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Slit scanning X-radiography for LWR fuel rod examination

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POSTER SESSION

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SCOPE OF X-RADIOGRAPHY EXAMINATION

The objective of this examination is to indicate the internal condition of the fuel rod.

In general terms, radiography of fuel rods is intended to provide information on the following points :

- dimensional changes in the fuel stack length
- displacement and fractures in the pellets
- important density changes in the fuel material
- state of the dishing of the pellets and changes in interpellet gaps
- distribution of thermal stress cracks in the fuel pellets
- configuration and extension of the fuel central channel (fast reactor)
- defects in metal internals

For fuel rods of the LWR type, X-radiography is used principally for internal dimensional controls on the plenum and fuel stack length, i.e. dimension of the rod, fuel pellet stack, plenum, length of pellets.

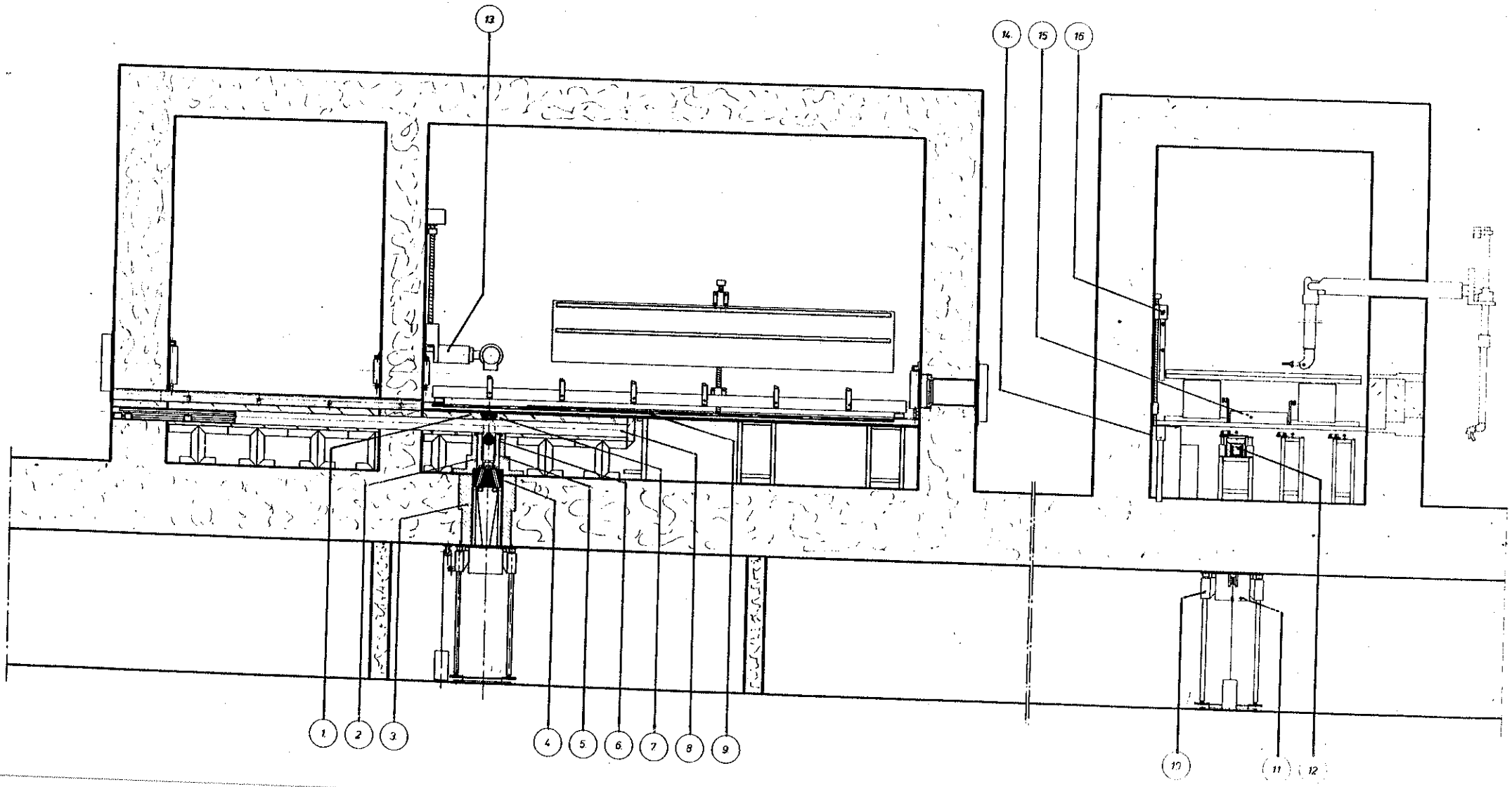
GENERAL ARRANGEMENTS

The slit scanning X-radiography is a travelling inspection method in which the darkening of the film by the γ-radiation of the fuel rod during exposure is reduced by inserting a collimator system between the film and the sample.

In LHMA, an examination bench for LWR fuel rods is operational covering fuel rod lengths of up to about 4.5 m. Fig. 1 shows a schematic drawing of LHMA's slit scanning X-radiography examination systems. Fig.2 indicates the nomenclature related to the scheme.

With the X-ray tube activated, a fuel rod, loaded on metrology bench III traverses a slit collimator synchronously with the X-ray film. The radiograph thus obtained will show the internal condition of the fuel rod and any changes in the fuel stack.

