

# CAD MODELLING OF RADIOACTIVE PLANT: THE ROLE OF DIGITAL PHOTOGRAMMETRY IN HAZARDOUS NUCLEAR ENVIRONMENTS

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## Abstract

The maintenance, refurbishment and ultimate decommissioning of nuclear installations increasingly depend upon remote operations employing a variety of robotic tools.

Planning, simulation and execution of robotic entries demand accurate 'as-built' CAD models of the plant geometry. These are usually derived from existing general arrangement drawings which are supplemented by ad-hoc surveys and imagery gathered during routine inspections.

This paper describes a number of strategies which have been developed to allow the remote measurement of active plant, emphasising the potential role of digital photogrammetry. In particular the paper will describe the component parts of a remote measuring system for hazardous environments (HAZMAP) which links a robotic measurement unit to a digital photogrammetric workstation allowing real-time image measurement and off-line CAD modelling via linkages between 3D plant design packages and a photogrammetric toolkit.

**Keywords:** CAD/CAM, Industrial, Photogrammetry

## 1.0 INTRODUCTION

Techniques for the construction of as-built models of plant items include traditional surveying measurements (by theodolite, tape and level), theodolite intersection (e.g. Leica ECDS system), close range photogrammetry, holography and laser ranging or triangulation (ASPRS 1989).

Of these techniques both photogrammetry and holography offer the potential of rapid acquisition of an image archive suitable for subsequent analysis. Access to such an archive is of considerable benefit in planning and execution of robotic operations since it enables the construction of as-built models of the plant which include both precise geometrical details of plant locations and details of clutter or debris which may not exist in design records.

Whilst as-built photogrammetric surveys of nuclear installations prior to commissioning are becoming increasingly common (e.g. Legac, 1991) many were designed prior to the advent of CAD modelling tools. In these situations the creation of accurate plant models is likely to demand the integration of engineering drawings with measurements from remote measurement systems.

Unfortunately the deployment of such measurement systems is adversely affected by the ionising radiation in active plant cells. The nature and magnitude of

acceptable radiation exposure varies between the systems but can be crudely represented by the Figure 1 which shows the effective limits for deployment of systems in terms of the integrated radiation dose (measured in Rads). Since varying dose rates (measured in Rads/hr) will be encountered in differing parts of the plant the time available for deployment and acquisition of remote measurements may vary from a few minutes to many hours.

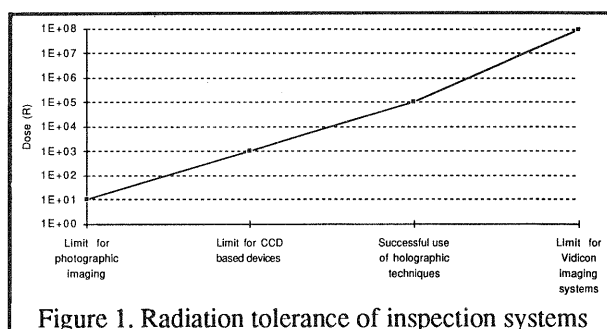


Figure 1. Radiation tolerance of inspection systems

The first section of this paper explores the potential for the use of such systems in radioactive environments and comments on documented experience of the techniques in the construction of CAD models of active plant.

Next the advantages of a hybrid prototype measurement system are described in the light of trials which are

currently underway under a European Community funded research programme.\*

Results from the trials, presented in section three, demonstrate the utility of this method and lead to the conclusion that digital photogrammetry may play a major role in the creation and maintenance of accurate as-built plant records.

### Measurement techniques for CAD modelling

Theodolite intersection has been widely used during construction to verify design plans and to provide control for close range photogrammetry (Legac, 1991) however with the progressive reduction in permissible radiation exposure for human operators and the relatively long data acquisition times it is clear that manual systems such as ECDS are unlikely to be deployed in active areas.

