by Bob Neves

Everything You Wanted to Know About X-Rays and Ray Guns, But Were Afraid to Ask

A classic science fiction weapon is the "ray gun." Both aliens and humans alike use rays to zap, disable, and destroy. From "Flash Gordon" to "Han Solo" to "Captain Janeway," the ray gun is the weapon of choice in Hollywood's vision of the future. As you can probably tell, I am a sci-fi buff, and I have quite a collection of ray guns from a variety of science fiction genres. This uniquely qualifies me to speak on the subject of x-rays and their uses in our terrestrial industry.

I'm sure you're full of questions. Just what are x-rays? Are there Y & Z rays? When will we be able to vaporize the neighbor's pesky cat with a ray gun? Why did Captain Kirk always get the girl in every episode? I will do my best to answer these and many more questions in this column.

Science fact, although not as glamorous as science fiction, has actually taken the concept of the ray gun and put it to constructive use. X-rays are used to check for broken bones, detect cancer, scan for guns at the airport, see inside sealed objects, analyze 2000-year old mummies, and inspect for cracks in welds and airplane structures. Regarding the electronics industry, X-rays are used to find voids in solder joints, determine the alignment and registration of circuitry, measure surface finish plating thickness & composition, and detect surface contaminates. There are also many applications in the Plastics, Oil, and Mining & Metals industries for x-ray tools. In contrast to science fiction, real science has come up with constructive ways to use these rays.

What Are X-Rays?

X-Rays are very high-energy electrons that zip about at several thousand electron volts. These high-energy electrons exist naturally as decaying particles streaming off of radioactive isotopes, and in fact many of these isotopes were originally used to produce x-rays in a variety of commercial x-ray based applications. X-rays that come from the radiation of an isotope have a unique energy voltage level that is distinct to isotopes from which they are created, and are therefore limited in usefulness and what they can measure. They are also typically low in energy, decay rapidly, and are expensive to replace. Today, x-rays are typically produced in x-ray tubes similar to those you have seen at the hospital (on E.R.) or at your dentist's office. These x-ray tubes work by freeing electrons using a high voltage power supply, and accelerating them towards a metal target fixed in the tube at energies of several thousand electron volts. When these high energy electrons hit the metal target, x-rays are then produced and directed out of the tube. The composition of the target used in the x-ray tube determines the energy level of the x-rays that exit the tube.

Each atom in every element we know has electrons orbiting around its nucleus in orbits that are designated with sequential letters of the alphabet starting with the letter "K." I don't know exactly why they started out with "K" but I'm sure there was a good reason at the time. As the electron orbits move out away from the Nucleus, the letters of the orbits go up (L, M, N, etc.). When a sample material zapped with high-energy x-rays streaming from a radioactive isotope or x-ray tube, electrons are ejected out from one or more of the orbits around the nucleus of the atoms in the sample material (see Figure 1 on next page). This ejection creates electron "holes" in one or more of the orbits around the nucleus. Atoms in general, are not too happy about this, and promptly fill these holes with electrons that are in orbit further out. When this "filling in" process occurs, the atom releases energy in the form of an x-ray. This energy release phenomenon is known as "fluorescence." Each element has a distinct way of replacing the ejected electrons and, in turn, the energy level of the x-ray radiated off by the fluorescence caused during the electron hole filling is unique to each element. The concentration of an element in a sample material is directly proportional to the quantity of x-rays given off at the "element specific" energy levels generated by fluorescence of the sample.

They Glow When Zapped

Some great scientists (Wilhelm Roentgen, Max Planck, and others) recognized this phenomenon and decided that if we could measure and quantify the energy levels from the x-ray fluorescence (XRF) of the atom, we could determine the relative quantity and composition of elements that are present in an unknown material.