FIG. 1 L.H.M.A. - SLIT SCANNING X-RADIOGRAPHY EXAMINATION SYSTEM



RADIOGRAPHIC INSPECTION

1. LEAD SHIELDING OF FILM CASSETTE TUNNEL
2. LEAD SHIELDING OF ROLL FILM SYSTEM
3. HEAVY CONCRETE SHIELDING
4. LEAD SHIELDING AND FILM GUIDING
5. X-RAY FILM
6. SHIELDED DRUM
7. X-RAY COLLIMATOR
8. FILM CASSETTE TUNNEL
9. FUEL ROD
10. TRANSLATION MECHANISM
11. FILM CAMERA WITH FILM-FEED CARTRIDGE AND FILM-CUTTING DEVICE
12. FILM CASSETTE SYSTEM
13. X-RAY GENERATOR AND IN-CELL FRAME
14. SHIELDED FUEL ROD STORAGE FACILITY
15. ROLL-TABLE
16. FUEL ROD LOADING BASKET

Fig.2 NOMENCLATURE FOR SCHEMATIC DRAWING OF Fig.1

The different rates of specimen and film advancement to be used depend on various parameters such as varying distances of the X-ray tube and film with respect to the specimen, different thicknesses and densities of the specimens, different aperture widths of the collimator, different types of films with different exposure times and the like.

EQUIPMENT

The X-ray radiographic examination of fuel rods is performed on metrology bench III of the LHMA hot cell for non-destructive examinations.
The main elements of the examination stage based on slit scanning type radiography are :

- a fuel rod translation system
- a film translation system for film displacement simultaneously with the fuel rod movement, using either a radiographic camera with roll film or a film cassette cartridge technique
- the X-ray source installation.

(a) Fuel rod translation system

The fuel rod translation system is composed of the following elements :

- A fuel rod supporting table with a length of about 6.0 m backed up by an extension tube fitted with fuel rod support elements allowing scanning translation to be made of fuel rods having a maximum length of about 4.5 m.

- A trolley, driven by a stepping motor system, under computer control, allowing accurate translation of the fuel rod under examination at a fixed distance above the slit of the X-ray radiography collimator.
  On this trolley, a chuck for positioning and clamping of the fuel rod end cap is installed.

- Roller supports fitted on the table and in the extension tube for fuel rod supporting over the entire length.

- The X-ray film denal collimator is installed in a lead shielding construction on top of a hexagonal tube in which a film cassette cartridge will be loaded. The slit width is a compromise determined by the X-ray flux needed and the effect of the γ-background radiation.
  Just beneath the collimator, a window, installed in the hexagonal tube tunnel, is loaded with a small frame onto which thin foils of aluminium and lead are glued.
  The aluminium sheet serves as an α-tight cover of the tunnel keeping the atmosphere separated from the hot cell interior. The lead foil acts as the front intensifier screen during X-ray exposure.

- A copper thickness equalization fixture is mounted on the table in order to reduce excessive radiation and to have a good representation of the contours of the round fuel rod.
  This system also guides the fuel rod under translation during exposure and avoids unsharpness due to vibrations.
  Fig. 3 gives an overall view of the X-ray test bench with a LWR fuel rod under translation movement and the X-ray tube positioned for exposure, while Fig. 4 shows a few details of the X-ray tube in-cell supporting frame and a view on the fuel rod translation tunnel.

(b) Film translation systems

The film cassette cartridge driven by a stepping motor drive unit under computer control will have a translation movement synchronized with the rod movement and almost at the same selected speed. In fact the velocities of the film and the rod have the same ratio as their distances from the focus of the X-ray tube. The length of the cassette has been limited to about 2 m.
The hexagonal tube, in which the film cassette is loaded, has been shielded by lead over its entire length.
Fig. 5 shows a schematic view of the film cassette tunnel with its in-cell shielding and supports, while Fig. 6 gives details of the film loading arrangement.

