polyester and cotton blend fabric with vinyl monomer	Burlington Industries (USA)	Commercial	Accelerator
Cellulosic fiber with styrene	Takasaki Research Establishment (Japan)	Pilot	Accelerator
Polyethylene films with vinyl monomers	Sekisui Chemical (Japan)	Pilot	Accelerator
Polymerization			
Ethylene	Brookhaven National Laboratory (USA)	Pilot	Co-60
	Takasaki Research Establishment (Jap.) and several others (USSR, France, Italy)	Pilot	Co-60
Ethylene, vinyl compounds	Farbwerke Hoechst (Fed.Rep.of Germany)	Experimental	Co-60
Trioxane	H.B.N.P.C. (France)	Pilot	X-rays
	Takasaki Research Establishment (Jap.)	Pilot	Accelerator

TABLE 3.3.1 (cont'd)

Chemical process	Location	Status	Source
Polymerization (cont'd)			
Coating, polyesters with styrene and acrylics	Radiation Dynamics (USA)	Commercial	Accelerator
Polyesters in glass fibre laminate	Ford Motor (USA)	Commercial	Accelerator
Wood-plastics combination	American Novawood (USA)	Commercial	Co-60
	Lockheed-Georgia (USA)	Pilot	Co-60
	Gamma Process (USA)	Commercial	Co-60
	Atlantic Richfield (USA)	Commercial	Co-60
	Radiation Machinery (USA)	Commercial	Co-60
	Nuclear Materials & Equipment (USA)	Commercial	Co-60
Chemicals			
Bromination of hydrocarbons (ethyl bromide)	Dow Chemical (USA)	Commercial	Co-60
Sulfoxidation of hydrocarbons (SAS)	ESSO Research (USA)	Pilot	Co-60
Chlorination of hydrocarbons	Takasaki Research Establishment (Jap.)	Pilot	Co-60
Chlorination of benzene (BHC)	Wantage - UKAEA	Experimental	Co-60
Oxidation of paraffin	(Rumania)	Industrial	Co-60
Oxidation of benzene in aqueous solution	Takasaki Research Establishment (Jap.)	Experimental	Co-60
Cracking of hydrocarbons	Institute of Petroleum and Chemical Synthesis (USSR)	Pilot	Accelerator

3.4 Radioactive Tracers

The exact number of tracer tests performed annually is impossible to define. The many techniques are in widespread use in industrial research laboratories, particularly in the chemical and metallurgical industries, and most of the large industrial concerns have either their own special department to employ the techniques or they have personnel trained in their use. National atomic energy organizations invariably have a group of people specializing in industrial tracing and giving a service to their country's industry. In the U.K., more than 200 industrial establishments use radioactive tracers for different investigations whilst the figure for Japan is greater than 100.

Only 10 years ago, almost each individual use of a radioactive tracer in a plant investigation was fully reported in the scientific literature. Nowadays this type of investigation is rarely publicized although the number of such tests has increased significantly. This can be attributed to the fact that the techniques are routine, well-known and accepted as such by the scientific and engineering community.

It is difficult to differentiate between research applications and process control applications although full-scale plant investigations have the biggest impact. These include studies of material transport, the determination of volumes and optimum mixing times, the location of leaks and obstructions and the dispersion of effluent in rivers, lakes or oceans. Although the successful exploitation of these techniques is a function of individual enthusiasm and competence, they make a significant contribution to plant efficiency and product quality throughout the world.

4. BRANCH INDUSTRIES

4.1 General

Radioisotope techniques are well established in all branches of industry and because of the large number of applications it is not possible to deal with every single technique applied in a particular industry. Gamma radiography could be, and perhaps is, applied to inspection problems in every industry and for this reason it is not dealt with in detail here. Its usage is necessary and obvious.

The proponents of radioisotope usage stress the economic advantages to be gained although intangible benefits such as improvements in product quality and increased safety from inspected products are probably more important. The basis for these economic benefits is as follows:

(a) Saving of raw material. Many sheet materials such as steel, aluminium, plastics, glass etc., are sold by area and both the manufacturer and consumer are interested in having products which conform to very close tolerances. Thickness gauges can perform the measurements which result in closer tolerance control and hence raw material savings. Paper, on the other hand, is sold by weight but a uniform product is very desirable and of indirect benefit to the manufacturer who might sell more because of this.

(b) Reduction of rejects. Out-of-tolerance products are in many cases unsaleable. In other cases they are sold cheaply or reprocessed. In starting a production run it is desirable to reach a target product thickness, say, in as short a time as possible. An accurate, rapid and continuous non-destructive measurement eliminates the need for time-consuming sampling.

(c) Reduced labour costs. Better product control and process efficiency increases output per man-hour. Automatic process control can also reduce manpower requirements.

(d) Reduction in plant "down-time". Measurements performed from the outside of pipes or vessels eliminates or reduces to an absolute minimum the necessity of shutting down a continuously operating plant to trace faults.

The benefits above are not exclusive to radioactive isotope applications. With the exception of (d) they apply to almost all instruments and processes. They should be borne in mind when considering the impact of radioisotope and radiation techniques on different industries.

The potential user will probably benefit most by learning of the different applications within his own industry. A classification based on industry has therefore been used with particular emphasis on the manufacturing industries. Table 4.1.1 summarizes the most common applications of radioisotope instruments in the different industries whilst Table 4.1.2 covers radioactive tracer applications.

TABLE 4.1.1

APPLICATIONS OF RADIOISOTOPE INSTRUMENTS ACCORDING TO INDUSTRY

(Cameron, J.F., Industrial Radioisotope Economics, Technical Report Series No.40, IAEA Vienna, 1965 - updated)

Industry	Type of gauge	Applications
Agriculture	T	Mass per unit area of leaves in studies of water economy and balance in plants
Forestry and fishing	D	Silage; standing trees and structural timbers; vegetable products; permeability measurements of unsaturated columns of soil in the laboratory; density variations in cores from trees and in extraction of resin; control of moisture content of veneers
	L	Grain level in silos and wells
	A	Moisture content of grain and living trees; density-moisture gauges in studies of water balance; water storage capacities of soils; evapotranspiration; effect of crops on moisture profile; effects of fertilizer, soil composition and irrigation on crop yields; water movement and irrigation practice
Mining and quarrying	T	Gamma backscatter gauge to measure the thickness of residual coal layer on floor and roof during automatic coal cutting
	D	Slurries in ore processing plants and in grinding mills. Transport of coal, ores and sand by hydraulic, pneumatic and conveyor-belt systems. Gamma backscatter gauges are in use to obtain inventory of coal stocks
	L	Switches for mine cars, hoppers, conveyor belts, storage bins. Counting and controlling movement of wagons
	A	Coal-ash measurement for washery control and coal blending operations; analysis of ores in mining and processing. Analysis of mine gases

T = thickness and mass per unit area; D = density; L = level (including package monitors and switches); A = analysis and coating thickness (including moisture); M = miscellaneous (pressure gauges, torquemeters, etc.)

TABLE 4.1.1 (cont'd)

Industry	Type of gauge	Applications
Manufacturing industries		
Food and beverages	T	Foods in sheet form such as dough for biscuits and cakes before baking, chocolate, cheese, meat products, chewing gum, etc.
	D	Liquid foods in evaporators (fish, meat, fruit juice, tomato paste, syrup, condensed milk), raw washed sugar in melting vessels, sugar solution, milk of lime; fat content of ice cream; mass flow of, for example, sugar
	L	Package monitors for controlling contents (soup, meat, beans, coffee, beer) of cans, bottles, packets; counting containers
		Level gauges on silos, hoppers, storage vessels, process vessels, e.g. limestone and coke in lime for sugar refining; chemicals used in processing foods; grain, sugar beet, separation of fat from protein; evaporated grain syrup (whisky manufacture)
	A	Moisture content of lactose; ^{40}K as indication of lean meat content of carcases. Analysis of foods
Tobacco	D	Monitoring and controlling tobacco packing in cigarettes
Textiles	T	Control of coating and impregnation processes in production of cellulose fabrics, tufted carpets, leathercloth, tyre fabric, artificial leather, linoleum, adhesive and abrasive cloth. Control of warpknit fabrics in heat setting; thread mass per unit length; pick-up of moisture and extent of drying; wear of fabrics and garments
	D	Polymer solutions and synthetic yarn solutions before spinning
	L	Contents of process vessels, e.g. viscose fabric in dissolvers; fabric in steam chambers

TABLE 4.1.1 (cont'd)

Industry	Type of gauge	Applications
Wood and cork	T	Plywood, chipboard, veneers, moisture and resin content of wood
Paper and paper products	T	Paper of all qualities and thicknesses; paperboard, pulp; "bone-dry" weight of paper when combined with a dielectric gauge; studies of paper formation. Control of coating and impregnation processes, e.g. polyethylene on paper, gummed paper, laminated plastics
	D	Process fluids including lacquer and slurries of calcium hydroxide, clay, clay-starch and lime. Pulp at the input of a paper-making machine
	L	Storage and process vessels, e.g. wood chips in preheaters; Pulp and chlorine in bleaching towers
	A	Paper leaching
Printing, publishing and allied industries	A	Thickness of bi-metallic casts for offset printing, stereotypes and printing plates; thickness of ink and coatings on paper .
Rubber products	T	Rubber sheet, foam rubber. Rubber sheet on calenders; rubber coated or impregnated material such as tyre cords, floor covering; tyre wear
	D	Latex solution used to make foam rubber
	L	Products and processed materials in storage; transport and process vessels
Chemicals and chemical products	T	Plastic film from extruders; plastic-coated paper and fabrics; laminated products; wall thickness of plastic tubes and bottles; wall thickness of pipes and tanks, in chemical plant

