

Overview of the Bulk Activation Radioactive Tracer Test Method

Radioactive tracer technology is an important tool for measuring component wear on a real-time basis, and is especially useful for measuring component wear in operating engines. To illustrate this measurement technique, work using bulk activated tracers to measure connecting rod and piston ring wear is described below. To facilitate these measurements, new connecting rod bearing sections and top compression rings were exposed to thermal neutrons in a nuclear reactor, and then installed in the test engine. Simultaneous irradiation of each group of parts produced artificial radionuclides that were separately characteristic of the ring and bearing wear surfaces. Gamma rays emitted from radionuclides of irradiated wear particles abrading from these parts during engine operation served as detectable tracers as the particles circulated in the lubrication system (Figure 1). Measuring the level of radiation associated with these particles using a gamma ray spectrometer provided a direct measure of the mass of wear particles present in the oil at the time of measurement (Figure 2). When corrected for natural radioactive decay and compared to calibration data, these measurements gave the direct amount of wear suffered by the parts during a given test period. With this technology, it was possible to measure ring and bearing wear simultaneously, in real-time, without disassembling the engine for inspection.

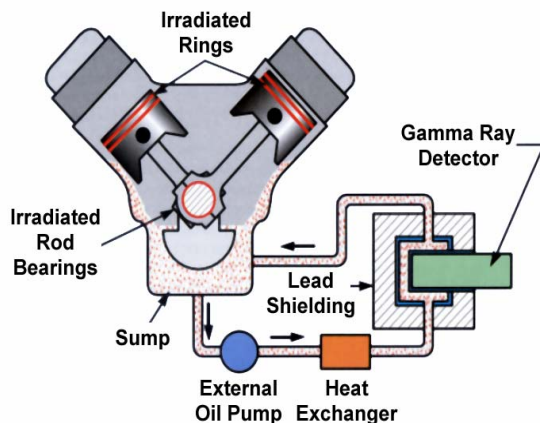


Figure 1. Schematic of Sampling Loop; Detector Monitors Gamma Ray Tracers from Irradiated Wear Particles



Figure 2. Engine and Detector in Engine Test Cell

Because this method is highly sensitive, very small changes in wear were accurately detected and quantitatively measured, allowing meaningful tests to be accomplished over very short test periods (typically a few hours). The amount of wear measured per test (typically micrograms) would not have been detectable by physical inspection. Furthermore, since physical inspection of the parts was not required, possible changes in material clearances and in the engine's wear state were avoided, hence test-to-test continuity was maintained such that sequential tests provided meaningful results.

The ability to measure wear using bulk activated tracers depends on the ability to develop appropriate radionuclides during neutron activation. This, in turn, depends heavily on the metallurgy of the wear surfaces of interest, and becomes especially important when more than one part is being considered. To measure wear from two or more parts simultaneously, it is necessary to produce at least one suitable radioisotope (tracer) in each part that is characteristic of the parts wear surface, yet mutually exclusive so that each part is uniquely tagged. When each part provides at least one unique tracer, the gamma spectra produced by monitoring the wear debris during testing can clearly show each part's contribution to wear as a function of time. This is because the frequencies (or energies) of the gamma rays emitted from the radioactive wear particles are uniquely characteristic of a given isotope and serve to identify it. In addition, the intensities of the gamma rays are proportional to the amount of the isotope present. Tracers used in this example were Cr-51 for the ring faces, Fe-59 for the ring sides, and Sn-113 for the bearings, each with a half-life of 27.7, 44.5, and 115.1 days, respectively.

Prior to irradiation, ring and bearing material specifications were reviewed, and metallurgical analyses were conducted on actual ring and bearing surfaces and cross sections to confirm their potential for producing suitable tracers upon neutron activation. X-ray fluorescence scans were used to determine elemental content of the wear surfaces and their distribution as a function of depth from the wear surfaces. Two requirements were necessary. First, the wear surfaces and their near surface materials must contain elements that will produce suitable isotopes upon irradiation (some strong gamma-emitting radionuclides, with non-overlapping energies). Second, the isotope-producing elements must be homogeneously distributed within the surfaces through the depths of interest. A representative SEM photomicrograph and elemental analysis data for typical bearing are given in Figure 3.