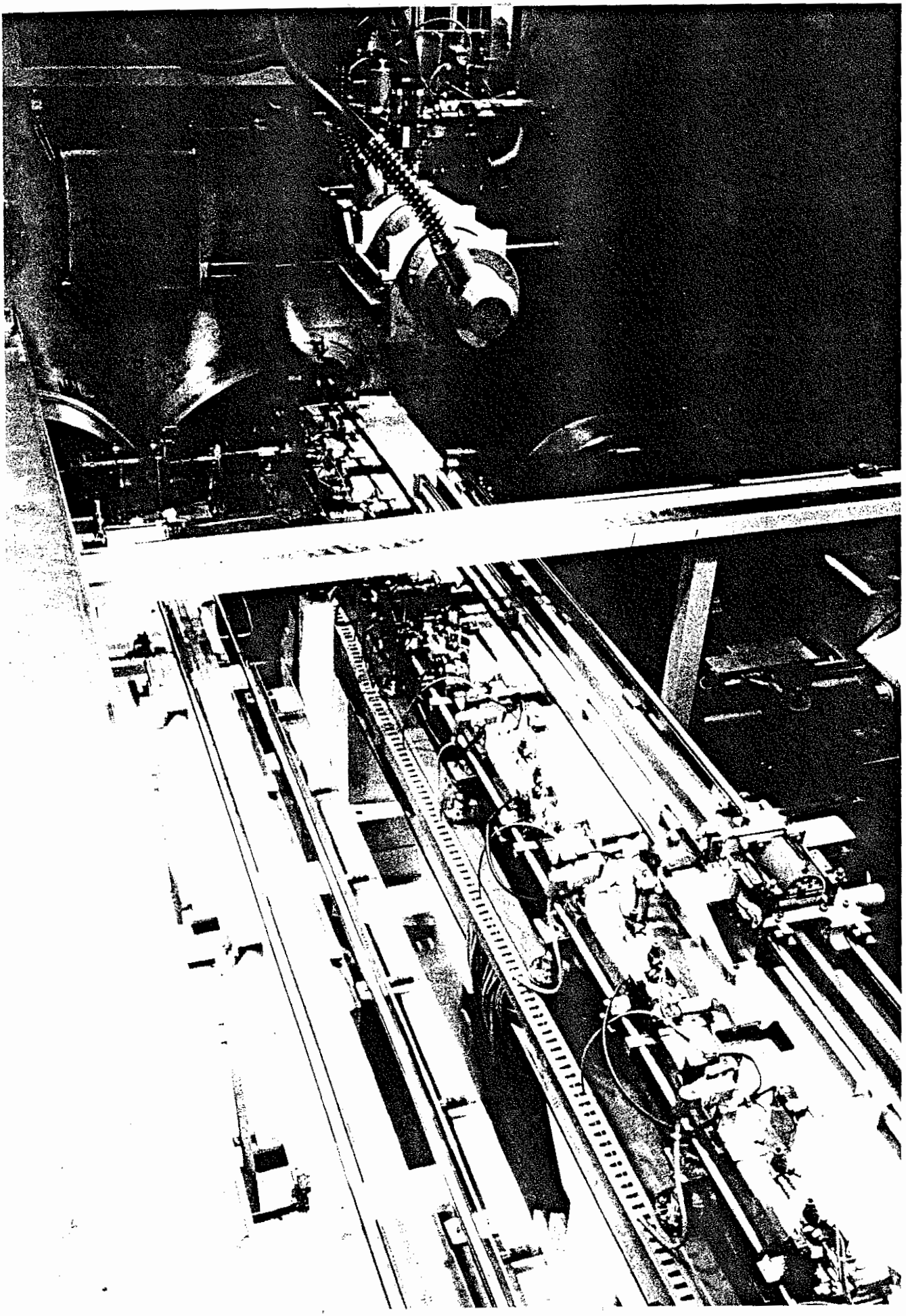


Fig.3 X-RAY TEST BENCH WITH FUEL ROD UNDER TRANSLATION MOVEMENT AND X-RAY LAMP POSITIONED IN LINE.

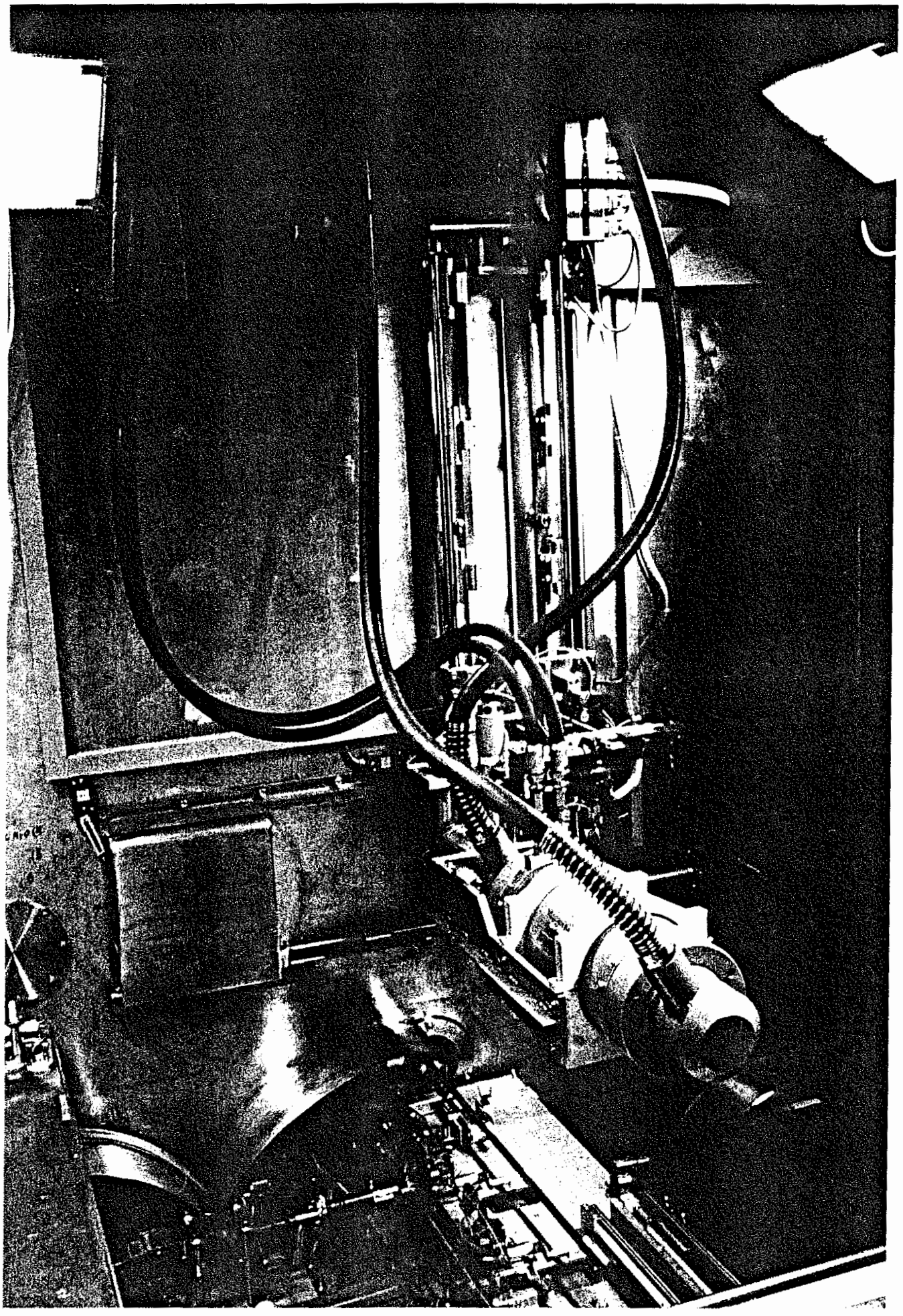


Fig.4 DETAIL OF X-RAY LAMP WITH SUPPORTING SYSTEM. VIEW ON FUEL ROD TRANSLATION TUNNEL.