TABLE 4.1.1 (cont'd)

Industry	Type of gauge	Applications
Chemicals and chemical products (cont'd)	D	Many products and process solutions such as milk of lime, hot brine, organic materials, acids, alkalies, detergents; to control solvent extraction, blending, distillation, evaporation and the input to spray dryers
	L	Level gauges on many product and process materials (e.g. acids, carbon-dioxide, sulphur dioxide, methanol, ammonia, asphalt, coal, coke, lime, cement, plastics, catalysts) in storage and process vessels; checking operation of distillation columns. Package monitors on products such as soap powder, detergents, aspirins, toothpaste, cosmetics
	A	Moisture content of products such as detergents; chlorine content of chlorinated hydrocarbons; potassium content of fertilizers; resin to glass radio of glass-epoxy materials; concentration of uranium and plutonium in solution
Products of petroleum and coal	T	Asphalt impregnated products (roofing paper and shingles)
	D	Interface detection in pipeline pumping operations; catalyst in cracking units; amount of catalyst in oil; fluidized catalytic processes
	L	Coke level in continuous coking unit; interface location (e.g. kerosene to water); alignment of coke guide and coke car when pushing coke from ovens; hydrocarbons on trays in distillation columns; level of butane and propane in cylinders; hot oil in melting tanks; many other raw materials and products in storage and process vessels
	A	S, Co, Pb, N, O and Cl and F content and carbon/hydrogen ratio of petroleum products; boron in boron compounds, moisture content

TABLE 4.1.1 (cont'd)

Industry	Type of gauge	Applications
Non-metallic mineral products	T	Paper and textiles coated with abrasives; glass sheet; glass and asbestos fibres; asbestos-cement sheet; slate; selection of refractory bricks
	D	Sand, lime, cement; asbestos-cement slurries used in making pipes and shingles; lime-mud slurries feeding to lime kilns; clay slurries in cement manufacture; refractory bricks
	L	Molten glass in furnaces; silt in silt basins; sand, clay, cement; switches control cutting of glass sheets
	A	Glass/resin ratio in fibre glass; boron, potassium, lead, selenium, in glasses; boron in a variety of forms; potassium in ores
Basic metals	T	Pipes in ingots; hot- and cold-rolled sheet metal, tubes and rods; steel sorting; wear of furnace walls; wall thickness of pipes, tanks
	D	Powdered and slurried ores in processing plant
	L	Charge in cupola of blast furnaces; liquid metal in crucibles and moulds; load level in electrothermal kilns and furnaces; dust in electrostatic precipitators; coal, coke and ores in storage bunkers, hoppers and process vessels
	A	Elemental composition of metallic ores and furnace melts; moisture content of foundry sand, ores for sintering, blast-furnace coke; composition of exhaust gases from furnaces
	N	Density and temperature of exhaust gases

TABLE 4.1.1 (cont'd)

Industry	Type of gauge	Applications
Metal products	T	Coated and laminated metal products; bolts, collapsible tubes
	D	Detonating fuse
	L	Alignment of critical parts in ammunition
Machinery	T	Sheet material used in machinery such as strip metal, coated and impregnated papers and textiles, rubber and plastic sheet; condenser paper, porous rubber sheet and plates for batteries
	D	Rubber latex; sulphuric acid for batteries
	L	See basic metals
	A	Thickness of coatings or platings on components
Transport equipment	T	Sorting of sheet materials used in transport equipment such as steel for car bodies and ships hulls, leather cloth and other plastics for upholstery and tubes; plastic-coated radomes; thickness of cooling passages in turbines; engine wear research; wear of missile nose cones
	D	Products used in transport equipment
	A	Products used in transport equipment, e.g. S and Pb in H/C, metals
	M	Tachometer; altimeters; rotor-stator movement; location of tools
Miscellaneous	T	Photographic emulsion; photographic base paper; coating of precious metal in jewellery

TABLE 4.1.1 (cont'd)

Industry	Type of gauge	Applications
Construction	D	Suction dredging; asphalt; cement-stabilized soils; backfilling of trenches; concrete; location of reinforcing bars; evaluation of efficiency of concrete vibrators and control optimum vibration time; inspection of hollow concrete columns; fluidized coal
	L	Filling of wagons and tank cars; sand and cement in hoppers, mixers, crushers, furnaces
	A	Soil density and moisture gauges in constructing buildings, dams, roads, airfields; concrete
Electricity gas, water and sanitary services	T	Pipes, boiler tubes, hoppers; soot deposition
	D	Water content of snow; sewage sludge; mass flow of coal, coke; research on steam/water ratios; coal in stockpiles
	L	Blockages in ducts conveying powdered coal to furnaces; coal and coke in hoppers, wagons, conveyor belts; water in boilers
	A	Ash content of coal in furnace feeds
	M	Clearance between turbine blades; direction and velocity of flow in boiler tubes; location of water and gas leaks
Community services	D	Suspended sediment concentration and density of sediment deposited in oceans, lakes and dams
	A	Ancient coins, relics; mineral content of bone
	M	Altimeters
Transport storage and communication	D	Suction dredging
	M	Control of trains

TABLE 4.1.2

APPLICATIONS OF RADIOACTIVE TRACERS ACCORDING TO INDUSTRY
(Beswick, C.K., Radioisotope Tracers in Industry and Geophysics, STI/PUB/142, IAEA, Vienna, 1967)

Industry	Type of application	Applications
Agriculture, forestry and fishing	MT	Flow rates in irrigation studies; water movement and water balance studies; evapo-transpiration rates; effects of fertilizer, soil composition and irrigation on crop yields; pollen movement
	Vol.	Water storage capacity of soils
	LD	Irrigation canals and pipes
	ED	Fish waste in rivers and seas
	V	Air movement during hay drying
Mining and quarrying	MT	Velocity of solids in suspension; flotation studies in mineral processing
	M	Homogenization of dry materials
	LD	Water seepage in mines; underground gasification
	V	Air movement in mines
	L	Identifying mine cars; location of unexploded charges
	W	Pipelines in hydrotransportation; lubricant and machine component studies; grinding balls
Food and beverages	MT	Washing efficiency studies; transfer of contaminants and additives from wrappings, tins, etc.; flow patterns in sugar subsiders
	M	Efficiency of food mixers; distribution of vitamins, fats, additives and minor constituents in foodstuffs

MT = material transport; M = mixing studies; Vol. = determination of volume; LD = leak detection; ED = effluent dispersion; V = ventilation; L = labelling; W = wear and corrosion.

TABLE 4.1.2 (cont'd)

Industry	Type of application	Applications
Food and beverages (cont'd)	Vol.	Sucrose content of sugar beet; water content of food pulps
	LD	Storage tanks for beer and wine
	ED	Factory waste in rivers and seas
	V	Air movement in storage rooms and factories; air filter testing
	L	Identification of wines by activable tracers
Tobacco	M	Saucing efficiency in raw tobacco preparation
	V	Air movement in storage rooms
Textiles	MT	Residence times of fibres and viscose; washing efficiency studies; flow patterns in process vessels
	M	Dye and colour distribution studies; distribution of lubricants on artificial silk, nylon and rayon; distribution of wool fibres during carding
	W	Wear of fibres
Wood and cork	MT	Impregnation studies with fungicides
	M	Distribution of glue in laminates
	W	Wear of wood-cutting tools
Pulp, paper and paper products	MT	Flow rate of water, cooking liquors, pulp, chemicals, effluent and fibres; movement of chips in continuous digesters; concentration dynamics in bleaching towers; flow patterns in process vessels and on paper machines

TABLE 4.1.2 (cont'd)

Industry	Type of application	Applications
Pulp, paper and paper products (cont'd)	M	Fibre distribution studies
	ED	Waste dilution studies
	W	Abrasiveness of filler and fibrous materials, e.g. asbestos
Printing, publishing and applied industries	MT	Transfer of printing ink
	M	Penetration and distribution of printing ink
Rubber products	MT	Residence times and flow patterns in extruders; permeability of gases and liquids through plastic and vulcanized materials
	M	Mixing of carbon black, zinc oxide and other pigments and fillers and distribution in final products by using autoradiography
	W	Tyre wear
Chemicals and chemical products	MT	Flow rates, flow patterns and retention times of gases, liquids and solids; catalyst loss, efficiency and poisoning; carry-over and re-circulation in process vessels.
	M	Mixing and blending of gases, liquids and solids
	Vol.	Cooling water; gases and liquids in circulating systems
Products of petroleum and coal	LD	Heat exchangers, double-walled process vessels, underground distribution lines, pressurized containers during storage
	ED	Dilution of wastes in rivers and seas
	L	Go-devil location
	W	Corrosion of tanks and process vessels

TABLE 4.1.2 (cont'd)

