5.7. Scientific Instrument.

The IUE scientific instrument (SI) collects the astronomical data and is designed to obtain ultraviolet spectra of astronomical objects down to a faint limit of approximately or equal to fifteenth magnitude. The SI consists of two assemblies. The optical unit includes the sunshade, telescope, spectrographs, four spectrograph cameras and two FES's. The electronic assembly includes the experiment electronics assembly (EEA), two FES electronics modules, camera system interface unit (CSIU), and camera electronics box (CEB). The figure 5-72 shows the distribution of these units.

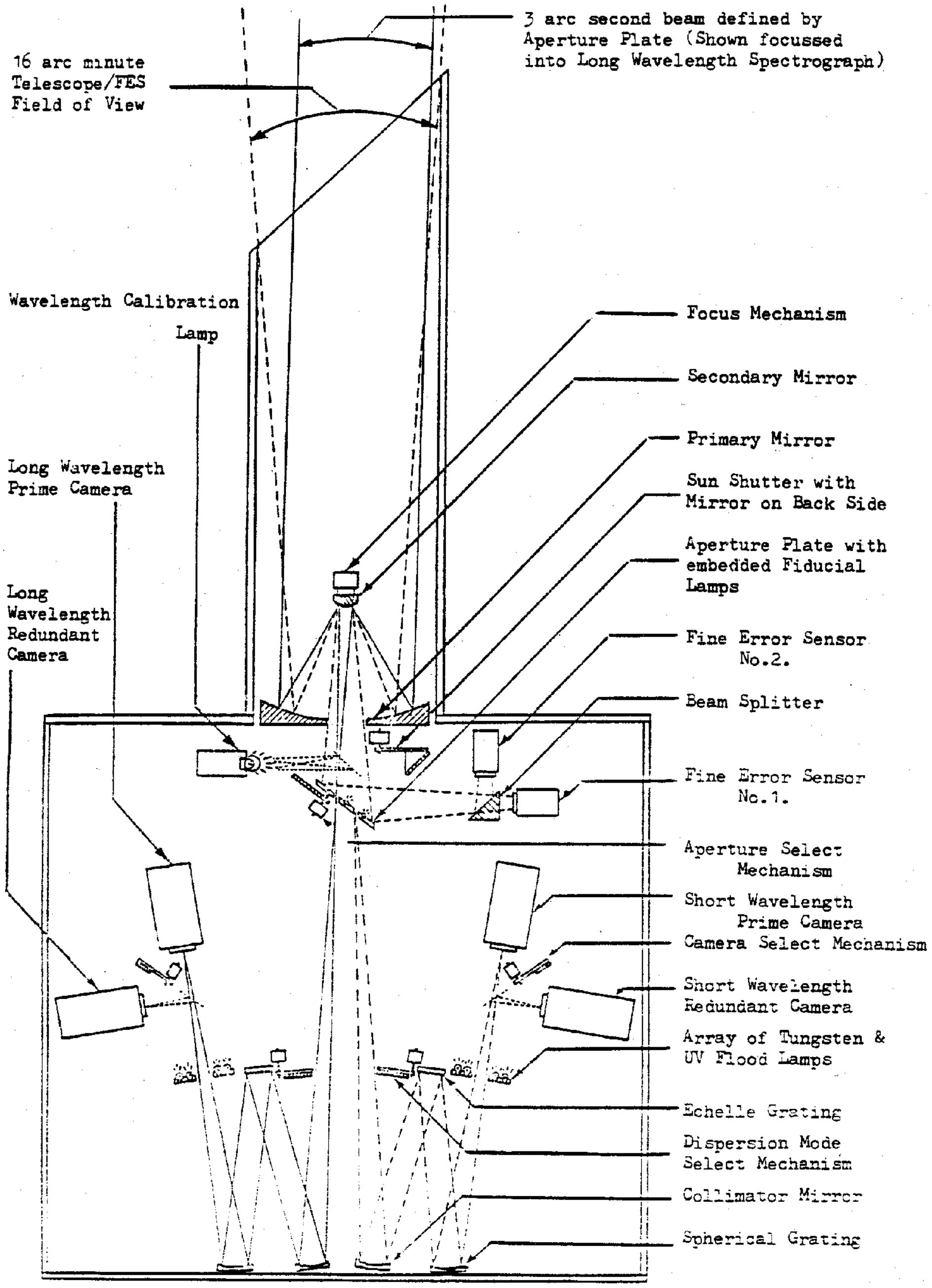

Figure 5-72. Detailed Optical Schematic of the IUE Scientific Instrument.