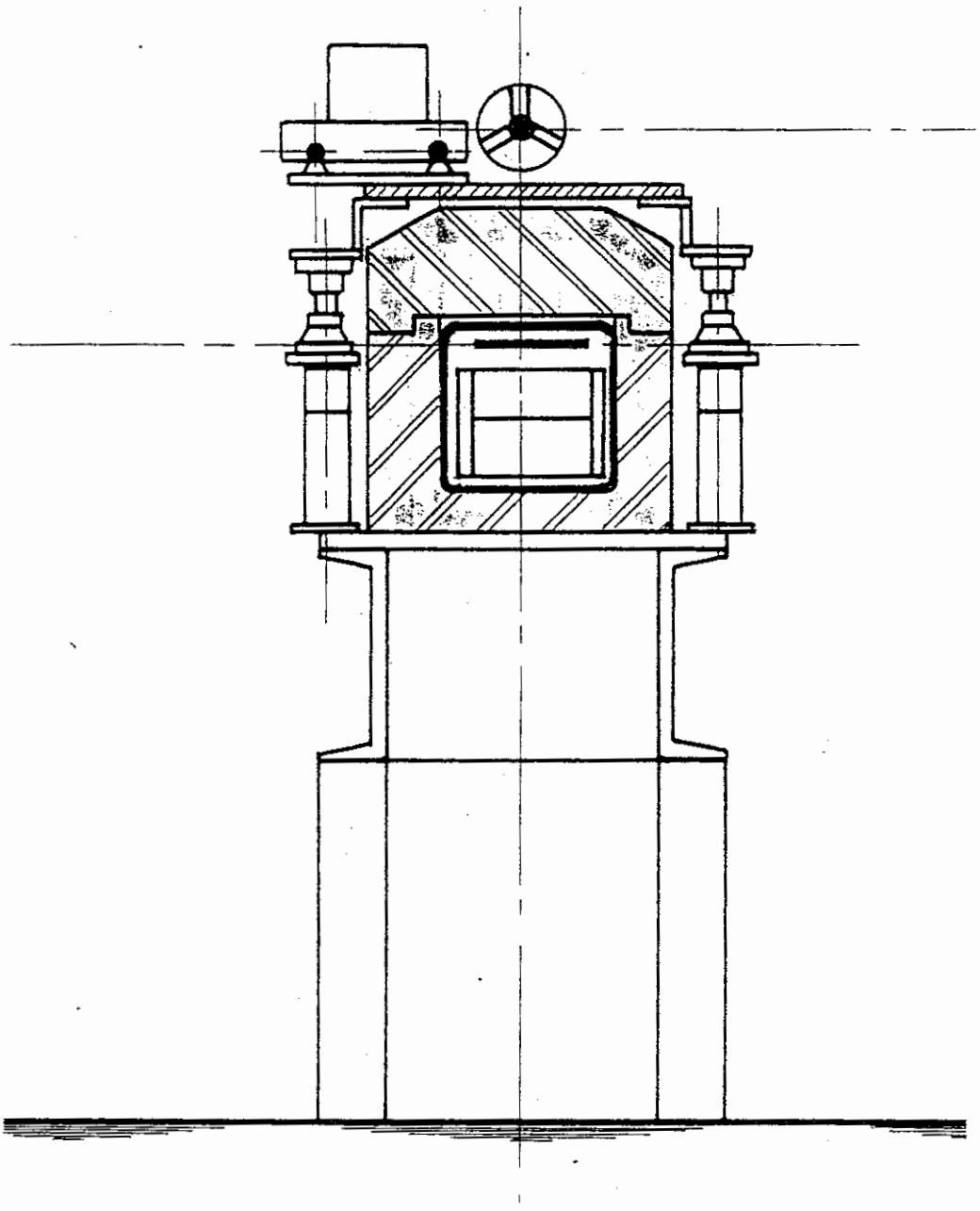


FIG.5 FILM CASSETTE TUNNEL WITH SHIELDING AND SUPPORTS

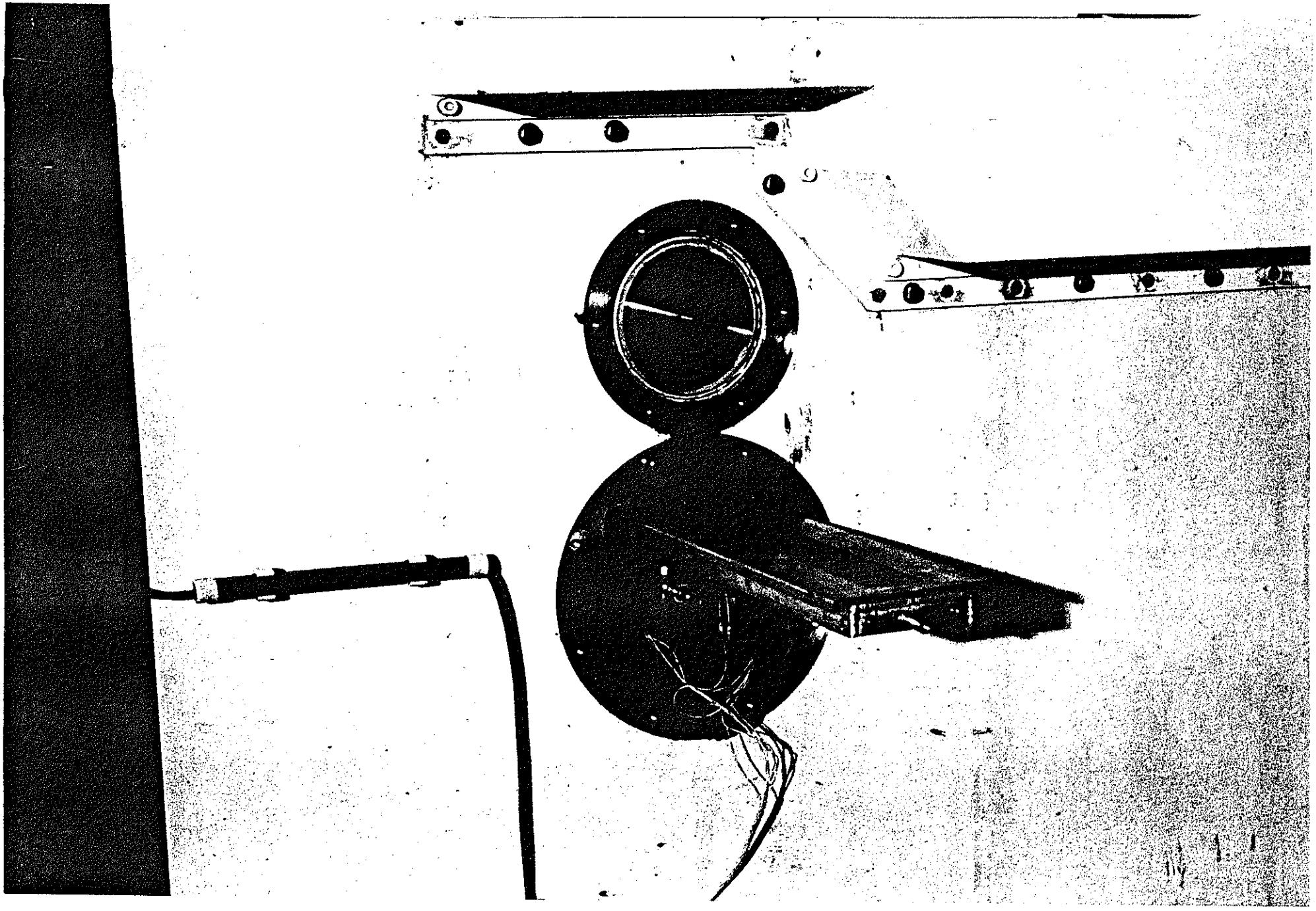


Fig. 6 DETAIL OF FILM CASSETTE LOADING SYSTEM.

The radiographic camera, using roll film movement is the other possibility of the X-ray radiographic examination system.
A second, shielded passage, in the axis of the collimator slit, has been made through the floor of the cell, and the camera is loaded in a frame, allowing a translation movement in vertical way, in the basement under cell M1.
The scheme of Fig. 7 shows this realization through the cell floor.
The main parts of the camera are the film drive mechanism and film cutting system, the film guiding rollers and the exposing chamber with drum which will be raised just underneath the collimator slit inside the cassette tunnel opening.
Film tension is achieved by two small asynchronous motors, activated in a rest position, keeping the film under tension, and rotating only at film movement.
Simultaneously with the fuel rod movement in front of the collimating slit, the film drum will be in rotation and continuously exposing of the running film is obtained.
Fig. 8 shows the radiography camera arrangement.

(c) *X-ray tube installation*

X-ray generator of 420 kV, the lamp of which is installed inside the cell on a frame, fixed to the lateral wall of the cell, allowing the necessary movement for aligning and distance regulation giving an exactly vertical projection of the fuel rod on the film.
The positive and negative generators as well as the cooling group are installed on the cell roof.
Special feed-throughs have been made for the electrical cables and cooling circuits. Fig. 9 shows schematically the X-radiography unit.
See Fig. 4 for some details of this mechanism.