Industry	Type of application	Applications
Non-metallic mineral products	MT	Retention, distribution, recirculation and flow patterns in rotary kilns for cement; deposition of fuel and in rotary kilns; origin of inclusions in glass; flow patterns in glass furnaces and tanks
	M	Portland cement concrete and bituminous concrete; additives in concrete
	L	Concrete for particular mix identification
	W	Grinding balls in cement mills; refractory linings in glass furnaces; corrosion of glass
Basic metals	MT	Movement of charges in blast furnaces; gas velocity and flow patterns in blast furnaces; flow rates and flow patterns of molten metals; liquid-solid interface studies; origin of inclusions, decomposition studies of ores; exchange reaction studies, e.g. iron between slag and metal
	M	Distribution of alloying components; elements distribution studies, e.g. tungsten and cobalt in steel
	Vol.	Slag and metal melts
	L	Special melts
Metal products	MT	Flow patterns in aluminium castings; plating studies
	L	Joints in wire drawing
	W	Corrosion of tanks, etc.
Machinery	MT	Rate of build-up of deposits and combustion efficiency in internal combustion engines; flow rates in cooling systems; filter efficiency for gases and aerosols

TABLE 4.1.2 (cont'd)

Industry	Type of application	Applications
Machinery (cont'd)	L	Machine parts, e.g.turbine blades
	W	Machine parts, e.g. gears, bearings, pistons, dies and cutting tools
Transport equipment	MT	Lubrication studies in gear boxes, railways and engines; engine deposit studies; fuel combustion and distribution studies; flow rates of fuel in aircraft
	M	Blending of liquid and solid fuels
	LD	Fuel and gas leaks in automobiles and aircraft
	V	Air movement in railway cars, automobiles and aircraft
	L	Components in aircraft assembly
Miscellaneous	MT	Distribution of cement and asphalt injections
	M	Concrete, asphalt and additives
	LD	Water seepage in dams and buildings; newly laid water mains
	L	Buried survey stakes
	W	Brick and fireclay
Electricity, gas, water and sanitary services	MT	Turbine rating; flow rates of gas, steam, water, sewage and solids; efficiency of liquor scribbers; settling tank studies, e.g. retention times of sewage sludge, mineral carry-over in steam in boilers
	LD	Reservoirs; dams; gas and water mains; underground gasification systems; pressurized cables
	ED	Sewage pollution studies in rivers and seas
	W	Turbine blades

TABLE 4.1.2 (cont'd)

Industry	Type of application	Applications
Community services	MT	Efficiency of filters, e.g. gas masks, bacteria filters in industry
	ED	Distribution of stack gases and dust
	V	Air movement in hospitals, libraries, etc.
	L	Criminal investigations, e.g. finger prints
Transport, storage and communication	LD	Underwater repeater station; pressurized telephone cables
	V	Air movement in store rooms and refrigerators

4.2 Mining and Quarrying

The efficient exploration, extraction and processing of mineral orês is desirable as these natural resources, when they are available, usually make a significant contribution to the national economy. Nuclear techniques contribute mostly at the exploration stage where they have been used for many years in the oil industry. The same techniques are now spreading to mineral prospecting and it can be safely predicted that they will eventually bring the same economic advantages. Although most of these applications are in borehole logging, many investigations are connected with mine safety and efficiency and should not be ignored.

The safest way of obtaining information on mineral deposits is by extracting and studying a core taken from a borehole. This is an expensive and time consuming practice and sufficient and similar information can be obtained in many cases by lowering various types of nuclear instruments down the borehole. These instruments provide information on the depths of deposits, their extent and in the case of oil and gas they can identify productive zones. They measure density, porosity, water content and the thickness of different strata. Together with other non-nuclear logs an almost complete picture of sub-surface conditions can be obtained. Borehole activation analysis and radioisotope X-ray fluorescence analysis instruments are now in use so that remote and instantaneous deposit evaluation is possible. It is generally accepted that these techniques have reduced by at least a factor of five the number of boreholes needed to evaluate a deposit. As some boreholes cost many hundreds of thousands of dollars to drill this represents a very significant saving.

In coal mining in the U.K., continuously moving mechanical miners are used to remove coal rapidly. A gamma-backscatter device is built into these miners to keep the cutting surface in the coal seam and at the same time leave the minimum amount of coal behind. This ensures that the cutting blades are not blunted, that coal washery efficiency is not impaired by the presence of large quantities of rock and that sufficient coal is left behind to support the roof.

In underground ore handling, loading and transport operations can cause serious bottlenecks in the confined spaces of a mine unless they are properly controlled. Level switches mounted on mine cars, hoppers and conveyor belts are widely used to remotely regulate these operations and one mine in the USSR is reported to employ 400 such devices. Again, the economic advantages are obvious but such systems are only justified in large, automated operations.

On the other hand, the rapid evaluation of ore is a desirable facility in any mining or exploration operation. Portable radioisotope X-ray fluorescence gauges are used routinely for this purpose. In Zambia and Poland such instruments are used underground to evaluate copper deposits. In the U.K. a similar type of instrument has helped in the re-opening of abandoned tin mines. One exploration company reports that the use of this type of instrument has reduced from 300 to 10 per week the number of samples it flies out of remote areas.

In mineral benefication, rapid analysis is essential if the processing plant is to be optimized and a uniform grade of product assured. Nuclear techniques have made continuous on-line analysis at reasonable cost and, as a result, automatic control of processing operations will soon be routine.

In concentration plants using gravity feed, a steady uniform rate of feed is essential for the efficient operation of tables, jigs and spirals. Erratic feed conditions result in a lower quality of the final product. In flotation or leaching plants, correct feed control allows the consumption of reagent to be kept to a minimum. A more uniform product, a more efficient separation and a minimum of recycling are achieved through the use of gamma density gauges.

4.3 Food and Beverages

One of the earliest reported savings in the food industry was from the use of the radioisotope dilution technique to measure vitamin B_{12} contents. Although the alternative method, a microbiological technique, cost about the same per test it was far less accurate. A producer of animal food claimed to have reduced the annual number of determinations in his plant by a factor of 10, thus saving more than $ 500,000,-. A smaller company saved $ 21,000,- per year. The same technique when applied to the measurement of vitamin D saved another manufacturer $ 40,000,- per year. This technique is now standard throughout the food industry.

Thickness gauges are used to ensure the uniformity of products in sheet form such as biscuits, chewing gum, chocolate, etc. Apart from regularizing the appearance of these products, uniform thickness is essential if modern packaging techniques are employed.

Similarly, consumer confidence is preserved if food or beverage containers are ensured of having the correct level of filling. Package monitors are used extensively for this purpose on production lines and level gauges are used to control the contents of hoppers, silos and storage vessels.

Gamma density gauges are widely used to ensure an equal weight of powdered products, such as agglomerated milk solids, in containers. Since the bulk density of these products varies considerably it is essential that packages should be filled on a weight rather than a volume basis. The same type of gauge is used to control the output feed rate from evaporators to maintain a constant solids content in such products as tomato paste, concentrated fruit juice, condensed milk and meat extract.

In baby meat the fat content should not exceed 5% of the total mass and reduction is carried out by centrifuging the hot meat. As the fat content decreases, the density increases. A density gauge is used to determine when all but 5% of the fat has been removed.

Whilst all of these techniques give considerable advantages to the manufacturer in allowing him to meet specifications with the minimum of excess, perhaps as important is the guaranteed uniformity of product which the customer gets.

4.4 Tobacco

A modern cigarette making machine produces up to 1,500 cigarettes per minute. The satisfactory operation of such a machine, so as to produce cigarettes of uniform weight, involves the feeding and proper packaging of about 1.5 kg/min. and the detection of non-standard products requires a detector with a very fast response. Dielectric gauges are used to measure the moisture content of the bulk tobacco and, together with beta-gauges, these ensure a uniform dry weight.

Tobacco itself is a very cheap raw material but some countries put a heavy tax on the tobacco rather than the final packet of cigarettes. In these cases it is extremely advantageous for the manufacturer to reduce its consumption of raw material to an absolute minimum whilst still meeting packaging demands. In other cases, the manufacturer wishes to produce a homogeneous, well-filled cigarette to satisfy customer requirements. In either case the beta gauge can perform the desired measurement and is fitted to modern cigarette making machines as a routine.

Enormous secrecy surrounds all aspects of the cigarette industry and economic data is difficult to obtain. One report has suggested that in the USA the cigarette industry saves $ 50,000,000,- from the use of these gauges alone but this figure is difficult to substantiate.

4.5 Textiles

The most widespread nuclear technique in the textile industry is the use of the beta thickness gauge to measure and control the mass per unit area of fabrics and coatings applied to them.

The tension applied to warp-knitted fabrics during the heat setting process determines the uniformity of the final product, e.g. cotton webbing, coarse linen and ribbon. Beta transmission gauges ensure optimum conditions in dyeing and finishing operations.

Coating materials are usually applied to fabrics by drawing them through a bath after which the take-up is controlled by passing the fabric through squeeze rollers. By using differential beta transmission gauges to measure both the treated and untreated fabric, the amount of coating material can be deduced and the information used to control the gap between the squeeze rollers. This type of measurement can be applied with equal success to both large and small factories. The economics of these processes have been studied in France and several examples can be quoted.

One large plant producing 4 million metres a year of PVC coated textiles installed seven thickness gauges and as a result saved about 2% of the raw material previously used. The seven gauges were amortized in six months. A smaller company used two gauges in a similar application and amortized them in one month. In the Netherlands, a small factory claims that savings of 25-50 g PVC/m^2 are possible. Cost benefit ratios of 1:20 and even 1:50 are common in these applications.

