31. Mass Spectrometers

Mass spectrometers capable of measuring ions of 230 atomic mass units or greater and having a resolution of better than 2 parts in 230, as follows, and ion sources therefor:

31.1. Inductively coupled plasma mass spectrometers (ICP/MS);

31.2. Glow discharge mass spectrometers (GDMS);

31.3. Thermal ionization mass spectrometers (TIMS);

31.4. *Electron bombardment mass spectrometers which have a source chamber constructed from or lined with or plated with materials resistant to UF_6;

31.5. Molecular beam mass spectrometers as follows:

(a) Which have a source chamber constructed from or lined with or plated with stainless steel or molybdenum and have a cold trap capable of cooling to 193 K (–80°C) or less; or

(b) *Which have a source chamber constructed from or lined with or plated with materials resistant to UF_6.

31.6. *Mass spectrometers equipped with a microfluorination ion source designed for use with actinides or actinide fluorides.

Introductory Note

Mass spectrometers are composed of three basic systems: an ion source, a mass analyzer, and an ion detection system. Mass analyzers come in a variety of types, including bending magnets, quadrupole lenses, quadrupole ion traps, and charged deflection plates. The detection system can also be built around a number of different devices, such as a Faraday cage or an electron multiplier. High performance mass spectrometer systems can be constructed from subassemblies that are common off-the-shelf items or can even be fabricated by students in a modern university shop.

This entry does not include exports of certain especially designed or prepared magnetic or quadrupole mass spectrometers capable of taking on-line samples of UF_6 from the feed, product, or tails streams of a uranium enrichment facility. Such mass spectrometers are covered in sections for isotope enrichment equipment. (See previous chapter.)

Typical Appearance

As Manufactured: Mass spectrometers vary in size and complexity from simple suitcase-sized instruments that cost thousands of dollars to complex, very heavy instruments costing a million dollars or more. Mass spectrometers and mass spectrometer ion sources that are covered by the specifications above vary widely in appearance. Furthermore, those that are controlled and those that are not may have the same external appearance. It is the type of ion source, an internal component, and the resolution, determined by the design of internal components that determine whether the spectrometer meets the criteria. Examples are described below.

31.1. Inductively Coupled Plasma Mass Spectrometers (ICP/MS)

A complete ICP/MS is shown in Figure 31.1.1. It consists of a quadrupole mass analyzer with a resolution better than 1 part in 300 and an inductively coupled plasma ion source. The spectrometer is controlled by a computer, which can be seen on the right side of Figure 31.1.1. The critical component is the ion source, in which samples consisting of gases or solids in aqueous solution can be ionized by aspirating or injecting them into an inductively coupled plasma (ICP) torch.

Figure 31.1.1. A typical inductively coupled plasma mass spectrometer. (Courtesy of Thermo Jarrell Ash Corporation.)

31.2. Glow Discharge Mass Spectrometers (GDMS)

Glow discharge ion sources are characterized by high-voltage electrical connections. Therefore, a high-voltage warning label may be attached to the instrument.

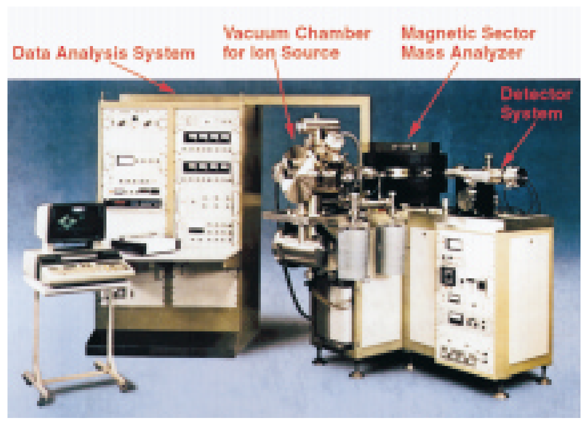

Figure 31.3.1. A TIMS system with a magnetic sector mass analyzer.

31.3. Thermal Ionization Mass Spectrometers (TIMS)

Figure 31.3.1 shows a complete TIMS system. The ion source distinguishes a TIMS from a GDMS. Thermal ionization sources have one or more filaments. The sample to be analyzed is deposited on a filament and vaporized as the filament is heated.

31.4. *Electron Bombardment Mass Spectrometers

A complete electron bombardment mass spectrometer is shown in Figure 31.4.1. The angular geometry of the spectrometers, shown in Figures 31.3.1 and 31.4.1, is characteristic of systems with magnetic sector mass analyzers. The electron bombardment source is usually used to ionize gases and volatile liquids. Atoms and molecules of the sample material enter the ionization chamber, where they are ionized when bombarded by a stream of electrons. Ions formed in the chamber are accelerated into the mass analyzer by a system of charged plates called an ion lens. The lens focuses the beam of ions for injection into the mass analyzer through an exit slit plate. An electron bombardment ion source is installed in a vacuum chamber (usually a cylindrical stainless steel vessel) such as those that can be seen in Figures 31.3.1 and 31.4.1. Electrical connections from the source assembly to the exterior of the vacuum chamber are made by feedthroughs with ceramic insulation. High-voltage electrical connections and a high-voltage warning label may be associated with the charged plates of the ion lens. Electron