Sunshade, Baffling and Shutter.

The sunshade, a hood with a 43° cutaway angle placed over the front of the telescope tube, and the baffle system exclude stray light from the FES's which have longer wavelength response and wider effective passbands per image element than the spectrograph cameras. Test and calculations indicated that with the proposed design, scattered sunlight will cause no difficulties in making observations of faint objects down to a magnitude equal to 16.

The sun shutter protects the cameras and FES's from prolonged exposures to high-level sources. The shutter can protect the instrument from direct Earth or moonlight if required, and from direct sunlight for short periods. It automatically closes in the event that excessive telescope illumination is detected by a photodiode. In addition to its automatic mode the Sun Shutter may also be operated by command.

The sun shutter experienced several anomalies along the mission. The most frequent one happened five times, it unexpectedly closed itself without apparent reason. On November 26, 1985 the sun shutter remained in the "slew" mode after the command to close it had been uplinked, it was reopened and closed successfully. Additionally incidents of the anomaly occurred through the remainder of the mission.

Telescope.

The telescope is an f/15 folded reflective optical system used to collect photons from celestial objects and present it to the ultraviolet spectrograph for analysis. It consists mainly of the primary and secondary mirrors and the mechanical structure required to support mirrors.

The telescope gathers light from the object under observation and focuses it to provide the proper image at the entrance aperture of the spectrograph. The telescope, a 45 cm diameter f/15 Ritchey-Chretien design, consists of a beryllium concave hyperbolic primary mirror 45 cm in diameter and a convex hyperbolic fused silica secondary mirror 9 cm in diameter, which produce an image size for the 80% collection ring of 1 arcsecond for a point source of light. The telescope is 130 cm long and has an effective focal length of 675 cm. It provides a 16 arcminute useful field of view at the focal plane.

After launch, the telescope's focus was adjusted to compensate for the extra terrestrial environment. This was achieved by movement of the secondary mirror along the longitudinal axis of the telescope. The mirror was driven by an incremental stepper motor in the focus mechanism. After that, only thermal focus adjustments were made.

Spectrographs.

The spectrographs disperse the on-axis image formed by the telescope into a spectral display at the face of the selected spectrograph television camera. The spectrograph consists of two similar instruments, each of which operates over a selected portion of the spectral range, from 1150Å to 3300Å, and provides a resolution no worse than 0.2Å at any wavelength. The long wavelength spectrograph covers the range from approximately 1800Å to 3300Å and the short wavelength spectrograph from approximately 1150Å to 2000Å.

The spectrograph design permits operation of each spectrograph in either of two modes: high dispersion (1Å/mm)/high resolution (0.1Å) and low dispersion (60Å/mm)/low resolution (6Å), which produce approximately velocity resolution between 10 and 25 km/sec for high resolution and between 600 and 1500 km/sec for low resolution.

Each of the spectrographic instruments consists of an entrance aperture, a collimator mirror, an echelle grating for the high-dispersion mode of operation (replaced by a mirror for the low-dispersion mode), and a spherical diffraction grating, which acts as both a camera mirror and spectral disperser. Its dispersion direction is perpendicular to that of the echelle grating. The echelle grating disperse the spectrum dividing the entire ultraviolet spectrum into many overlapping orders. The spherical gratings separate these orders.

The aperture plate contains four holes, one pair for each spectrograph. The small apertures are nominal 3 arcseconds in diameter. This aperture size, in conjunction with the shade design, will limit the background light to the equivalent of a 16th magnitude object or less. The large apertures, nominal 10 by 20 arcseconds, were the most frequently used. These two large holes could be closed by use of the aperture select mechanism.