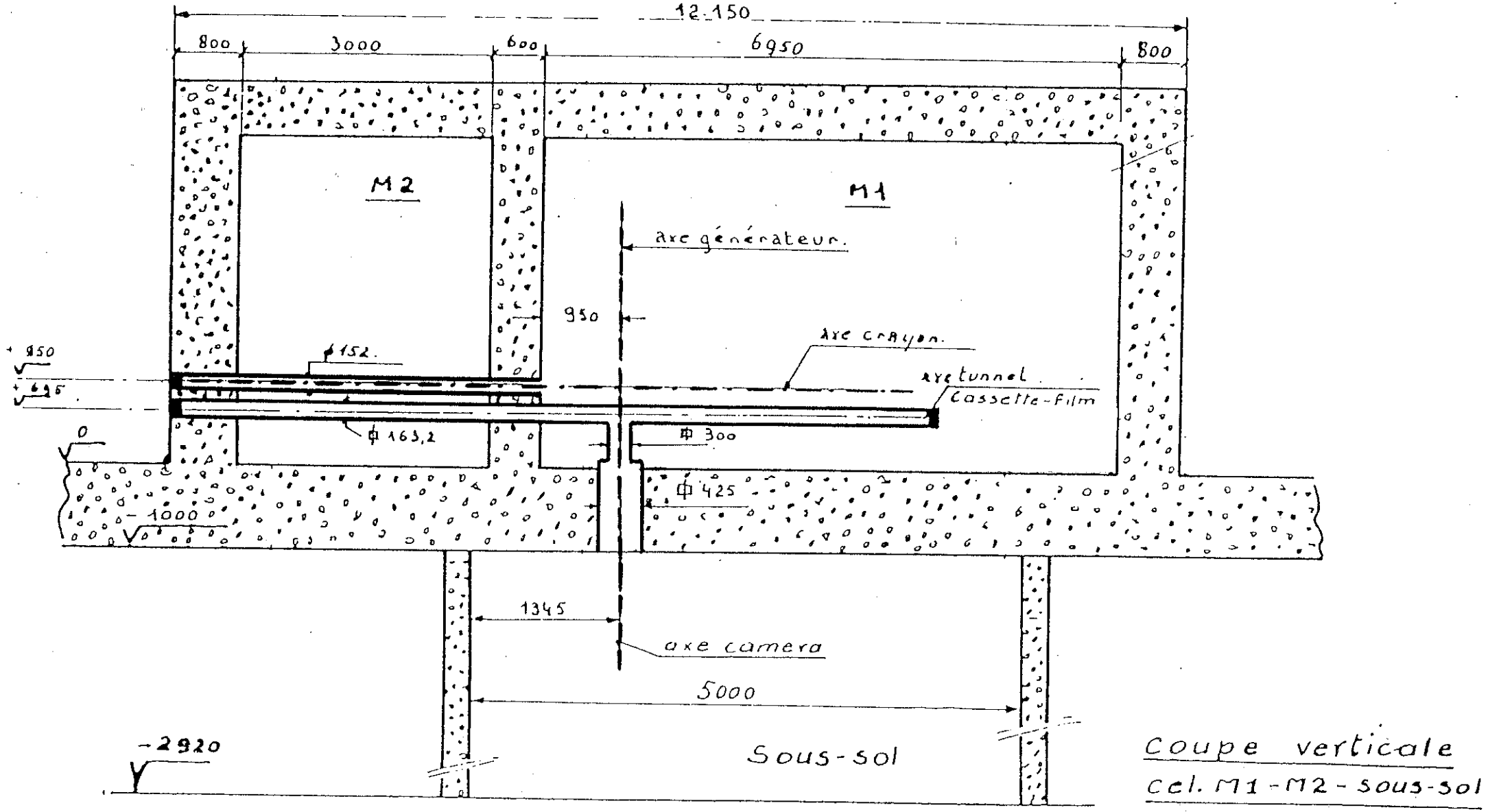


Fig.7 SCHEMA SHOWING CELL FLOOR PASSAGE FOR CAMERA SYSTEM

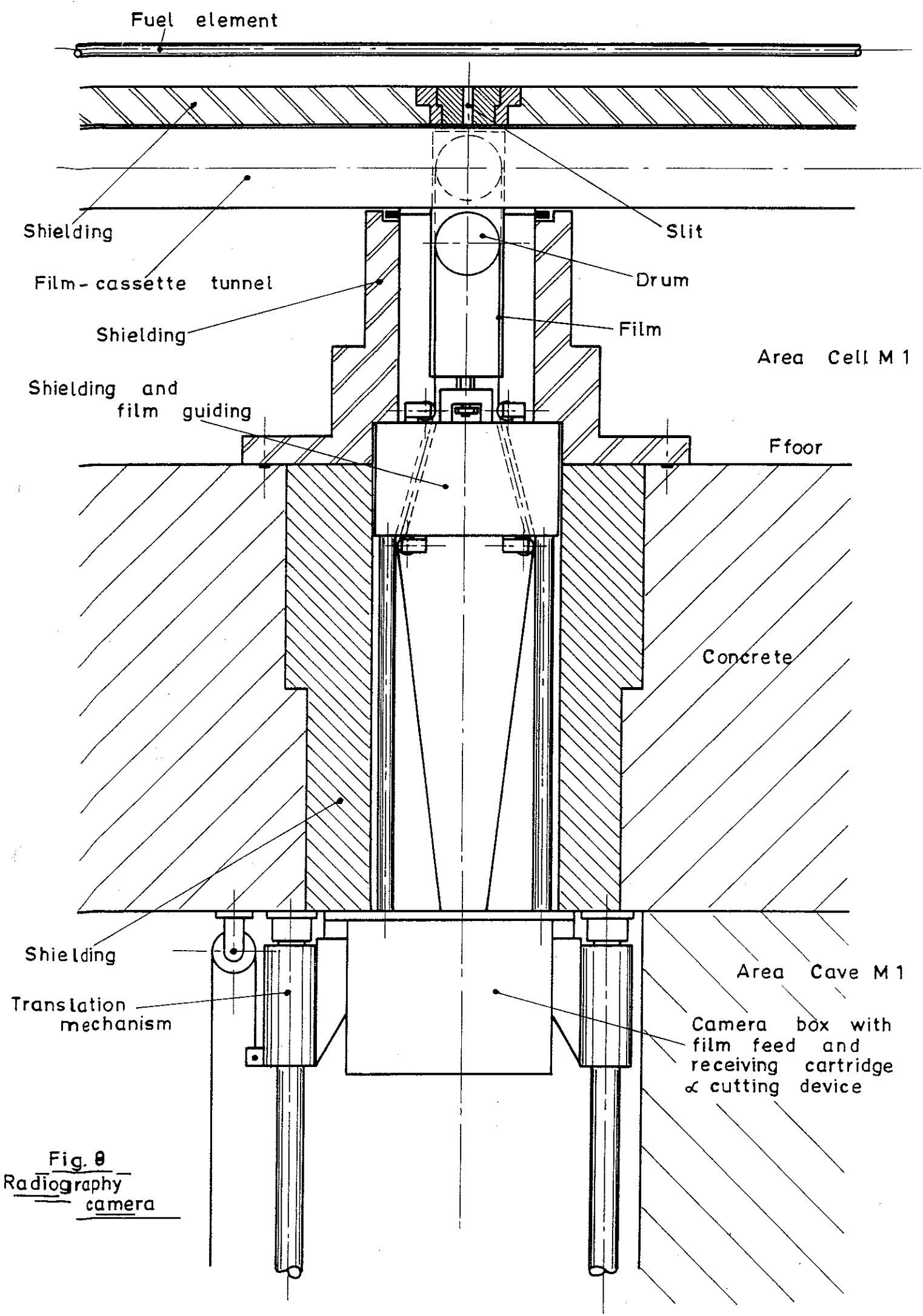


Fig. 8
Radiography camera

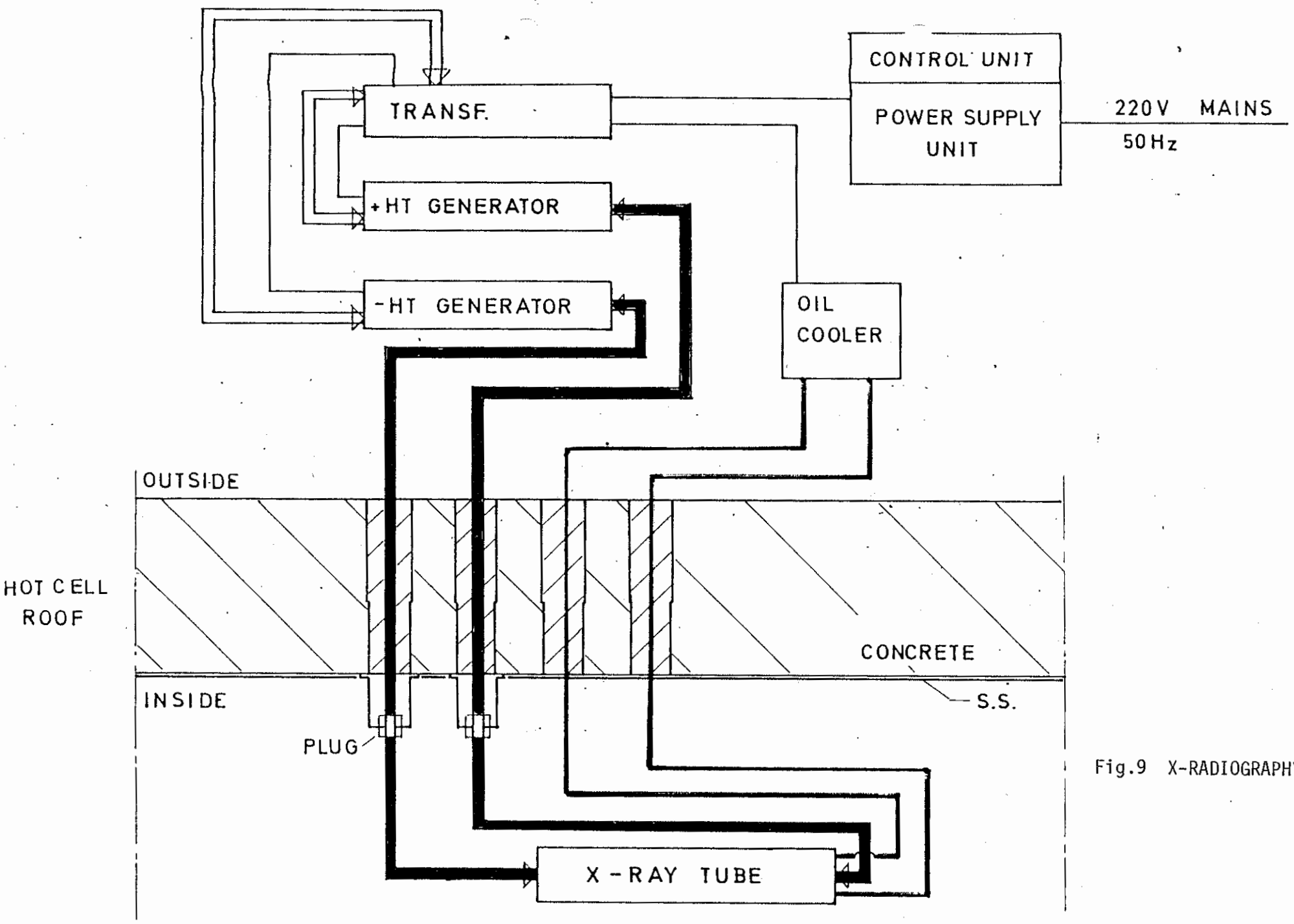


Fig.9 X-RADIOGRAPHY UNIT

DATA

- translation movement of the fuel rod
  - low speed range : 1 to 100 mm/min
  - high speed range : 100 to 1500 mm/min
  - positioning accuracy : ± 0.5 mm

- length of supporting table : 6.9 m

- total length of rod supporting system : 11 m

- film translation
  - film cassette movement : stepping motor drive system
    variety of speeds can be selected
  - film cassette : length : 200 mm
    width : 100 mm
    film width : 60 mm
  - roll film movement : stepping motor drive system
    variety of speeds can be selected
  - roll film : width : 60 mm
- collimator slit : 1 mm, 2.5 mm; 5 mm x 25 mm
- X-ray film type : industrially available
- X-ray generator : industrial X-ray equipment "ISOVOLT 420"
  - output voltage : 60 to 420 kV, stepless adjustable
  - output current : max. 10 mA
  - programme controlled system "ISOVOLT US2"
- vertical travel of the X-ray tube : 1 m

The velocities of the film and the rod have the same ratio as their distances from the focus of the X-ray tube.

EXAMINATION PROCEDURE

The fuel rod to be examined is loaded on the roller supports of the bench and clamped in the chuck of the trolley. The rod is brought into position, entering partly the extension tube with the bottom end cap at the left side of the collimator slit.

Operation with film cassette cartridge

- The X-ray film strip of about 2 m in length is loaded into the cassette which is charged then on the cassette trolley drive system and positioned at the left side of the slit collimator aligned with the fuel rod.
- The X-ray tube is put into operation.
- Activating the rod drive system and the cassette trolley drive system, both under computer control, will translate simultaneously the rod and the film with a maximum displacement of 2 m.
- For fuel rods with a length > 2 m, several reloadings of film strip will have to be made until the entire length of the rod, with some determined overlapping, will be radiographed.

Operation with roll film camera

The film feed cartridge, loaded with about 10 m of X-ray film, as well as the receiver cartridge, are positioned into the camera.
The camera is then raised and locked into position as close as possible underneath the slit of the collimating system. The X-ray tube is put into operation.
Activating the rod drive system and the motor of the film rotating drum, both under computer control, will translate the rod and simultaneously move the film until the entire length of the fuel rod has been radiographed without interruption.