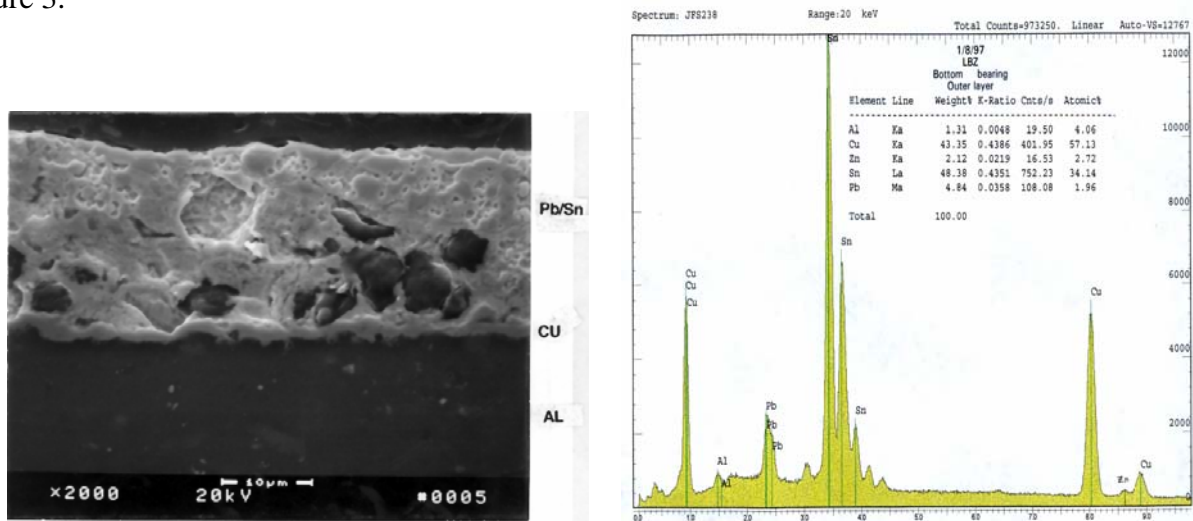


Figure 3. Scanning Electron Photomicrograph of Bearing Showing Lead-Tin Wear Surface, Copper Diffusion Barrier, and Aluminum Layer (Iron Base not Shown), with Corresponding Metallurgical Data.

Total radioisotope activity after irradiation depends on the specific metallurgy and mass of the

rings and bearings that are actually sent to the reactor, on the neutron flux density in the reactor, and on the time of ring and bearing exposure to this flux. Total activity in the engine depends on the number and activity of the installed rings and bearings and on the amount of time these components have been out of the reactor prior to installation.

Because gamma-ray spectrometers measure the number of gamma rays emitted from the activated wear particles, as well as their energy levels, charting activity and the rate of change in activity within particular energy bands of interest (for Cr-51, Fe-59 and Sn-113) gives a clear picture, after converting from activity to mass, of total ring and bearing wear as a function of test time. During testing, activity was repeatedly measured (numerically) as counts per unit time over a relatively short time interval of ten minutes. These discrete data points provide numerical averaging with a relatively long time-constant. Consequently, they are considered to be more accurate than, for instance, continuous strip chart data, which are based on much shorter counting times.

As noted, the test engine was equipped with a sampling loop (ref Figure 1) which continuously directed a portion of the crankcase oil to the detector, which measured the gamma activity of the irradiated wear particles as they accumulated in the oil stream over discrete time intervals during testing. This produced a sequential series of gamma spectra for each test. Because of differences in metallurgy, and therefore in the isotopes produced during irradiation, ring and bearing wear was separately detectable by analyzing data from specific regions of interest in each incremental gamma spectrum. An essential step in the process of radioactive tracer wear measurement is calibration to relate measured radioactivity data to wear metal mass.

The overall data reduction process can be summarized as follows: First, all activity spectra for a given test run are analyzed to determine net activity in the appropriate regions of interest, then corrected for natural radioactive decay. Next, initial background activity (also decay corrected) is subtracted to normalize the start of each test to zero. (Recall that after each test, the engine lubrication system and sampling loop, including the cell housing the detector, are thoroughly flushed to remove residual wear particles. Nevertheless, some background radiation is likely to remain, and this must be subtracted from the count data obtained during the subsequent test. Background activity is determined from pre-test measurements with sample loop circulation on, but with the engine off.) Activity data are then converted to give metal mass. End of test wear levels for each test, showing cumulative wear, are statistically analyzed and plotted for each series of test as a function of time to show bearing and ring wear trends with time and simulation condition. This is necessary to consider the wear response to each simulation and the affect that previous testing may have on any given test or test series. Since wear experienced during each test is irreversible, carryover affects may influence subsequent tests during sequential testing.

Along with the real-time activity data being accumulated for each test run, bottle sampling is accomplished before and after each test. Cumulative wear, calculated from the real-time data, is compared with net activity from the bottle samples as a further check on data integrity. The ratio of these results should track well, although the ratio is usually not equal to 1 because of differences in the engine test cell and laboratory counting geometries, counting times, and sample volumes.

Two radioactive test methods are commonly used in engine wear studies, namely, surface or thin layer activation (SLA/TLA) and bulk activation (BA), as described above. The choice of

method for any given project depends on specific test objectives, component metallurgy, configuration or site particulars, or other factors that may favor one method over the other. Much of our recent work has been accomplished using the bulk activation method because of its increased sensitivity, which allows better definition of cause-and-effect relationships and shorter test times. The responsiveness of this method is illustrated in Figures 4 and 5. Here changes in wear and wear rate are observed almost simultaneously with changes in engine operation. As noted, this is a major advantage of the bulk activation, radioactive tracer, test method, and would not show up during conventional wear testing. Radioactive tracer technology, bulk activation and SLA, is not limited to engines, but can be used with many other mechanical components, such as pumps, fuel injectors and transmissions, as long as suitable metallurgy is present to provide measurable radionuclides after irradiation.