The IUE Three Agency Coordination Meeting adopted recommended values for the dimensions of the apertures, which are presented in the table below. These values do not reflect the true physical size of the apertures but rather the size as projected on the camera faceplate.

Dimension	LWP	SWP
Major Axis Trail Length (arcsec)	21.84 ± 0.39	21.48 ± 0.39
Large-Aperture Length (arcsec)	22.51 ± 0.40	21.65 ± 0.39
Minor Axis Trail Length (arcsec)	10.21 ± 0.18	9.24 ± 0.11
Large-Aperture Width (arcsec)	9.91 ± 0.17	9.07 ± 0.11
Large-Aperture Area (arcsec^2)	203.26 ± 9.28	209.74 ± 6.23
Small-Aperture Area (arcsec^2)	6.32 ± 0.86	6.58 ± 0.86

After passing through the selected aperture, the diverging beam is directed to a collimator mirror. The collimate beam then falls upon an echelle grating which produces a spectrum dispersed in one dimension. This dispersed beam is redispersed and focused by a spherical grating providing a two dimensional spectrum display on the camera faceplate. The low dispersion mode is selected by placing a plane mirror in the optical path in front of the echelle, so that the collimate beam is dispersed only by the spherical cross-disperser. The result is a conventional single-dimension spectral display. This low dispersion image is approximately 60 times as bright as the equivalent high dispersion image, but the spectral resolution is degraded correspondingly to 6Å.

Only one camera (prime or redundant) in the active spectrograph (long wavelength or short wavelength) may be used to observe the target at any one time. The prime or redundant camera is selected by the appropriate camera select mechanism. So, redundant cameras are reached by the interposition of a small plane mirror set at 45° to the optical path.

Spectrograph camera system.

The function of the spectrograph camera system is to convert the spectral display from the spectrograph into a suitable video signal. The system uses a Westinghouse WX 32224 SEC television camera tube. The photocathode of this tube, designed for visible light response, requires the use of a wavelength converter to transform the ultraviolet spectral display into visible radiation. The combination of the converter and the WX 32224 SEC vidicon provides a UV wavelength sensitive system in the range of 1150Å to 3300Å. The figure 5-73 shows a diagram of a spectrograph camera.

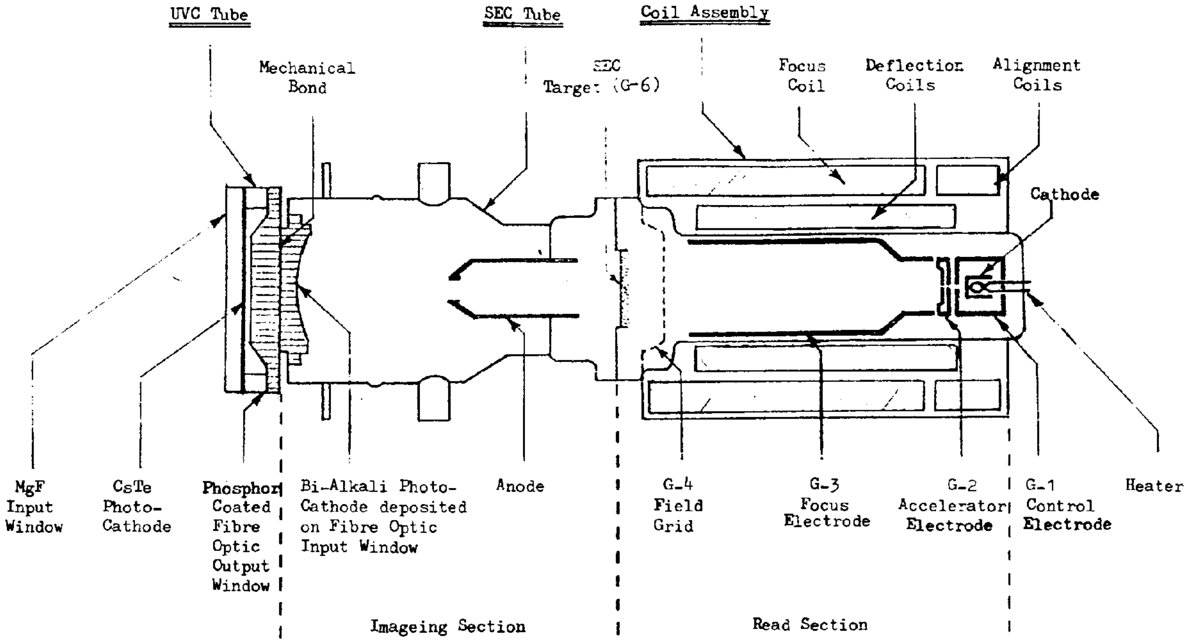

Figure 5-73. SEC/UVC Tube Pair and Coil Assembly.