Whilst the development of automated theodolite intersection systems (e.g. Leica SPACE system; Kyle, 1990) may allow remote operation the emphasis of these systems on high precision pointwise measurement of objects for on-line intersection is not appropriate if rapid acquisition is dictated by the environment. Thus whilst the system described in the body of this paper has much in common with such techniques the emphasis is on rapid acquisition of data with off line CAD restitution.

Obviously close range photogrammetry offers the capability for rapid data acquisition and has thus been widely utilised in radio-active areas (Clayton, 1989; Legac opp.cit.; Martin, 1988 etc.). In the case of conventional photo-chemical imaging the limiting factor in successful use of such techniques is the fogging of the film by the radiation (See Figure 2).

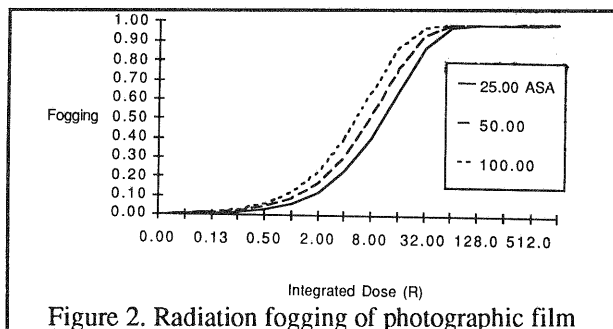


Figure 2. Radiation fogging of photographic film

An empirical formula developed by Clayton and Jones at the UK Central Electricity Generating Board (now Nuclear Electric) presents a relationship between the fogging of panchromatic film and absorbed dose of Gamma activity around 1.0 MeV such that

$$F = 1 - e^{-1.3 \cdot 10^{-2} \cdot (ASA)^{0.5} \cdot R}$$

where  $F$  = fog level =  $(t_f - t_o) / (t_f + t_o)$

$t$  = transmittance of exposed film

$t_o$  = transmittance of unfogged film

$t_f$  = transmittance of fully fogged film

ASA = film speed ASA number

$R$  = absorbed radiation dose in Rads.

In most circumstances fogging will occur at integrated doses which are higher than the acceptable level for human operators. Thus the availability of systems for the deployment of the cameras may limit the utility of photographic acquisition. However, with sufficient ingenuity, photogrammetric measurement is possible in even highly active areas by minimising exposure to the radioactive field through sophisticated remote handling methods (Clayton, 1989). Restitution of photographic images may be accommodated on existing analytical plotters which link to 3D CAD modelling packages (e.g. the Leica DSR range which may be used with Intergraph's MicroStation CAD tool). Alternative strategies include the digitisation of photography on a high precision scanner with restitution and CAD construction on a softcopy photogrammetric workstation. Such a system has been implemented in the UK by Offset Services Ltd and offers the advantage that photogrammetric tools can be closely coupled to a range of plant modelling packages. Many other softcopy workstations are either commercially available or at an advanced stage of development (see Ebner et al., 1991 for a recent summary). The use of such tools seems to offer considerable flexibility in the construction of CAD models - a theme which is developed more fully in Section 2.

Measurements from holography have found application in a number of diverse fields including aerospace, electronics and even medical and dental applications. Holographic recording has been shown to be effective in highly hostile environments (to  $10^5$  Rads, Glanville et al, 1985). Holographic techniques offer advantages over conventional close range photogrammetry in that they provide very dense storage of information (Tozer and Webster, 1980) and, since no image forming optics are employed, problems relating to depth of field may be bypassed. Most importantly the data stored provides 3D information about the scene rather than the 2D information stored in conventional intensity images. Thus a single holographic record has the capability of covering a three-dimensional field that would need perhaps multiple stereo pairs of images for three dimensional reconstruction by close range photogrammetry (Gates, 1986). This makes holography a very attractive proposition in the densely cluttered environments typical of nuclear installations where accessing suitable vantage points is often very difficult. However when large objects, such as engineering structures, are to be recorded the stability of the imaging system may give rise to some difficulties. Holographic recording media are relatively slow (rated at a fraction of

