Monitoring wear and corrosion in industrial machines and systems: A radiation tool

Under an IAEA-supported project, countries are studying applications of a technique known as thin layer activation

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It is well known that the reliability of industrial equipment and machines, transport systems, nuclear and conventional power plants, pipelines, and other materials is substantially influenced by degradation processes such as wear and corrosion. For safety and economic reasons, appropriately monitoring the damage could prevent dangerous accidents during operation of industrial installations or vehicles and avoid production losses from the breakdown of machinery.

When the surfaces of machine parts under investigation are not easy to reach or are concealed by overlying structures, nuclear methods have become powerful tools for examination. They include X-ray radiography, neutron radiography, and a technique known as thin layer activation (TLA).

TLA is one of the most effective methods for monitoring wear and corrosion. By remote measurement, critical parts in a machine or a processing plant can be examined under real operating conditions, and the rate of wear and corrosion determined. TLA's main feature is the creation of a thin radioactive layer under the investigated surface, commonly by irradiating the object under study in an accelerator (cyclotron).

The methods for activating machine parts using an accelerator are sufficiently developed. They now enable highly sensitive measurements of the rate of surface destruction within a range of 0.0001 to 1 millimeters per year. TLA has been used as a tool for measuring the wear rate of a variety of components. These include bearings, camshafts, vehicle brake disks, as well as piston rings and cylinder housings of an internal combustion engine. More recent applications include the evaluation of corrosion and erosion phenomena in pipelines, vapor and gas turbine blades, off-shore platforms, and nuclear power plants. Its benefits to industry significantly exceed the costs of irradiating machine parts at accelerators and purchasing adequate radiometric equipment.

In response to interest among its Member States, the IAEA in 1991 initiated a co-ordinated research programme on nuclear methods for monitoring wear and corrosion in industry. Its scope includes the further development of irradiation technology employing charged particle accelerators, and various technical studies on practical applications of TLA in different industries. Six institutes from China, Hungary, India, Romania, and Russia participate in the programme. Their efforts are being concentrated on the development of new irradiation devices, measuring systems, and practical monitoring of wear and corrosion, among other areas. This article presents a brief technical overview of TLA, including reports of several case studies.

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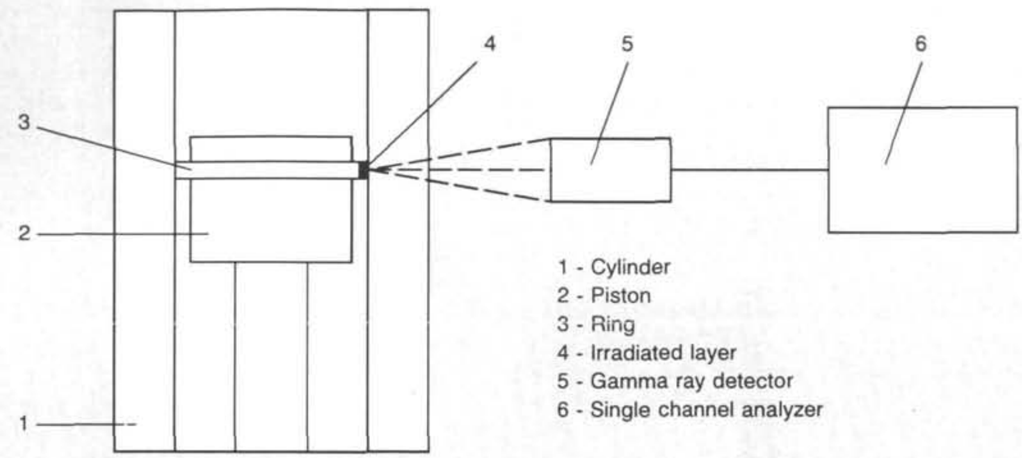
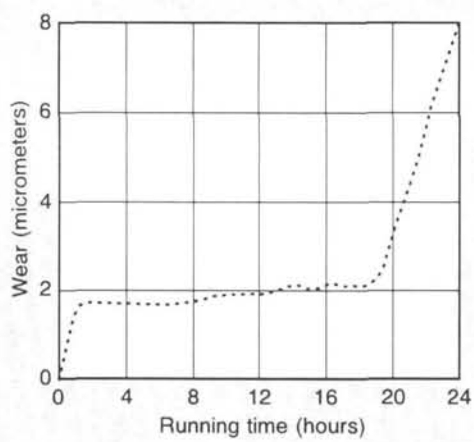
TLA: Modified tracer technology