The converter selected for use in the spectrograph camera is an ITT (type F4122) 40 millimeter proximity-focused UV converter. This tube uses a magnesium fluoride input window with a CsTe photocathode and a fiber optic output window that can be coupled to the secondary electron conduction (SEC) tube. The photocathode converts the incident ultraviolet spectrum into a corresponding photoelectron image. These photoelectrons are accelerated by a high electric field (5 kilovolts across a 1.3 millimeter gap) and proximity-focused onto the output phosphor screen where much of their energy is dissipated in the production of photons of blue light. The yield at the phosphor is typically 60 photons out per photoelectron; with a photocathode efficiency of approximately 15%, the overall gain of the UV is approximately 10 blue photons out per ultraviolet photon in. The efficiency of the screen is maximized by a surface layer of aluminum which reflects backward emitted photons in the direction of the output window and eliminates halation effects because of ultraviolet photons transmitted by the photocathode and reflected back to it.

The converted image from the UVC is transferred by way of a fiber optic coupling to the blue-sensitive bialkali photocathode of the SEC television camera tube. Included in this fiber optic coupling is a set of fiducial marks, a square array of 13 by 13 opaque areas each 100 micrometers square and (2.0 + 0.005) millimeters apart which provides a geometrical reference for the evaluation of the spectra. The photoelectrons generated at the SEC tube photocathode is accelerated through the electrostatically-focused image section onto the target. The target consists of a low-density porous layer of potassium chloride (approximately 10 micrometers thick) supported by an aluminum oxide membrane (approximately 50 nanometers thick) and backed by a thin aluminum signal plate. Some fraction of the energy of each photoelectron is expended in the production of several secondary electrons in the potassium chloride. This energy is swept towards the signal plate by a 12 volt bias across the target leaving a multiplied positive charge image on the target. The secondary electron gain (positive charges on target per incident photoelectron) is a function of the incident electron energy. The gain should be different (around 50, 15 and 5) in function of the voltage setting (6.1 kilovolts, 4 kilovolts and 3.2 kilovolts respectively). Operationally, the maximum voltage was almost always used. The SEC target can integrate and store the image for many hours.

During the readout mode, an electronic beam effectively scans the SEC target in a rectangular pattern of digital steps. The scan parameter counters are decremented in response to a signal generated by the spacecraft data system, so that the read scan is synchronized with the output of telemetry. The beam is deflected digitally to scan a raster maximum of 768 by 768 picture elements (pixels) in 37 micro steps across the image. At each pixel, the read beam is pulsed on by the G1 modulator for 6 microseconds, after allowing time for the deflection amplifiers to settle. The beam recharges the target, giving rise to an output video pulse corresponding to the positive charge on the target at that pixel. The analog video signal is transferred to the DMU.

The LWR and SWP were the normal operational cameras until September 14, 1983. On this date the LWP camera was used as prime until the end of the IUE mission.

Fine Error Sensor.

The FES is an image dissector sensor capable of multimode operation accomplishing the dual role of a field camera, target recognition and acquisition, and fine error sensing for pointing error generation. A more detailed description of the FES is contained in section 4.5.7.

Additionally, the FES functions as a photometer (for providing information on objects brightness). In 1990, it was approved that a data archive should be created consisting of the FES guide star tracking data taken during long exposures. In early November, 1992, the FES streak light anomaly appeared and the photometer archive was found not to be useful any more.

Lamps.

- **Flood Lamps.** The camera faceplate may be illuminated by arrays of incandescent (tungsten filament) or ultraviolet (mercury discharge) flood lamps. The tungsten flood lamps are used in the camera target preparation sequences, and the UV flood lamps are used for calibration purposes.