The first commercial plant for radiation sterilization was built in Australia in 1960. Imported goat hair was, and still is, sterilized to eliminate possible contamination from anthrax spores before the hair was made up into tufted carpet. The carpet manufacturing process itself involves compressing the goat hair on to a rubber backing and beta gauges are used to control the product thickness and uniformity. These gauges were amortized in just over two months as a result of raw material and scrap saving.

Most tyre callenders used for applying body stock to dipped cord fabric are controlled with beta gauges. Apart from raw material savings which cover the cost of the gauge in about six months, more uniform and hence safer products result.

4.6 Wood and Cork

Radioactive applications have been used occasionally to measure the distribution of adhesives during plywood manufacture and beta thickness gauges are in limited use to control the thickness of veneers, chipboard and plywood.

The most significant use of radiation is in the production of wood plastic composites and in the curing of paints on plywood or hardboard. Both of these processes are relatively new and economic data is unobtainable. There are however a number of factors which would appear to justify both techniques.

Paint curing can be achieved in less than one second and cheaper paints can give the same, or better, finish as oven-cured paints. The accelerator used takes up far less space than curing ovens and can be switched on and off at will. The resulting finish is more durable and does not flake off. The reliability of modern accelerators makes them adaptable to fairly small production lines.

4.7 Paper and Pulp

It is estimated that about 40% of all radioisotope thickness gauges are used in the paper industry to measure basis weight of paper and paperboard and to measure and control adhesive and plastic coatings on these materials. The gauges give a direct and continuous measure of weight per unit area without coming into contact with the paper. The time spent in adjusting the machine to produce the correct weight is drastically reduced and this weight can easily be maintained throughout the reel. As a result, raw materials are used more efficiently and product quality is improved. The types of gauge range from fixed point measuring devices on small paper machines to 40 feet wide scanning systems used in computer control of the paper making process. Examples of the raw material and time savings resulting from their use are numerous with cost-benefit ratios of 1:15 quoted in many cases.

Level gauges are used extensively on storage and process vessels. In pulp production, wood chips are treated at a pressure of 10 atmospheres in a preheater before being pulped in a defibrator. The level of chips in the preheater is used to control their residence time and hence the quality of the pulp. A study carried out in Yugoslavia to compare the economics of plant operation before and after level gauge installation showed typical results. There was a decrease in power input of 630 kW/h, a decrease in steam usage of 1.2 t/h and a 20% improvement in the physical properties of the products. The cost-benefit ratio was 1:8.

Radioactive tracers are used routinely in guarantee tests to determine mean residence times, mixing characteristics, etc. of pulp in process vessels. They are also used to plot dilution patterns of discharged factory effluent.

4.8 Chemicals and Chemical Products

This broad product group has the widest range of radioisotope applications. It includes the production of organic and inorganic chemicals such as acids, alkalis and salts, dyes and explosives, synthetic fibres, resins, plastics and rubber, and fertilizers. Also included are the manufacture of paints, the extraction of vegetable and animal oils and fats and the manufacture of many miscellaneous chemical products such as soaps, cosmetics, pharmaceuticals, polishes, etc.

Many chemical processes are difficult to control since reactions take place at very high temperatures and pressures in sealed, and sometimes steam-jacketed vessels. It is under these conditions that nuclear techniques are particularly useful. Accurate analyses and density determinations can be made in process streams; levels of materials in hoppers and reaction and storage vessels can be measured only with radioisotope techniques. Investigations of plant malfunction or "trouble-shooting" is carried out routinely to detect blockages or restrictions; to locate gas pockets in liquid streams and voids in solids; to measure the transfer rates of liquids, solids and gases and to determine the mixing efficiency of these same materials.

The manufacture of plastic sheet is controlled almost entirely by beta gauges and automatic control of the extruder is obtained by adjustment of the screw or the take-off roller speed. The main advantage of these gauges is that they allow the manufacture of closer tolerance and hence up-graded material. At the same time raw materials are conserved. Cost benefit ratios of 1:20 are normal in these operations.

Radioactive tracers, if properly used, can result in improved plant efficiency and large savings in time and materials by reducing shut-downs. Many of the large chemical companies use these techniques to their full advantage, the best example being in the U.K. where one plant estimates annual savings of $ 12 million from an annual investment of $ 350,000,-.

Numerous radiation processes for the simplified production of chemical products are at the pilot plant stage and several are in routine use.

Package monitors are used to ensure the correct filling of soap powders in cartons, tubes of toothpaste, boxes of tablets and cosmetic creams, liquids and perfumes in bottles. Savings resulting from the use of these devices are difficult to assess but customer satisfaction is assured.

4.9 Products of Petroleum and Coal

Density gauges are extensively used to detect interfaces in pipeline pumping operations. Different grades of oil are pumped consecutively through long pipelines and it is essential to know the position of the interface between successive grades so that the products can be routed to the correct storage vessel or branch pipeline. This type of measurement is of great economic significance since it is important that diesel oil, say, does not flow into a petroleum storage tank. The interface may be well-defined at the first pumping station but after travelling long distances it becomes diffused and only an accurate density measurement can indicate the correct cut-off point.

Level gauges are used to detect and control coke within petroleum coke drums, petroleum levels in storage tanks, kerosene-water interfaces, catalyst levels, liquid gas levels in butane cylinders, and a wide range of related problems. Nuclear techniques are unique to most of these applications. As long ago as 1958, one company in the USA producing gasoline reportedly saved $ 2 million in one year because radioisotope level gauges had made it possible to double the length of runs on "thermal" units before shutting down to remove coke. Another petroleum refining company reported savings of $ 300,000,- in the same period from the same application.

The analysis of hydrocarbons for sulphur, lead and other high atomic number elements is routine both in the laboratory and on-line. In most cases these applications eliminate the need for tedious chemical analysis through the use of a simple instrument.

All of the major oil companies use radioactive tracer techniques to determine the wear rates of piston rings in engines and hence evaluate the lubricating properties of oils. The most important chemical elements involved in research studies can be conveniently labelled with radioisotopes and the high sensitivity of tracer techniques accounts for their widespread use.

4.10 Non-metallic Mineral Products

Products whose mass per unit area is controlled with radioisotopes include asbestos-cement, glass, wallboard and coated abrasives. Gamma density gauges are used in the hydraulic transportation of sand, asbestos-cement slurries, clay slurries for cement manufacture and lime-mud slurries for lime kilns.

Gamma level gauges are used to control molten glass in furnaces where a high accuracy is required to ensure uniform products from the gravity feed system used. A typical installation costs about $ 6,000.- and one UK user reports annual savings of $ 500,000,-, largely from the reduction in rejects. This represents a 5% saving on isotope-assisted turnover.

Radioactive tracers are used to study material transfer problems in rotary kilns for cement manufacture. Retention, distribution, re-circulation and flow patterns are routinely investigated to ensure optimum operating conditions. Other tracer techniques determine the mixing efficiency of additives in conrete and bitumen and the source of inclusions in glass.

4.11 Basic Metals and Metal Products

This industry is one of the major users of radioisotope instruments. Thickness gauges are used extensively in the production of hot and cold rolled metals and for controlling coatings on steel. In a typical steel strip mill, molten metal is made into ingots which in turn pass to a blooming mill where a gamma transmission gauge is used to detect cavities. The thickness of hot rolled strip or plate is then measured with a gamma or bremsstranlung transmission gauge and thinner cold strips are controlled with beta transmission gauges. In cutting up operations, a fast beta transmission gauge is used to sort sheets of different thicknesses. In separate operations, steel sheets are continuously coated with zinc, tin, aluminium, paint and, more recently, chromium for the production of "tin-free" steel. Beta backscatter gauges are now being superceded by more accurate X-ray fluorescence gauges to measure and control these coating thicknesses.

Level gauges are used to control the feed to blast furnaces and furnace wall wear is measured by inserting small radioactive sources at different depths in the wall and recording their rate of disappearance.

Portable X-ray fluorescence gauges are used to identify different types of steel and neutron activation analysis is used to measure oxygen in steel in furnace operations. Activation analysis is also used to measure the iron content of iron ore.

Radioactive tracers are used extensively in basic research, especially to study boundary migration and the movement of alloying components and elements such as tungsten and cobalt in steel. Plant investigations, although not always routine, are made to follow the movement of blast furnace charges and to determine flow patterns in furnaces.

4.12 Machinery and Transport Equipment

Gamma radiography is used extensively to inspect cast and welded objects such as crank shafts, cylinder blocks, turbines, rotors, boilers, pressure vessels, pipes and aircraft parts. Although there are many examples of small savings resulting from this type of inspection, the real benefits come from the ensured reliability of the products.

Radioactive tracers are widely used to label moving parts in machines and engines to determine their wear rates. The movement of air in railway cars, aircraft and automobiles is studied routinely by means of a radioactive gas.

4.13 Civil Engineering and Construction

Many of the materials used in construction are produced with the aid of radioisotope gauges. This is especially true of sheet materials such as glass, wallboard, sheet metal, plastics, shingles and roofing felt.

Radioisotope moisture and density gauges are used extensively in the construction of roads, airfields, and dams and also in the mixing of ready-made concrete. The same instruments are used to measure density and moisture contents of concrete structures and to locate the position of reinforcing bars.

Gamma radiography is widely used to inspect the welded frames of buildings and other structures, and density gauges are employed in continuous dredging operations to keep the content of solid materials within certain limits. This latter application ensures efficient operation of the pumps without interruptions due to overloading.