\* The project is one of 16 funded under the European Community TELEMAT programme which is directed towards the development of tools for 'Remote operations in hazardous or disordered nuclear environments'.

one ASA) and thus are not greatly affected by radiation effects. However this means that under CW illumination absolute stability of the holographic camera must be assured with tolerances of the order of few wavelengths of light. This is unlikely to be possible within a civil engineering structure and therefore a high intensity pulsed laser must be used to make the recording. When playing back the recording under CW illumination the wavelength of the illumination must match that of the recording pulse in order for successful reconstruction. Trials by nuclear utilities indicate that that difficulties in arranging either the imaging stability or the correspondence of the wavelengths of the different illumination sources may effectively limit the potential applications of the technique for the measurement of large (>1m<sup>3</sup>) volumes.

Laser scanning devices have been widely employed in close range industrial inspection applications. Measurement is generally by intersection and is often termed active triangulation (photogrammetry being described as passive triangulation). Typically a point or line of laser radiation is scanned over the object to be measured and specular reflection from the object's surface is imaged on a linear or array CCD sensor. The geometry of the intersection depends upon the base-line distance between the laser source and sensor and the angular measurements determined from the laser scanning and imaging optics. Alternative techniques may employ active ranging in which polar measurements are determined from angular observations coupled with direct distance measurement from time of flight or phase based electromagnetic distance measurement (EDM) systems.

Much recent research has been directed towards the effective exploitation of such range images. Hardware developments include laser triangulation systems such as the SOISIC laser triangulation system from MENSIS (D'Aligny, 1991) which are capable very high precisions ( $\pm 1\text{mm}$  over 5m) at the expense of relatively long acquisition times or the LETI Advanced Laser Imaging System (ALIS) which is capable of capturing a low precision ( $\pm 1\%$  of range) 'range image' of 120 x 150 pixels at 4 frames per second. Such systems yield substantial amounts of data which must be structured if it is to be integrated into a CAD description. Automatic segmentation of such data continues to be of considerable interest to researchers in the machine vision community (e.g. Besl 1988, Bhanu 1987, Hoffman 1987, Kasvand 1988) but have not yet been widely applied to the highly complex scenes typical of a nuclear installation.

## 2.0 THE HAZMAP MEASUREMENT SYSTEM

The system developed in this project capitalises on several developments mentioned in section 1. In

particular the availability of relatively inexpensive motorised theodolites, CCD cameras, image digitisation and high powered graphics workstations have enabled the rapid development of a hybrid imaging system which can be modelled within a specialised softcopy workstation developed at UCL.