- **Wavelength Calibration Lamps.** The SI contains a single hollow cathode platinum wavelength calibration lamp which produces a large number of resonance lines over the entire IUE spectral range and is used to generate reference echellograms for both spectrographs. Radiation from this lamp is directed into both spectrographs simultaneously by means of a plane mirror positioned on the back side of the sunshutter which must be closed for the operation.

- **Fiducial and Black-hole Lamps.** Embedded in the aperture plate are small lamps that provide fiducial references for the FES and back-hole lamps that are positioned behind the various aperture openings to illuminate these openings for additional references for the FES.

Heaters.

In order to maintain a proper thermal environment, three redundant sets of heaters are used. Two of the sets are attached to the back sides of the primary and secondary mirrors. The third heater set is attached to the camera deck. Thermal control is provided by powering either the prime or backup heater of each heater set by ground command.

Electronics.

The scientific instrument electronics are required for the following: camera operation, mechanisms control, fine error sensor, power conversion and fiducial and calibration lamp control. The electronics necessary for these tasks are housed within the EEA, the FES electronics box, the CEB and the CSIU. Each camera subsystem consists of a camera head module (CHM) located inside the spectrographs of the optical unit, an associated CEM located in the CEB, and an associated camera supply interface module (CSIM) located in the CSIU.

Flux Particular Monitor.

The Flux Particular Monitor (FPM) senses the environment radiation level the spacecraft is experiencing. The IUE satellite passes through the outer Van Allen radiation belts each day. The trapped particle radiation causes increased fogging on the cameras during the time period of this passage. This radiation background often limits the length of the exposures that can be obtained during this passage.

The radiation levels are recorded as a voltage on the FPM and converted to an equivalent exposure on the camera in DN (digitized video data from the video chain) per hour. The approximate relation for the most sensitive portion of the cameras is: n DN/hr = 10^{FPM} . Typically, the daily variations of the radiation level produced FPM readings between 0 and 3 volts.

Since May 14, 1991 the voltage readings from the FPM became increasingly erratic and did not represent the true radiation environment. Therefore, it was concluded that the FPM was no longer a useful device. On October 4, 1991, the SMSS and FPM were turned off. The SMSS was turned off for two reasons. First, the FPM was a last minute add on to the spacecraft and was tied into the SMSS. Second, the SMSS was only useful during launch.

5.7.1. Camera Operating Sequences.

Camera operations sequences are controlled by commands issued by the ground-station computer in response to keyboard procedure calls. They are conducted in three operational phases: SEC target preparation, camera exposure and image readout.

- **Expose mode.**
  An image may be integrated on the SEC target in this mode where UVC and SEC image section high voltages are on (the readout section of the SEC tube is off).

  The exposure time, SEC image section gain (the maximum gain was the normal one), spectrograph mode (sort/long wavelength, entrance aperture, dispersion) and light source (stellar spectrum or onboard source such as wavelength calibration lamp or UV flood lamp) may be selected by the astronomer according to the needs of the observation. The minimum exposure time is 0.4096 seconds.

- **Read mode.**
  The stored charge image is read out from the SEC target to the ground using a pulsed digitally stepped electron beam. The readout section of the SEC tube is active whilst the image section and the UVC are off. This type of readout is destructive.

  The telemetered video data is sent to the ground in 5.24 minutes with a telemetry bit rate of 20 kilobits.

  The astronomer may select HI or LO head-amplifier gain (LO was normally used). In certain exceptional circumstances, the scan format, other than 768 x 768 pixels, may be permitted. Sometimes, these partial read-outs were done to only read the spectra area to save time.

  In 1989, non-standard partial reads were useful to check how the high solar radiation was affecting the spectra. A small area of the image being exposed was read to check the background. Of course, the image area had to be selected such that the scientific data were not affected. As the effect of these reads on the images was unknown, this procedure was disonlined.