Initial settings

The choice of the film, the exposure time and intensifier screens will be made according to the density and thickness of the materials to be examined and the intensity and energy of the gamma rays.
The width of the slit and the distance between X-ray source and fuel rod (film) must be adapted accordingly.
The velocities of the film and the fuel rod have the same ratio as their distances from the focus of the X-ray source.
Trolley translation (fuel rod movement), fuel rod levelling, film cassette driver unit, camera positioning and roll film driver unit as well as all lockings run under computer control, serving also the other measuring benches and mechanisms in the same NDE hot cell.
Fig. 10 illustrates the installation block diagram.

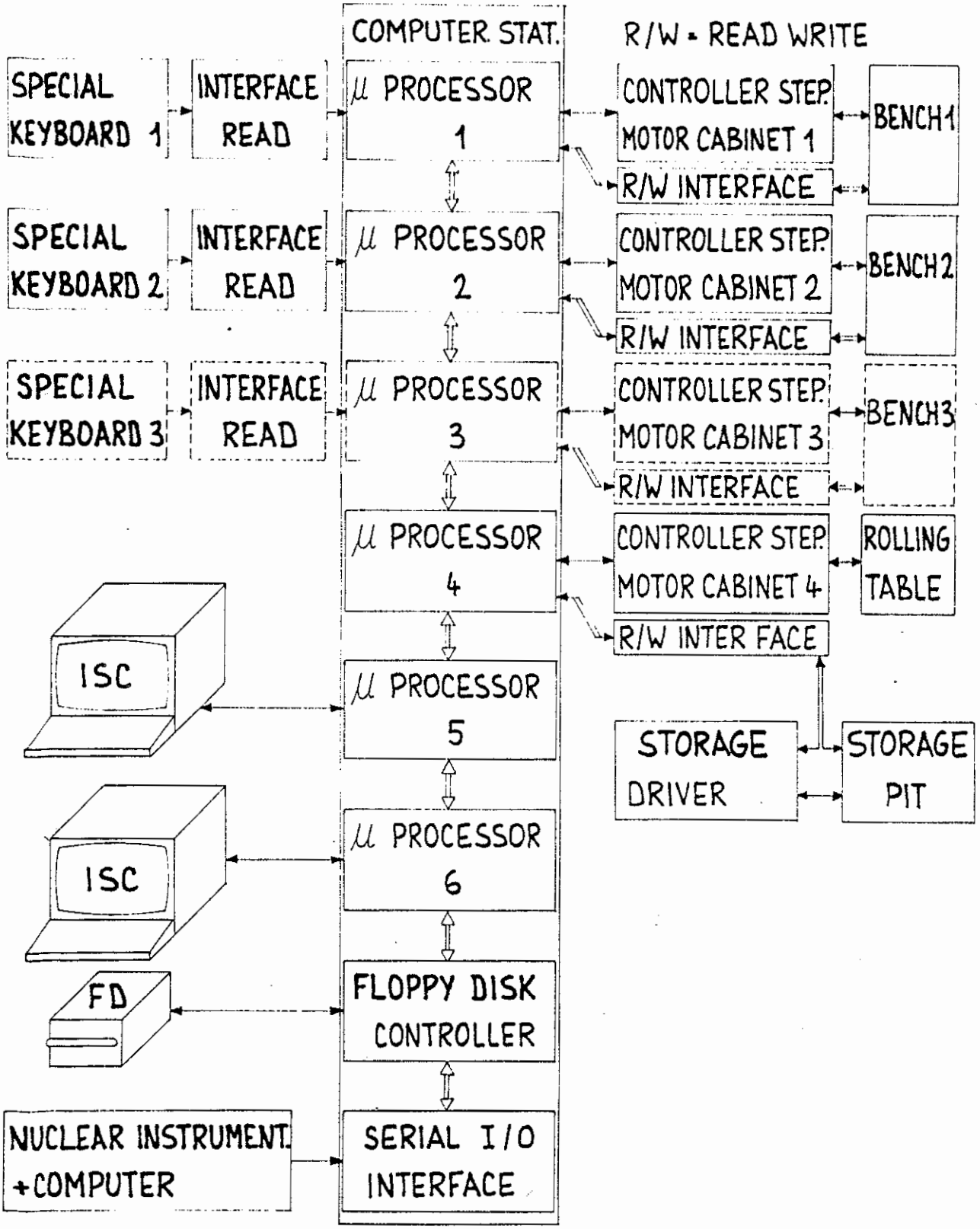


FIG. 10 INSTALLATION BLOCK DIAGRAM

EXPERIMENTAL CONDITIONS. EXAMPLES

Characteristics	LWR fuel rod Biblis reactor	LWR fuel rod BR3 reactor	Fast fuel pin Phénix reactor
- X-ray film type			
. roll film	Agfa Gev. D7		
. cassette film		Agfa Gev. D7	Agfa Gev. D7
. intensifier screens	not applied	2xSn foils (0.15 mm)	2xSn foils (0.15 mm)
- focus distance mm	711	740	678.3
- target-to-film distance mm	185	185	185
- collimator slit	10 mm x 30 mm	10 mm x 30 mm	10 mm x 30 mm
- rod scanning mm/min	12	12	16.5
- film displacement speed mm/min	15.12	15	21
- voltage/current	400 kV/4 mA and 150 kV/4 mA	400 kV/4 mA 200 kV/4 mA	400 kV/4 mA 150 kV/4 mA
- thickness equalization	applied for fuel stack	applied for fuel stack	applied for fuel stack
- multiplication factor	1.260	1.250	1.2727

LIST OF FIGURES