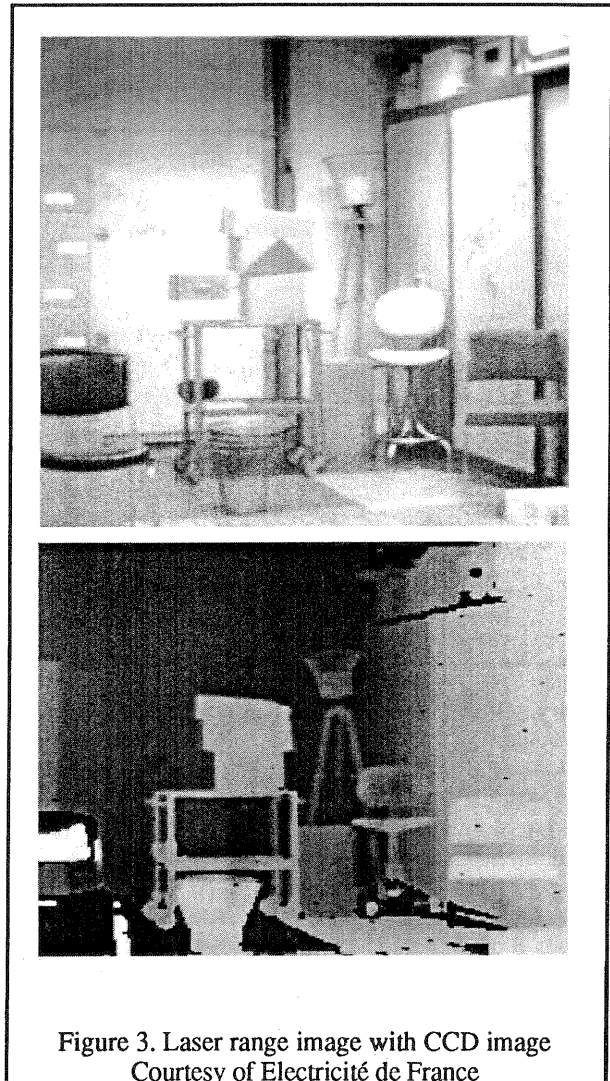


Figure 3. Laser range image with CCD image  
Courtesy of Electricité de France

The proposed system contains three modules which are represented diagrammatically in Figure 2 and comprise:

- the remote measurement unit;
- the photogrammetric module; and
- the CAD interface.

### The remote measurement unit.

Both CCD and vidicon cameras are used frequently by nuclear engineers for inspection of radioactive plant. Their environmental tolerance is well established



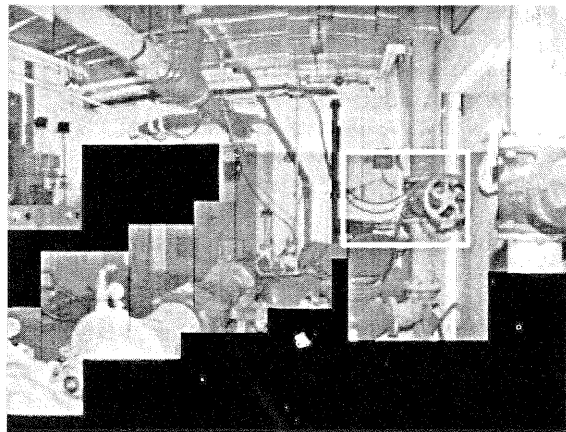
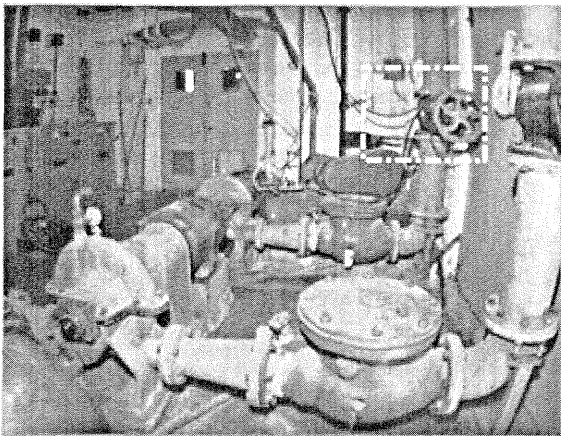
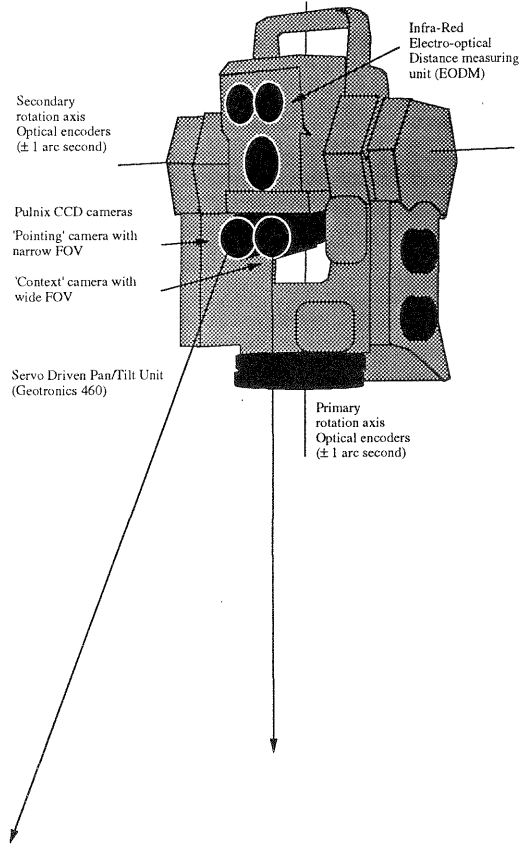
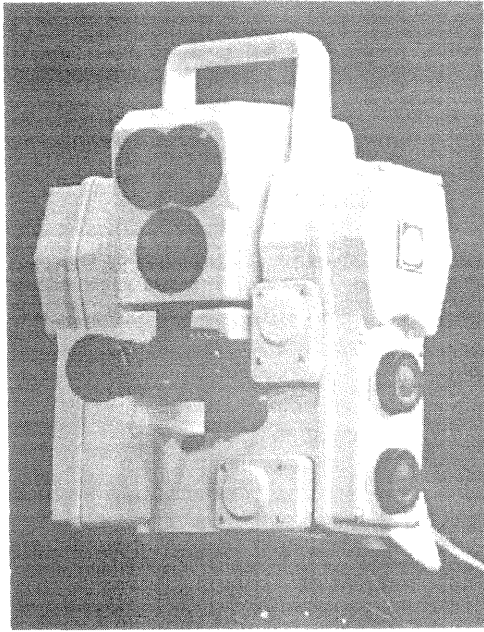