Radioactive tracers are used routinely to inspect buried water mains for leaks and to locate the source of water seepage in buildings and dams. Conversely, they are used to define the distribution of cement injections.

4.14 Electricity, Gas, Water and Sanitary Services

In coal-fired electricity generating stations level gauges are commonly used on steel or concrete storage hoppers and also to indicate blockages as crushed coal is fed through ducts into furnaces. Gamma backscatter gauges are used to measure the ash content of coal to ensure efficient furnace operation, but this has limited application so far as power station operations rely on coal washeries to provide the correct grade of fuel.

Radioactive tracers can be used to measure with high accuracy the flow rate of water through pipes.. This technique is used routinely to measure the flow of water through power station turbines and it has proved so reliable that it is now accepted as the standard method of turbine rating in the U.K. Similar tracer methods are used to measure the flow rates of water or sewage in pipes, channels or rivers. Sewage density is measured and controlled by gamma density gauges before being pumped into digestion tanks.

Although the technique is not universally accepted, many countries use radioactive tracers to study the dilution of industrial wastes or community sewage into large receivers. The technique not only gives dilution patterns but it is influential in determining the degree of purification required and the length, position and design of the discharge pipe. Large scale, all-weather tests which include measurements taken from boats might cost about $ 50,000,- or more but the results give savings out of all proportion to this. A somewhat similar technique is used to follow the movement of silt or sand in waterways by using labelled material.

Leaks in gas and water mains are accurately located by the use of radioactive tracer techniques, even when the pipes are deeply buried.

In pollution control, analysis of the particulate matter collected on air filters is done rapidly by means of X-ray fluorescence. The same type of application is found in water pollution where polluting elements and their concentrations can be identified rapidly. These techniques have only recently been introduced but their use is spreading rapidly.

5. APPLICATION AREAS IN DEVELOPING COUNTRIES

5.1 Industrialized Countries

Modern manufacturing methods within a particular industry vary very little with location. In developing countries, the size of individual operations is generally smaller than that of competitive industries in industrially developed countries, but the manufacturing tools are basically the same. The quality and composition of raw materials may differ and the distribution of manpower and skills can necessitate changes in manufacturing procedure. Technological and organizational flexibility readily overcomes these obstacles resulting in the production of acceptable goods, at least for the home market.

The quality control aspects of manufacture become increasingly important in the development of export markets where international competition demands adherance to strict specifications and it is in this area where radioisotope and radiation techniques have their biggest impact. The most quoted benefit from the use of radioisotope gauges, for example, is improved quality. Although it is difficult to assign specific cash values to this benefit, it is obvious that an increase in quality makes a product more competitive and thus more acceptable for export markets. It is unfortunate that quality control and reliability assume this importance only under these circumstances but as a consequence domestic standards might also be enhanced.

Whilst manufacturing facilities may be the same, the availability of measuring and controlling devices certainly varies. These are made mostly in the industrially developed countries and their acquisition , except as an integral part of new plant, can be a difficult and lengthy process. This applies equally to all types of refined measuring systems which are a necessary part of modern industrial manufacture and radioisotope gauges are no exception. On the other hand, they are in many cases easier to install and calibrate than other measuring systems.

Consider, for example, the manufacture of plastic sheet, a commodity for which there is a widespread demand. Many problems associated with the use of plastic sheet are closely related to thickness and it is therefore important that this parameter should be controlled both longitudinally and across the sheet. The effectiveness of heat sealing varies considerably with sheet thickness, the optimum sealing time increasing 50% for every 0.02 mm increase in thickness of sheet in the range 0.02 to 0.1 mm. Thickness variations are thus extremely important in operations such as extrusion coating polyethylene on kraft paper or aluminium.

Thickness measurements must be performed either before or immediately after the rubber rollers which take off the plastic sheet as it comes from the extruder. Spring-loaded micrometers were first used for this measurement, but these have the disadvantage of being in contact with the product and measuring only in a fixed longitudinal position, apart from their inherent measurement accuracy limitations. It is only by using the information obtainable from fast beta-gauges that the present production rates of high quality sheet has been possible. The measurement is non-contacting and can be made at either pre-determined positions or continuously across the width of the sheet. This is particularly important in the case of extruders which have a large number of adjustable elements and which produce wide sheets of thin (0.001 mm - 0.005 mm) plastic. Since the dies may be only 1-2 cm apart, the radioactive source in the beta-gauge is collimated so that a strip of width 1 cm is scanned. Automatic control of machine direction variations is obtained by automatic adjustment of either the screw or take-off roller speed. Profile control is accomplished by die adjustment, either manually or automatically, in accordance with the cross-sheet measurements.

This example of thickness gauge usage serves to demonstrate the effectiveness of a particular radioisotope technique and the impact it can have on product quality in a relatively simple manufacturing process. In addition, the high measurement accuracy obtained leads to economic benefits through reduced raw material usage and a lower reject rate. The process is the same irrespective of its location but measurement and control techniques may vary.

The manufacturer may not always be aware of the different measuring devices at his disposal. Only the largest production facilities can support research and development staff whose duties would include the evaluation and control of process variables. Smaller operations have correspondingly fewer technical staff who are usually fully occupied with maintaining production and are most concerned with immediate problems of maintenance and repair. They have little time to experiment with novel techniques, especially those which, rightly or wrongly, to them might have an aura of mistique or hazard. Under these conditions, the direct application of radioisotope and radiation technology with its demonstrated ability to improve process efficiency and product quality is the most rewarding approach.

Most industrialized countries have specialized institutions whose purpose is to provide information, evaluate and demonstrate the efficacy of process technology. The same institutions provide test and investigational facilities. Ideally, these bodies should be aware and have experience of not only nuclear techniques, but all the alternative methods of approach to the solution of industrial problems. In practice, since nuclear techniques might be the most recent, they are sometimes omitted because they are known only from textbooks or manufacturers brochures. The same countries normally have an atomic energy authority with at least one nuclear reactor and the associated research facilities. Qualified staff, many with experience gained outside their own country, deliver lectures at numerous training courses designed to make scientists and engineers aware of the principles of radioisotope and radiation usage. These courses include laboratory practice to teach methods of handling and applying radioisotopes and they are ideal for the scientist. They may not be the best type of training for the industrialist or the industrial engineer. Sometimes special short courses are designed for industrial personnel so that they become acquainted with the potential of nuclear techniques. Both types of course will undoubtedly bring returns in the long run but nuclear scientists are not necessarily the best persons to teach industrial technology. Many nuclear techniques are well out of the research and development stage and have become hard industrial fact. At this stage their evaluation and adaption are best left to the industrial rather than the nuclear technologist.

Although the same is not necessarily true of agriculture and medicine, instruction in the routine uses of radioisotopes in industry might best be left to those industrial institutions which fulfil the same purpose for other, non-nuclear techniques. To achieve this it becomes essential that these institutions be singled out for specialized training and assistance to enable them to perform this function. This is particularly true for radioisotope gauges which, whilst based on the same principles as demonstrated by laboratory practice and instrumentation, incorporate industrial design concepts which may not be familiar to the nuclear scientist. The application and operation of radioisotope gauges does not require the same training as other radioisotope techniques. They should be regarded as normal measuring devices with special attention paid to the possible hazards arising from misuse of the radioactive sources contained in them.

Radioactive tracers on the other hand require more careful handling and more extensive training is necessary to ensure proper use and control. Where industry is not large enough to support specialist services of this type, national atomic energy authorities have successfully organized teams of experienced staff, able to perform tracer investigations on request in collaboration with plant engineers. Similarly, several industries in some countries join together to provide the financial support needed to sustain a specialist group able to give a similar service. If well-organized, either system functions effectively with resulting benefits to the industries concerned.

Whilst it is not possible to state specifically that industrialized countries will all have the same basic industries, it can be assumed that these industries will include basic metals, chemicals, paper, tobacco, machinery, food and, perhaps, mineral processing. In all of these industries radioisotopes can be used extensively.

The basic metals industry covers smelting, refining, coke-oven operation and the manufacture of basic iron and non-ferrous products such as sheets, plates, strips, tubes, tin-plate and galvanized and aluminized sheet. In rolling and coating operations radioisotope thickness gauges are now almost the traditional measurement devices whilst radioisotope level gauges are particularly suited to the conditions pertaining in this industry for measuring liquid levels in furnaces and ores in hoppers. Simple, rapid and accurate radioisotope methods of analysis meet the demands for controlling the composition of steel and alloys. In large- to medium-sized operations there is no question about the use of radioisotope techniques for the above-mentioned purposes. They have proved themselves in hundreds or even thousands of similar applications, bringing both economic and technological advantages.

In the manufacture of cigarettes, beta gauges are an integral part of the process in many countries. Even when tobacco is inexpensive and does not carry high taxes, the production of uniform cigarettes with a constant packing density is desirable, whether the tobacco be tightly or loosely packed. The use of a relatively inexpensive radioisotope gauge to control product consistency to ±0.25% would seem to be justified from the quality aspect alone.

Most metal fabrication and machinery industries have a requirement for radiographic inspection and, whether performed by service organizations or by industry itself, this should be one of the first radioisotope techniques introduced. The need is obvious, training is straight forward, the equipment is inexpensive and the returns, in terms of improved quality, are high.