- **Prepare sequence.**
  A prepare operation is carried out before each expose in order to erase all trace of previous images, and to provide a reproducible low-noise pedestal or baseline on which the new image will be superimposed. Several prepare sequences are available; essentially, they all consist of pre-programed sequences of exposures to the tungsten floodlamps followed by read scans. The options are:

  1. Normal Standard Prepare (“SPREP”). Suitable for the majority of observations. It takes around 19 minutes for the LWP camera and around 15 minutes for the other cameras (the tungsten floodlamp exposures must be longer in the LWP) with a telemetry bit rate of 20 kilobits.

2. Fast Prepare ("FPREP"). A fast preparation sequence (around 3 minutes) designed for use when speed of operation is important and some degradation in image quality can be tolerated.

3. High-level Extra Prepare ("XPREP"). Designed to be used following severely over-exposed images. It takes around 15 minutes for the LWP camera and around 4 minutes for the other cameras. This mode must be followed by an SPREP or an FPREP.

5.7.2. LWP Scan Control Logic anomaly.

The LWP camera occasionally experienced problems in performing read scan; the scan was commanded but it did not start at all or did not start at the proper position. This anomaly was named the Scan Control Logic (SCL) anomaly and was first noted during the Commissioning Phase of IUE in February/March 1978. This problem was the initiator for selecting the LWR camera as the prime one in the long wavelength spectrograph.

A ground software fix was written to deal with the bad scans, so the chance of losing an image to a scan failure was very small. Indeed, since the LWP camera was used as prime, the frequency of these bad scans dropped dramatically. Apparently, the camera functions best when used often.

5.7.3. LWP flux anomaly.

A small number of LWP images had lower-than-expected flux levels due to unknown causes. This was detected from spectra of photometrically stable targets during monitoring campaigns, in which an occasional spectrum would have low fluxes compared to other spectra of the same target with similar setup and observing conditions. The LWP flux anomaly was first noted on July 24, 1991.

There were no indications of unusual pointing errors or engineering telemetry changes to account for the flux drop-off, which was about 25% below the expected flux. While the number of affected images is unknown, the number of identified images is believed to be small (on the order of a dozen).

5.7.4. LWR anomaly.

The LWR images were affected by a bright extended spot at the lower edge of the SEC target that was visible in long exposures. It appeared the first time between March 30 and April 14, 1983.The intensity of the spot was a linear function of the exposure time. The maximum intensity of the spot (and consequently its extension) linearly increased with time at a rate of 2.17e-3 DN/minute per day.

It was suggested that the spot was due to a flare in the UV converter. So, the LWR was used with reduced UVC voltage. The LWP camera was used as prime.

5.7.5. Microphonics.

A significant proportion of the spectral images obtained by IUE were affected by periodic noise artifacts (often called “microphonics”). This noise was different for each camera.

- In the LWP camera, the noise was introduced by the roll wheel speed change during maneuvers. However, only the portion of the image which was read down at the time the roll slew was in progress was affected.
- In the LWR camera, this problem was very obvious but was confined to a relatively small band in the image, the interference had all the characteristics of a damped electronic oscillator and pointed to an instability in the camera head preamplifier as a possible source of the problem.
- In the SWP, the noise was introduced by the roll wheel speed change during maneuvers and by the roll wheel spinning below ±100 rpm or above ±400 rpm. In SWP most, if not all, of the image was affected but normally with a lower amplitude than the LWR.

5.7.6. SWP pings.

The SWP pings were characterized by an enhanced noise level of 2-3 DN above normal over a few tens of lines. These had the appearance of an exponentially decaying sinusoid in the raw image and were similar to LWR anomalies, but of much lower amplitude.

They were related to low SWP camera head temperatures (THDA), appearing occasionally when the THDA reached 7.8°C, and becoming common for THDA’s of 7.5°C and cooler.

5.7.7. SWR failure.

The first malfunction of the SWR camera was detected during the initial inflight check-out phase in the period between February 15 and 18, 1978, when all of the sudden the GRID-1 voltage supply went from the nominal value -130 volts ± 2% to 0 volts.

During the continuation of the camera reoptimization on August 23, 1978, the GRID-1 voltage failed again during camera switch on. On this date, several attempts were made to turn on the camera and most of them were unsuccessful. The camera was declared to be not operational.