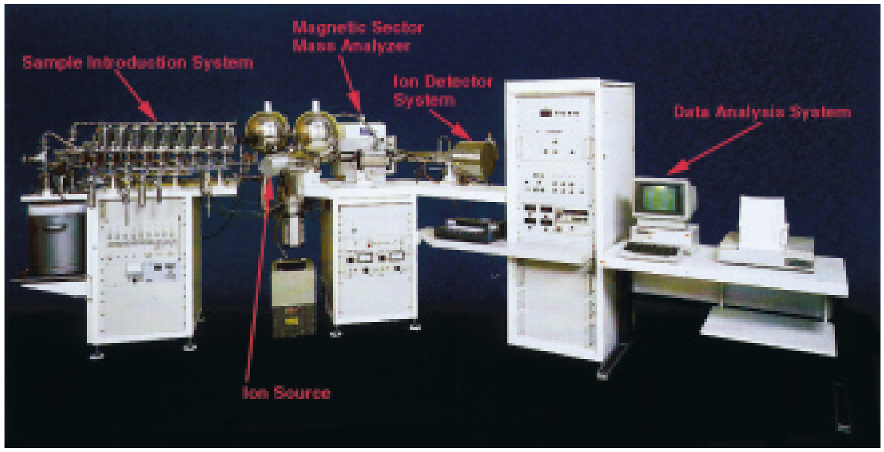

Figure 31.4.1. A magnetic sector mass spectrometer equipped with an electron bombardment ion source. (Courtesy of Finnigan Corporation.)

bombardment ion sources may be used with magnetic, quadrupole, or quadrupole ion trap mass analyzers.

31.5. Molecular Beam Mass Spectrometers

A molecular beam mass spectrometer detects and analyzes charged molecules. Therefore, the ion source for such an instrument includes a system that introduces molecules into the ionization chamber. Ionization could be performed by electron beams, lasers, or microwaves. In most uranium enrichment processes, the molecules of interest are fluorine compounds, notably uranium hexafluoride (UF_6). Therefore, the system that introduces the molecules to the ionization chamber must be constructed from (or lined with) materials resistant to corrosive attack by fluorinating agents such as UF_6. For example, nickel and nickel alloys (such as Monel®) with a high nickel content are suitable corrosion-resistant metals. Ion source components and gas-handling apparatus constructed from such materials may indicate a mass spectrometer that is to be used in a uranium enrichment facility.

31.6. *Mass Spectrometers Equipped with a Microfluorination Ion Source

Introductory Note

A microfluorination ion source includes a small chamber in which nonvolatile actinide source material can be fluorinated to form a volatile fluorine compound. The fluorine compound can then be introduced into a conventional ion source suitable for gas phase samples, such as an electron bombardment source. For example, a solid uranium compound can be fluorinated to form UF_6.

A shipment containing large electromagnets (including coils and pole pieces) may indicate a mass spectrometer. However, not all mass spectrometers use magnetic mass analyzers. Vacuum components with numerous electrical connections may also indicate that a mass spectrometer is being shipped. A high-voltage warning label is another notable feature of some mass spectrometers. Mass spectrometers may have a nameplate listing information that can be used to identify the instrument.

As Packaged: Figures 31.1.1 through 31.4.1 show that complete mass spectrometer systems consist of several subsystems, each of which may be packaged in a separate shipping container. Each component is encased in protective packaging material, such as Styrofoam® and placed into a cardboard box, which may then be placed into a wooden shipping crate. Numerous packages will be associated with a mass spectrometer shipment. Each major subsystem – the ion source, the mass analyzer, and detector – is likely to be packaged separately. Additional packages may include a computer and software, electronic controls, and a vacuum pumping system.

Spectrometers are usually shipped to the site where they are to be used, and a manufacturer's representative travels to the site to assemble the system and verify that it functions properly. Often, the system is evacuated and charged with a slight positive pressure using an inert gas such as argon. If a vacuum pump of the oil diffusion type is attached to the spectrometer and the pump is charged with oil, the shipping container may be fitted with a tip sensor, which detects and records tipping motions of sufficient magnitude to cause the oil to flow out of the pump and contaminate the rest of the vacuum system.

Cautions: Spectrometers pose no hazard to the person opening the shipping container. However, the instruments are delicate and should be handled with care to avoid damage. Knobs and valves should not be turned.

Nuclear Uses

Nuclear uses of primary concern are the determination of isotopic abundances of uranium, plutonium and other actinides. Samples to be analyzed are usually nitrate compounds in reprocessing facilities, fluorine compounds in enrichment facilities, and metallic forms in nuclear explosive device fabrication facilities.

32. Instrumentation and Process Control Systems for Use in Enrichment (SC II)

Instrumentation for monitoring temperature, pressure, pH, fluid level or flow rate specially designed to be corrosion resistant to UF_6 by being made of, or protected by, any of the following materials:

(a) Stainless steel;

(b) Aluminum;

(c) Aluminum alloys;

(d) Nickel; and

(e) Alloys containing 60% or more nickel.