By collecting the emitted x-rays and measuring their energies or wavelengths against their intensities, the elements in a sample can be both identified and quantified. Moving this idea into practical applications has created a whole industry around the x-ray fluorescence

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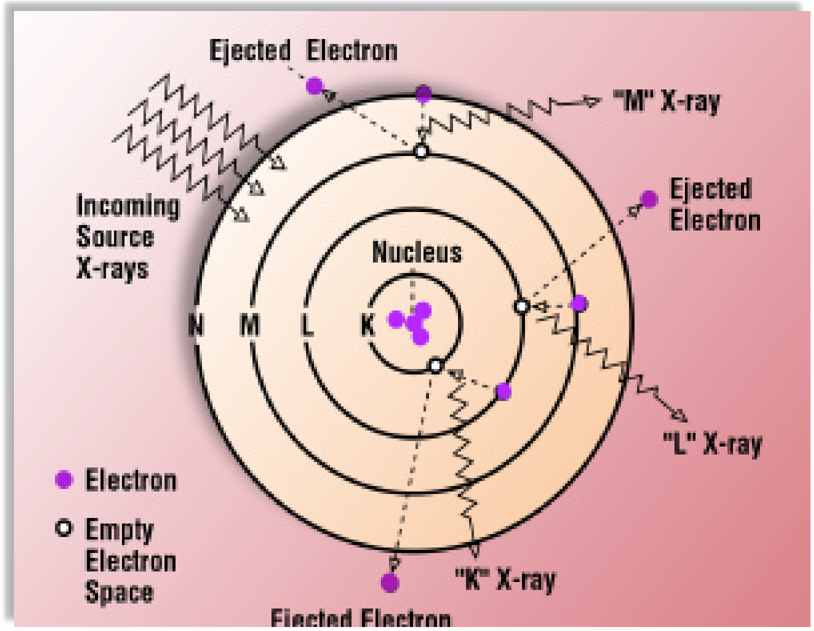
phenomenon. Early applications of this technology were in the fields of alloy identification and coating thickness measurement. Coating thickness applications found their way into the printed wiring industry in the form of Beta-Backscatter units that used radioactive isotopes as the x-ray source. Beta-Backscatter replaced microscopic cross-sectioning in many thickness-related applications because it was non-destructive, and had the ability to resolve thinner coatings than possible with micro-sectioning. In the last ten years, XRF coating measurement systems using x-ray tubes have replaced Beta-backscatter systems because of the lower random error and ability to measure several plating layers on the small samples our industry is building today.



Ray Gun Blueprints

Let's get down to the nuts and bolts of a basic x-ray fluorescence measurement system. The XRF actually consists of an x-ray source, detector, and a computer to analyze the data. The XRF detector counts the number of x-rays at each energy level detected within the area defined by the x-ray source and feeds this information to the computer. The more energy of the incoming x-ray source, the deeper into the sample the detector can pick up those radiated x-rays that are created when the atom replaces its electrons. The computer then compares the energy levels that are radiating from the sample to the known elements in its memory, and can correlate the energy levels measured to elements present. The tricky part is what to do with the information on the quantity of x-rays are being radiated by each element. This is where the computer really goes to work trying to determine what percentage of each element is present in the sample. The thickness of coated materials can also be calculated if the density of the coating and calibration standards are employed.

Calibration is the key to XRF composition analysis and coating thickness measurements. Unfortunately our friends at NIST only offer two Standard Reference Materials of use in XRF measurement: gold on nickel (SRM 1399b) and tin-lead composition (SRM 1131). Industry vendors manufacture other standards using NIST test methods that typically involve measuring the weight gain of a coating over a known area of substrate material using NIST-traceable weights. These standards typically have an accuracy in the neighborhood of ±5 percent. Since XRF units use calibration standards to determine thickness and composition, it is important to have a standards library in several thickness/composition ratings so that accurate comparisons to the unknown samples can be made.

Do You Need a Ray Gun?

XRF measurements are more important now then they have ever been. With the advent of choices in surface finishes (bondable gold, solderable gold, tin/nickel, tin/lead), having the right thickness or composition of the surface will determine the quality of the connection that can be made to that surface. Ray guns don't come cheap, but many labs provide ray gun services so that it is easy and inexpensive to get your parts zapped without all of the up-front costs of owning your own.

To answer the last question I'm sure you're wondering about, Captain Kirk did not always get the girl in every episode because of the size and power of his ray gun; he got the girl because of his fluorescent personality (when compared to Spock!).