Another completely routine application is that of the use of beta-gauges in the paper industry. These gauges range from large systems which scan continuously across 10 metre wide sheets to fixed-point measuring devices used on small paper-making machines. Since mass per unit area is one of the main parameters to be controlled in the paper making process, the installation of a non-contacting beta-gauge is almost mandatory on any machine, irrespective of location.

In the food industry, the use of modern packaging techniques makes it desirable to check the contents of sealed containers or packages. Radioisotope package monitors accomplish this on even the fastest production lines, so eliminating tedious manual inspection procedures and guaranteeing customer satisfaction.

Many problems arise in the bulk manufacture of chemicals in which radioisotopes offer the most expedient and sometimes the only feasible means of solution. In process measurement and control, accurate analyses and determinations of density can be made and difficult problems of level control in hoppers or in reaction and storage vessels become relatively easy with radioisotope techniques. Investigations of various forms of plant malfunction are greatly assisted by radioactive tracers. Several radiation-initiated chemical processes are worthy of consideration and others warrant research efforts.

Where medical products and supplies are manufactured, radiation sterilization should most certainly be considered as one technique to be employed. If used in conjunction with modern manufacturing methods and packaging techniques, it can greatly facilitate cumbersome sterilizing procedures and help guarantee sterility.

The above are typical examples of radioisotope and radiation techniques which can be readily introduced into the industries of developing countries. Very few special skills are required to do this, but the returns can make a significant contribution to economic and industrial development.

5.2 Semi-Industrialized Countries

This group of countries can generally be expected to support medium-sized production operations with old-fashioned manufacturing techniques competing against modern methods. The modern industries can certainly benefit from the use of nuclear techniques, in many cases to the same extent as their counterparts in the industrially advanced countries. Greater care must be taken in evaluating the measuring and control methods to be applied under these conditions and the need for assistance in this will probably be greater also.

If, as is quite likely, nuclear research facilities exist in these countries, they probably contain the best collection of modern investigational equipment together with scientific expertise of a high standard. In addition to the inevitable research work which is a necessary function of these establishments it is highly desirable that the special skills and technology which exist there are made available to assist in national development programmes. A close relationship between such establishments and industrial institutions can only result in a sounder-based industrial development.

The older industries warrant special attention if they are to survive and produce acceptable goods. These industries usually rely on the special skills and talents of long-serving employees to ensure product quality, but this may not be sufficient in a competitive market.

For example, steel may not be produced in these countries but there will always be a demand for galvanized steel sheet for use in low-cost construction projects. The traditional method of checking the thickness of zinc on steel is the wet chemistry weigh-strip-weigh technique which involves weighing a standard sized sample, dissolving the zinc and re-weighing the basic steel of the sample. Radioisotope instruments exist for making this measurement more accurately and in a few seconds at the push of a button, without any special nuclear or electronic knowledge. This means that a check which previously required the services of a qualified chemist can now be performed by unskilled staff.

In many instances these checks are only made occasionally because of the expense of retaining a chemist. They can now be done routinely to ensure closer manufacturing tolerances and probably result in raw material savings. The same arguments apply to the production of tin-plate.

Thickness gauges are necessary in the production of sheet materials, but the type of gauge which is sufficient or essential for a particular process depends on the degree of control possible in the manufacturing machinery. With new machinery radioisotope thickness gauges are probably desirable because of high production rates and the close tolerances which machine adjustments allow. Older machinery might have lower production rates which do not necessitate high-speed thickness measurements and, more important, the machines might not be capable of adjustments to follow the accurate measurements of radioisotope gauges. Under the latter conditions process automation does not serve a useful purpose but a simple radioisotope thickness gauge installation might be justified. Only a process study can determine the best measuring technique for a particular process and this probably implies that an industrial institution, competent to judge, should be available. Such an institution or a nuclear research centre would also be in a position to service and maintain all types of measuring instruments. A broadening of the functions of these bodies might be justified in these circumstances.

The one nuclear technique which can be said to be absolutely essential is radiography. The establishment and availability of a service group with the necessary training and experience to check welding in construction work or the fabrication of process vessels and pipelines can make a significant contribution to the enforcement of safety standards.

Whilst the small, modern industries can undoubtedly benefit from the application of some radioisotope and radiation techniques, particularly level, thickness and density measurement, the older industries might do so only after careful evaluation. The task of improving process efficiency and product quality might be tedious but it is not unsurmountable if available technical resources are used wisely.

5.3 Non-Industrialized Countries

Except for isolated cases, it is only possible to discuss the potential benefits which might be derived from radioisotope usage in these countries. Some manufacturing industries will exist and, depending on their level of development, they may well be able to profit from the introduction of these techniques. On the other hand, as industry is established in these countries, it has the advantage ob being able to choose the most modern technology. If this is done, nuclear science will undoubtedly make its contribution, probably more realistically than under other circumstances.

The transfer of technology is best done when it is assessed and based on experience elsewhere. This is true not only of radioisotope techniques, but of any other instrumental, process or manufacturing scheme. The introduction of new industrial ventures might be as a result of governmental planning or through the initiative of individuals. Where a national authority is responsible for superintending industrial development schemes, there is always the possibility of national institutions being consulted to give guidance on the best technology available. In the private sector there will be a tendency to accept an exact copy of a plant which functions well elsewhere. It is not easy in either case to influence the choice of measuring or control systems which may be required and it may not be advisable to do so. Any radioisotope technique worthy of consideration will be accepted if previous experience has proved it to be an economic and technical success.

There may be more scope for the use of radioactive tracer studies in development schemes. For example, the discharge of effluents into the sea, lakes or rivers can be fully evaluated before the erection of a new factory and precautions taken to limit future harmful effects. Such studies require the services of well-qualified engineers but their use has proved to be invaluable in some countries. Similar techniques are used routinely for the control of sewage discharge from new urban settlements whilst the pattern of silt movement in new harbour construction is evaluated conclusively if radioactively labelled silt or sand is used in full-scale tests.

Again, with the exception of gamma-radiography, there is little point in trying to force the introduction of radioisotope techniques under these circumstances. The need for these and other non-nuclear methods will evolve naturally and, provided that suitable training is given to the growing numbers of scientists and engineers in non-industrial countries, each method will eventually find its own level of acceptance.

6. CONCLUSIONS

Industrialized countries invariably have their own national atomic energy authorities. Qualified and competent staff, trained in all branches of nuclear science are available and a wide variety of training courses is given regularly to industrial management and engineers. It is unfortunate that the vast sums of money spent in promoting nuclear technology are out of proportion to the immediate returns which might be expected in terms of national development. Many reasons are given to justify these large programmes; preparations for atomic power development, improvements in scientific understanding, raising educational levels, benefits to industry, medicine and agriculture, etc. These justifications largely break down in practice. Nuclear power stations normally come under the control of the power generating authorities whose own staff, after short periods of training, are competent to operate nuclear facilities. Nuclear research tends to be academic rather than applied and the teaching of nuclear technology is better placed in universities and other educational establishments except where very specialized training is necessary.

Although nuclear research will undoubtedly bring long-term benefits in raising the level of scientific achievement in many countries, it is in the applied sciences that the greatest immediate contributions can be made. In diagnostic medicine, radioisotope techniques are used extensively in both the public and private sectors. The techniques are relatively simple and they have been refined to make their easy application possible. The extent of the use of radioisotopes in biology and medicine can be gauged by observing the very wide range of isotopes and labelled compounds produced specifically for this purpose. On the one hand the techniques are universally accepted and on the other, the market is sufficiently lucrative to attract producers of radioisotopes. To a lesser extent the same is true of agricultural applications which are also well-defined and straightforward. The use of radioisotopes and radiation in these areas have brought rich rewards.

In industry, these rewards have still to be realized. This is not to say that industry does not benefit from the use of radioisotopes. Take, for example, the use of thickness gauges in the paper industry. A conservative estimate of the annual savings in time and raw material from the use of one of these gauges is $ 7,000,-. There are roughly 20,000 such gauges in use which gives a savings figure of $ 140 million per year from this application alone. Many of the other gauging techniques are even more lucrative. Unlike medicine and agriculture, however, the range of techniques available is very wide and each application has to be examined separately and the instrumentation or experiment designed, planned and executed on an individual basis. There are also much fewer personnel involved in exploiting industrial applications compared to the other fields and several reasons for this can be advanced.

In order to exploit radioisotope techniques in industry it is necessary to have a broad, if not thorough, knowledge of all branches of industrial processes. The chemical engineer, for example, in small or industrially-developing countries is usually better qualified in this respect than his counterpart in highly industrialized countries, where specialization is necessary. He has to be inventive and imaginative and learns quickly by experience. The demand for this type of person is great and he normally finds a stimulating and lucrative position in industry quite easily. Such a person is seldom prepared to work within the strictures of finance and opportunity imposed by governmental establishments. The applied scientist does not always get the same financial and social recognition as his academic colleagues and in many developing countries this fact tends to upset the proper balance between pure and applied science.

Since he is dealing with and introducing a relatively new technology, the industrial radioisotope specialist finds himself playing the rôle of a salesman to some extent. This is a quality not found naturally in scientists. He also has to work in environments quite different from those encountered in the laboratory. One of the most difficult aspects of training scientists in this type of work is to scale up laboratory practise to the plant level. The confidence required to carry out a large scale tracer study in an oil refinery for example can only come through experience.