Introductory Note

Pressure-measuring devices have means by which they can be connected to process lines as well as electrical connections for the electrical input and output signals (see Figure 32.1). Pressure ranges and manufacturer's information (model, serial number, etc.) are typically provided on a nameplate attached to the transducer itself. Sheathed thermocouples have electrical connections for output signals. Most industrial thermocouple probes have quick disconnect fittings for ease of use in the process environments, as shown in Figure 32.3. As indicated in the language of this Annex 3 entry, the surfaces of these instruments that come in contact with the process fluid are likely to be made from or protected by materials that are resistant to the corrosive uranium hexafluoride (UF_6) gas.

Figure 32.1. Capacitance diaphragm pressure transducer.

Typical Appearance

As Manufactured: Pressure-measuring transducers that could be used to measure the pressure of UF_6 gas as it is processed in a uranium enrichment plant are shown in Figures 32.1 and 32.2. Capacitance diaphragm transducers can be used to measure pressures in the range from about 0.001 to 105 Pa or even higher. Capacitance transducer housings may be cylindrical, as shown in Figure 32.1, or box-shaped. The transducer shown in Figure 32.1 is typical of those that could be used in a gas centrifuge uranium enrichment plant. Its cylindrical housing is about 65 mm long with a diameter of about 75 mm. The tube that connects the housing to the process gas is about 125 mm long and has a diameter of about 15 mm. The unit weighs about 0.9 kg.

A sheathed thermocouple that could be used to measure UF_6 temperature is depicted in Figure 32.3. Standard sizes of sheathed thermocouples are from 153 to 610 mm in length with diameters from 1.6 to 6.4 mm.

As Packaged: These sensors and instruments are usually packaged in form-fitting Styrofoam® protective material and placed in cardboard boxes for shipment. In addition, the more sensitive transducers will be shipped in a sealed plastic bag, surrounded by bubble wrap, and packed in foam packing material.

Nuclear Uses

Pressure and temperature measurements are made in the process streams of uranium enrichment plants in which the process fluid is UF_6 gas (gas centrifuge and gaseous diffusion) or a mixture of UF_6 and a carrier gas [molecular laser isotope separation (MLIS) and the aerodynamic processes].

Figure 32.2. Vacuum gauge display unit and sensors.

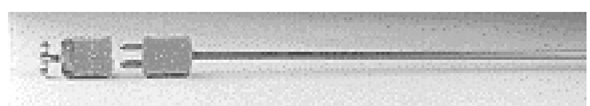

Figure 32.3. Sheathed thermocouple with quick disconnect.

33. *Software Specially Designed for the Control of Uranium Enrichment Plants or Facilities

Introductory Note

Supervisory control and data acquisition (SCADA) software is user customized for a given application. Therefore, the graphical user interface could appear quite different even with the same software package. Although detailed examination of a computer-generated process flow diagram could show that the software has been customized for uranium enrichment, it may be difficult to distinguish SCADA software for chemical processing facilities from that developed for an enrichment operation.

Typical Appearance

As Manufactured: SCADA software systems are widely available for remotely controlling and monitoring facilities over traditional communication channels. A typical graphic user interface is shown in Figure 33.1. SCADA software can perform data logging and archival, trend analysis, alarm monitoring, and process control and can be customized for a particular application. SCADA terminals are connected to remote terminal units that provide local process control through programmable logic controllers. A number of suppliers provide SCADA software packages for the Microsoft Windows, Windows 95, and Windows NT operating systems. Process control software has also been developed to run on early personal computers, mainframe computers, and workstations under other operating systems such as UNIX and MS DOS.

As Packaged: SCADA software is provided in a variety of media including floppy disks and CD-ROMs. These are packaged along with manuals in cardboard boxes typical of the software industry.

Nuclear Uses

Commercially available software can be customized to remotely control and monitor uranium enrichment processes. Alarm monitoring and set point adjustment, as well as data logging, trending, and archival, can also be provided by such software packages.

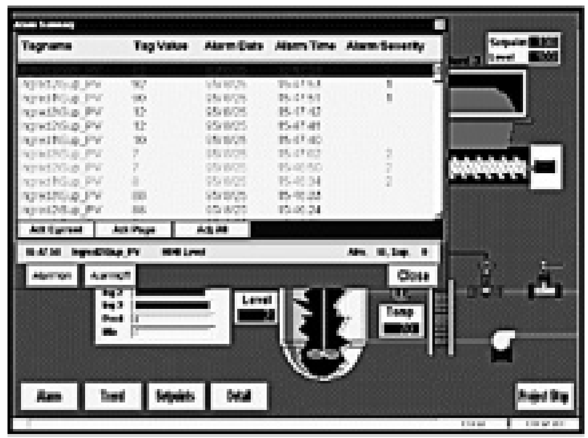

Figure 33.1. Graphical user interface for a typical SCADA software package.

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