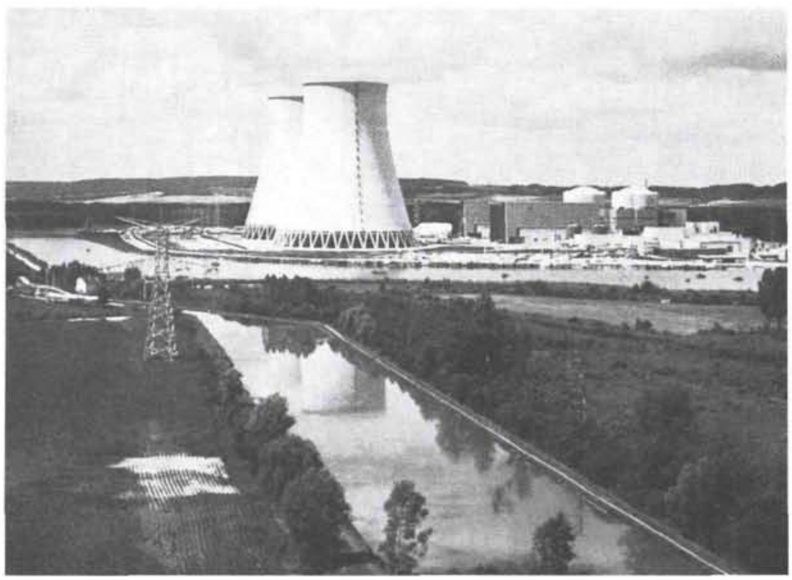
TLA should be considered as one modification of radioactive tracer technology. In this method, radioactive tracers are created by irradiation of investigated objects in an accelerator. Due to the limited range of the charged particles in the condensed matter, the thickness of the activated layer usually is considerably smaller than the thickness of the machine part. Generally speaking, the radioactive tracer's depth distribution is not uniform and must be

Typical experimental set-up for monitoring of wear and corrosion by TLA



Wear of piston ring in internal combustion engine





Thin layer activation (TLA) studies are done in industry for measuring and monitoring processes that degrade machinery and parts. Recent applications include evaluation of corrosion and erosion phenomena in pipelines, turbine blades, off-shore oil platforms, and at nuclear power plants.

determined in a separate experiment using special techniques.

The irradiated machine part is then assembled into the machine and the activity of the radioactive tracer is measured by an appropriate gamma spectrometry system. In the case of wear processes (corrosion or erosion) the tracer's activity decreases at a higher rate than the rate of its natural decay. The activity of the radioactive tracer usually does not exceed about 10 microcuries, and in most cases there is no need for special shielding against radiation. *(See graph and table.)*

Case studies from research activities

Internal combustion engines. TLA today is extensively used for wear monitoring of internal combustion engine parts, including such important friction pairs as the piston ring and cylinder.

Researchers in Russia have investigated the wear rate of a piston ring under various operating conditions. In one experiment, the ring's chrome-plated surface was irradiated by alpha-particles with 28 mega-electron volts (MeV) of energy at an angle of 30° to the surface. The thickness of the activated layer, which contained the radionuclide manganese-54, was equal to 25 micrometers. Results indicated that the rate of wear increases dramatically after about 18 hours of running time. *(See graph.)*

Interesting results also have been obtained using TLA at the Institute of Physics and Nuclear Engineering in Bucharest, Romania.The outer part of a piston ring was activated by energy deuterons of 8.5 MeV, which produced the radionuclide cobalt-57 that served as the radioactive label. The results of monitoring demonstrated that the wear rate was not uniform over the circumference of the piston ring but had two maximum points.

Other aspects of transport processes also are being examined. At China's Institute of Atomic Energy in Beijing, for example, researchers are investigating the influence of the quality of diesel fuel on the wear rate of diesel locomotives.

Pressure vessels. In the United States, TLA has been used to monitor erosion and corrosion occurring on the inner carbon steel wall of a pulp digester at a paper mill. Representative samples of the same steel as that used in the digester wall were irradiated and tested. Subsequent weight-loss measurements and comparison with ultrasonic thickness measurements established that the corrosion rate measured by TLA gave accurate results over a much shorter time scale.

Machine tools. In Hungary, scientists at the Institute of Nuclear Research of the Academy of Sciences have developed on-line wear measurements of the cutting edge of superhard turning tools made of polycrystal artificial diamond and cubic boron-nitride. Researchers irradiated the tools by protons at a cyclotron and then tested them under laboratory conditions using a grinding machine.

Other materials. Research also is being done using TLA for monitoring degradation processes of engine cam nose, knitting machines in the textile industry, artificial hip joints, gun barrels, compressors, materials for nuclear power plants, bearings, rails and railway wheels, gears, and pipeline equipment, for example.

A deployable technology

Based on its practical applications, chiefly in industrialized countries, and ongoing research, TLA could be readily deployed in more developing countries, given the appropriate infrastructure. It should be underlined that the availability of the appropriate accelerator (for example, a cyclotron or tandem accelerator) in the country is not a prerequisite for using TLA. The irradiation of machine parts could be carried out in those countries that already have an appropriate accelerator. Such an approach would obviate the need for a large capital investment to construct an accelerator facility, and it would speed up the technology's transfer to the developing world.❐

Depth distribution of cobalt-58 in irradiated iron

Distance from surface (micrometers)	Activity of cobalt-58 (relative unit)
0	1.000
40.6	0.992
82.3	0.982
120	0.970
159	0.957
197	0.940
234	0.916
270	0.896
306	0.874
341	0.842
376	0.806
409	0.779
442	0.748
473	0.705
505	0.657
535	0.605
565	0.551
593	0.491
622	0.432
648	0.378
675	0.323
693	0.272
726	0.229
749	0.183
773	0.143
795	0.107
816	0.074
837	0.050
856	0.026
875	0.014
893	0.004
910	0.001

Note Irradiation by protons at initial energy of 22 MeV