In spite of these difficulties, there are numerous examples of successful groups exploiting radioisotope techniques very successfully. Usually, however, this success is based on the enthusiasm of a small number of persons who are fully aware of the potential of the technology which they exploit.

In countries where the size of individual industries is small or the products are aimed only at the local market where competition is not strong, there is little incentive to invest in new technology. National standards may not exist and, if they do, may not be strictly enforced. Management may not even be aware of these new techniques. In exploiting export markets, however, quality control plays a very significant rôle. Nuclear methods are a very good basis for non-destructive testing and quality control and it is the responsibility of the national atomic energy centres, many of which possess a country's most modern and sophisticated test equipment, to ensure that their technology is not restricted to atomic energy programmes but is passed on to industry for the direct benefit of the consumer.

Too often there is inadequate contact between industrial management and the organization responsible for promoting nuclear applications. Industry does not readily seek advice from these organizations but will accept it if it is based on sound principles and judgement and backed by technical knowledge. This again points to the need for a careful selection of staff and to the necessity of judiciously collecting and disseminating information.

Gamma radiography is a technique which is fully exploited in industrialized countries. It is inexpensive, relatively simple to use and the training required is not excessive. It is probably the only nuclear technique which is approaching saturation in some countries but in many of those countries where industry and construction are expanding rapidly it has yet to be fully utilized as an inspection tool. Many of the advantages from quality control are intangible but reliability is a very strong sales point. It is reflected in the need to hold in stock fewer replacement parts, in the number of returned products, in the safety of such things as welded boilers, pressure vessels and pipelines, and in customer satisfaction. Radiography helps to achieve all of these objectives and it is a powerful tool in non-destructive testing.

Beta thickness gauges are used extensively in the manufacturing industries, particularly in the paper, chemicals and plastics, basic metals, textiles, rubber and cement industries. They show excellent returns on investment through savings in raw material and a reduction in waste and they result in a higher quality product. Their use can accurately be described as routine although in many cases the electronics design and components used leave scope for improvement. The fact that a very large number of these gauges are installed in spite of their early drawbacks testifies to their necessity as measuring devices. Modern gauges, using the most advanced electronics and mechanical design are extremely reliable under severe environmental conditions and their measurement precision is unequalled in most of the on-line applications. Sophisticated automatic control systems are now being built into many of the continuous sheet processes, the beta thickness gauge being the measuring device to make this possible. A large number of coating measurements which were previously made unreliably can now be made satisfactorily with X-ray fluorescence gauges. As the new generation of thickness gauges, these devices incorporate the most modern technology and open up a new field for exploitation. Industrialized and semi-industrialized countries manufacture sheet materials of all types in large and small operations. Many of the machines for making these sheet materials are equipped with radioisotope thickness gauges when delivered. Existing industry, provided that its machinery can be adjusted to meet the accuracy of measurement from the gauge, can be readily equipped with these devices to give immediate economic gains and product improvement.

Density gauges are used mainly in the cigarette industry where they have obvious benefits in both raw material savings and product quality. They are fitted automatically to all new machinery but can be easily incorporated into existing machinery. In terms of returns through the application of a particular technique, this example is the outstanding one for density gauge installations. There are numerous variations of gamma density gauging, particularly in the chemical, petroleum and mining industries, but none of these applications is sufficient to warrant a concerted effort to promote their usage. The individual gauging installations are necessary and readily justified on economic and technical grounds. They have developed slowly to solve measuring problems which cannot be overcome by other methods. Good examples of this are the transport of petroleum products through pipelines, gauging of unpleasant liquids such as sulphuric acid and sodium hydroxide and the control of dredging and sewage treatment operations.

Radioisotope level gauges have been used in many cases quite indiscriminately. In some countries, nuclear instruments are produced at the expense of other measuring devices just because the nuclear industry developed more rapidly and sooner than others producing control devices. Within the confines of an atomic energy programme it is possible to mass produce simple radiation switches which can easily be adapted to a wide range of applications. It is not necessarily wrong that this technique, which works well and reliably, should be promoted at the expense of others under these conditions. The benefits to be derived from level gauge usage are largely in labour saving and increased productivity, although some outstanding returns on low investments have occurred in the petroleum and chemical industries. These two industries are the largest users of level gauges, closely followed by the mining and power producing industries. In underground mining these devices are widely used in remote-controlled operations and there are numerous examples of their installation on large hoppers and sealed vessels.

Analytical instruments employing radioisotopes offer distinct advantages, primarily in the mineral exploration and extraction, steel and petro-chemical industries. In logging for oil, gas, coal and mineral deposits these devices are universally accepted because of their ability to provide rapid information. They also reduce dramatically the need for analytical chemists whose services are at a premium in developing countries. Activation analysis and X-ray fluorescence are techniques which are already contributing significantly to geochemical and geobotanical mineral exploration and these provide an excellent link between atomic energy authorities and mineral survey organizations in the development of natural resources. The techniques are ideal for use in developing countries where nuclear facilities exist and can be used in a programme directly connected to national development. They are used to a lesser extent in the petrochemical industries, but their application in these industries in developing countries can make a significant contribution to product quality control. Moisture and density gauges are used primarily in road construction but the interpretation of results is not always straightforward and the instruments can give misleading information if used by inexperienced personnel. On the other hand, their advantages are considerable and the correct balance between the need for and use of these techniques has to be judged on an individual basis.

Radioisotope instruments have not been fully exploited in the developing countries although there is plenty of evidence to show that they could make contributions to product quality control and efficient plant operation, probably in excess of those experienced in industrially advanced nations. The development of these instruments has been slow but they can now be said to be entirely suitable for use in the most demanding conditions, requiring a minimum of maintenance. Only the simplest of instruments, such as level switches, should be manufactured where component quality and engineering design is suspect since these factors have been proved to hinder rather than advance the acceptance of nuclear technology. In most cases, the instruments can be applied with equal ease and results to all sizes of industry where process control is desirable.

Radiation processing has some aspects which make it particularly attractive to developing countries. The manufacture of medical products under aseptic conditions is not always easy in tropical areas or in those countries where cottage industries produce most of these materials. Radiation sterilization should not be viewed as a means of directly overcoming these difficulties but it has proved to be the most convenient sterilizing technique for disposable and packaged products. It is particularly suitable for countries with de-centralized production facilities since sterility can be controlled at one central point and the need for numerous autoclaves can be eliminated. A radiation sterilization plant is simple to operate and can be run by very few persons. Also of importance is the fact that returns on capital investment are high. Improvements in hygienic standards are rapidly achieved through the introduction of this technique.

Although the radiation treatment of textiles to improve their properties is not widely spread, the products are excellent. The manufacture of crease and stain resistant fabrics is largely confined to industrially advanced countries and well-patented chemical techniques are predominant. The cotton-producing countries have much to gain in terms of expanding export markets if they could manufacture these fabrics. The radiation processes are not so restrictive from the patent point of view and the possibility of exploiting them is certainly worthy of study.

The manufacture of wood plastic composites by radiation has been dismissed by many as too expensive a technique to be applied in the developing countries. The possibility of using the technique to produce inexpensive construction materials is attractive, particularly if waste materials such as bagasse or cheap woods can be utilized and the cost of monomers reduced. Recent developments appear to have overcome these difficulties and the technology should not be disregarded. Similarly, the rapid curing of painted sheet materials such as plywood and steel is of equal importance to the developing countries as the industrially developed ones since a large portion of the products are exported.

The application of some radioactive tracer techniques is routine in investigating the efficiency of industrial processes, particularly in the chemical and steel industries. Wide acceptance of these methods is hindered mainly by the fact that only large concerns can afford the luxury of maintaining a team of qualified technologists to use them in trouble-shooting investigations. This problem has been successfully overcome in several small countries by a number of industries joining together to support a central radioisotope laboratory whose services are at their disposal at all times. A similar philosophy applied in developing countries might well produce more rapid and satisfactory results than relying on the sometimes ineffective efforts of national atomic energy authorities. The benefits to be gained from the use of these techniques are considerable but the direct participation of industry is necessary if these rewards are to be realized. Most of the obstacles to the widespread use of radioisotopes in industry apply to the use of tracers and in particular to possible radioactive contamination and the resulting health hazards. There is little evidence of serious contamination problems arising from the use of tracers in industry and, in fact, these should be completely avoidable in properly planned and executed investigations. It is through tracer studies that the use of radioisotopes in industry can still expand considerably.

In summary, it can be concluded that some radioisotope and radiation techniques bring economic and technological benefits to many types of manufacturing processes. After 25 years of development and usage, the most successful applications are easily recognizable through the extent of their acceptance. This is particularly true of radioisotope gauges. The techniques can be applied with equal facility to all sizes of process but there are still many countries whose industry, through lack of knowledge, reluctance or fear of radiation, is not taking advantage of these methods. Efforts to promote radioisotope applications have not always been made in the best way. Perhaps too much emphasis has been placed on the nuclear aspects of this technology rather than on the requirements of industry for the solution of a particular problem. The "market" for these techniques is far from saturated and properly planned promotional activities can make their benefits available to new and existing industries throughout the world.

7. RECOMMENDATIONS

The promotion of proven radioisotope and radiation technology is best done by individuals or institutions who fully understand the requirements of industry and the exacting conditions under which any measuring system or applied scientific development must function. Whilst atomic energy organizations have well-qualified staff competent to make scientific evaluations of nuclear applications, the number of persons within these organizations who can assess these applications objectively from the industrial point of view is small. The nuclear scientist can rarely do more than point out the technical advantages and limitations of radioisotope gauges, for example, and quote second-hand information on process performance and economics resulting from their use under similar circumstances. In many instances this has been and is sufficient for the industrial user to form his own judgement on the value of a particular nuclear technique to his manufacturing problem.

Another, and perhaps more important limitation, is that radioisotope gauges are manufactured in a relatively few industrially developed countries. The potential user in the developing countries has little opportunity to evaluate this type of equipment at first hand. This is not to suggest that these gauges should be designed and assembled in the developing countries. On the contrary, whilst laboratory instrumentation under the control of specialists is relatively easy to build and maintain, industrial equipment with its long history of development has to meet more exacting requirements and only the simplest devices, such as level switches, should be considered for local manufacture in most cases.

(a) To supplement the existing efforts of national atomic energy authorities, the application of well-established <u>radioisotope gauging techniques</u> should be promoted by industrial centres. Thickness, level, density and analytical gauges in the chemical, plastics, tobacco, mining, paper and metal industries are the most appropriate and immediately rewarding areas.

(b) The developing countries should assess the implications which the introduction of these techniques might have on efficiency and quality control in the manufacturing industries and the economic benefits to be expected. This might best be done by requesting the services of a team of specialists made up of both technologists and industrial economists to assist local staff in evaluating this potential in particular industries.

(c) On the basis of these cost-benefit studies, UNIDO might consider the possibility of demonstrating the advantages of radioisotope techniques through the provision of industrial gauging equipment with a further process study at a subsequent date. Such evaluations would provide a realistic basis for thoroughly evaluating radioisotope thickness gauges, say, in the sheet metal, plastics or paper industries of developing countries. Studies of this kind have not previously been undertaken.

(d) The relative ease with which gamma radiography can be taught and the rewards it can bring make it a most attractive non-destructive testing technique. Evaluations by specialists of the need for this technology might lead to the formation of non-destructive testing groups with a resulting improvement in fabrication standards. Only the very large industries can afford to support such groups but the availability of a service organization able to perform radiographic and other testing operations on demand in a country or region has obvious possibilities. Developing countries should draw on the expertise available to obtain an assessment of local situations, provide training and suggest regulatory systems to guarantee a high standard of inspection. The introduction of gamma radiographic techniques can be the foundation on which to build up a complete non-destructive testing network.

(e) Medical products, whether they be bandages, dressings, swabs or more precise devices such as syringes, sutures and instruments, are manufactured in most countries. Radiation sterilization is an acceptable, safe, simple and convenient method of raising hygienic standards of properly packaged materials. With the assistance of specialists, the need for small, batch plants or larger, centralized facilities to meet industrial requirements should be appraised. At a later stage expertise should be made available to help introduce modern packaging techniques and advise on the regulatory functions necessary to ensure the efficient operation of this type of plant.

(f) The number of plants for continuously coating sheet metal with tin, zinc and paint is very large in developing countries. Some timber-rich countries produce painted plywood, mainly for export markets. The radiation curing of painted surfaces has many technical advantages over heat curing and, whilst not generally introduced, it should be carefully considered for processes of this type. A thorough evaluation of this technique, its technical and economic ramifications and its adaptability to the conditions pertaining in industry is warranted and this will be best achieved through case studies.

(g) In thosa countries which have a nuclear reactor, the production of some radioisotopes is usually one of the first undertakings. If a supply of suitable radioisotopes is available, radioactive tracer techniques can make a considerable contribution to the efficiency of operation of industrial processes. In small countries or those with small industries, a centralized tracer organization with direct industrial participation can play a useful rôle but the biggest difficulty is in convincing industry of the effectiveness of such a service. UNIDO should assist in this by making available the services of specialists with experience in this type of operation to help evaluate the effect it could have on the operational efficiency of a group of companies and in providing guidance in the establishment and co-ordination of the activities of such a group.

The above suggestions and recommendations should be considered in the context of industrial instrumentation and process development as a whole. Radioisotope and radiation techniques should not be looked upon as novel or as something for the specialist. They are merely other tools for industry to employ to achieve better product quality and process efficiency. In describing their contribution, however, it is necessary to be specific and comparison with the many other measuring methods would be unwieldy. In many cases the techniques offer unique solutions to industrial process problems and their still expanding use testifies to their success. Industry has yet to be fully educated as to the merits and relative simplicity of these techniques and UNIDO possesses the necessary resources and machinery to make this possible. Appendices I, II and III are examples of the types of project which might initiate this effort.

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APPENDIX I

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
UNITED NATIONS DEVELOPMENT PROGRAMME

Special Industrial Services

Project Data Sheet

1. Reference Number: Country:

Project Title: Assistance in Quality and Process Control: Radioisotope and Radiation Techniques.

Date formal request received:

Government Department submitting request:

Specific Government Agency concerned with the project:

2. Description of the project: The Government requires assistance in defining industrial processes where radioisotope techniques could have a significant impact. More specifically, the report of the expert should include:

(a) an assessment of those industries which might benefit most from the use of radioisotope gauges;

(b) a detailed examination of particular measurement and control problems within these industries to which radioisotope techniques can offer a solution;

(c) economic studies of the effects of introducing these techniques;

(d) an assessment of the improvement in quality control to be expected;

(e) recommendations for implementing the introduction of those techniques which might offer the most significant and rapid benefits.

3. Background Information: The development of manufacturing industries in the area has led to a need for the introduction of non-destructive testing and quality control methods as a means of product improvement. Within these industries, the ability of radioisotope gauges to achieve this purpose has been amply demonstrated, at the same time leading to a more efficient utilization of raw materials and savings in waste and rejects. Effective cost-benefit studies are necessary before industry embarks on the use of these reliable but sometimes novel techniques and these studies must be made under industrial conditions to optimize their usefulness.

APPENDIX I (cont'd)

4. Project Budget:

Components: Consultant - salaries and travel expenses, report preparation (3 persons)* $ 9,000,-

5. Request approved:

____________________   ____________________

for UNIDO   for UNDP

Date: __________   Date: __________

* This figure should be multiplied according to urban centres to be visited and to the complexity of the problems involved.

APPENDIX II

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

UNITED NATIONS DEVELOPMENT PROGRAMME

Special Industrial Services

Project Data Sheet

1. Reference Number: Country:

Project Title: Assistance in Non-Destructive Testing: Radiography

Date formal request received:

Government Department submitting request:

Specific Government Agency concerned with the project:

2. Description of the project: The Government requires assistance in defining the need for gamma and X- radiography techniques for the inspection of welds and machinery components and suggested mechanisms for dealing with these problems. The report of the expert should include:

(a) an examination of the construction and manufacturing industries where non-destructive inspection is an integrated function;

(b) an assessment of the benefits to be gained through the use of X- and gamma radiography ;

(c) a definition of local practices in these areas;

(d) suggestions for improving these practices and regulating them;

(e) recommendations on desirable institutional and regulatory arrangements, particular technical aspects to be further examined and general principles relevant to the local situation.

3. Background Information: The non-destructive testing method which is most independent of operator skills is radiography. Its use as an inspection technique, particularly in remote or inaccessible areas, is well-established and the economic and less tangible benefits such as increased safety and improved reliability are obvious. Although data exists on some individual users of the method, no evaluation of the implications of its more widespread application is available and it is against this background that there is a need for institutional and regulatory arrangements to be examined.

APPENDIX II (cont'd)

4. **Project Budget:**

Components: Consultant - salaries and travel expenses, report preparation. (2 persons)* $ 6,000.-

5. **Request approved:**

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for UNIDO

Date: ________________

____
for UNDP

Date: ________________

* This figure should be multiplied according to urban centres to be visited and to the complexity of the problems involved.

APPENDIX III

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

UNITED NATIONS DEVELOPMENT PROGRAMME

Special Industrial Services

Project Data Sheet

1. **Reference Number:** **Country:**

   Project Title: Assistance in Medical Product Production: Radiation Sterilization

   Date formal request received:

   Government Department submitting request:

   Specific Government Agency concerned with the project:

2. **Description of the project:** The Government requires assistance in defining schemes for the production of sterile medical products, particularly where radiation sterilization might improve product quality and overcome difficulties arising from de-centralized production. The report of the expert should include:

   (a) an examination of the extent of medical product manufacture and its geographical distribution;

   (b) a definition of local practices for sterilizing these products;

   (c) an examination of the economic and technical implications of introducing radiation sterilization and a comparison with other methods;

   (d) recommendations for desirable manufacturing and regulatory arrangements relevant to the local situation.

3. **Background Information:** The increased production of disposable, sealed and packaged medical supplies has led to radiation sterilization being accepted as a most convenient and reliable method. It is particularly advantageous in the processing of heat-sensitive products and where small, de-centralized manufacture makes local sterility control prohibitively expensive. No data currently exists on the need for this method, the effect which is might have on upgrading existing products or its adaptation to new manufacturing practices.

APPENDIX III (cont'd)

4. **Project Budget:**

Components:	Consultant - salaries and travel expenses, report preparation (2 persons)*	$ 6,000,-

5. **Request approved:**

____________________ for UNIDO

Date: ________________

____________________ for UNDP

Date: ________________

* This figure should be multiplied according to urban centres to be visited and to the complexity of the problems involved.

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