Figure 5. The HAZMAP remote measurement unit

relates to the pointing of the CCD camera is acquired with each image tile and written to the image header. For the localisation of the hybrid camera a reduction to centre computation is carried out within the extended bundle adjustment module. This converts directions observed at the eccentrically mounted CCD cameras to equivalent directions at the rotation centre of the pan/tilt unit.

Image measurement tools allow the determination of the image coordinates of target points using the graphics screen and mouse pointing device of a standard graphics workstation. Images may be displayed as individual tiles, a panoramic mosaic or as tile segments on an image 'paste-board'. Image enhancements such as

hardware zooming and contrast stretching allow for identification of image coordinates at the single pixel level, centre of gravity operations allow the automatic measurement of appropriately targeted points with a precision of  $\pm 0.1$  pixel. Facilities also exist for the injection of geometrical primitives into all appropriate view for the rapid manual determination of best fitting objects and their export to the CAD system (Figure 6).

The orientation and transformation toolbox required for geometrical evaluation of the image tile measurements utilises the direction observations and all available information from object space (e.g. dead reckoning information, distances, directions) to derive a suitable

CAD-model of the object. Essential parts of this evaluation process are:

- determination of the image and theodolite orientations,
- determination of the coordinates of the spatial object point field,
- camera calibration: determination of the interior orientation parameters,
- instrument calibration: determination of the relative position between the theodolite's telescope and the camera which is rigidly mounted on the theodolite.

All these tasks can only be fulfilled if a set of suitable orientation and transformation programs are available. Such a toolbox must be capable of efficient processing of the following geometrical observation types:

- image coordinate measurements;
- theodolite readings (horizontal and vertical directions);
- distance measurements in object space;
- directly observed object point coordinates and coordinate differences;
- observed interior orientation parameters: camera parameters; and
- observed exterior orientation parameters: position and rotation of a camera or a theodolite.

Any combination of these measurements assigned with proper weights must be processed simultaneously in a combined adjustment - sufficient redundancy is assumed - in order to derive best estimates for the network parameters and to guarantee a maximum of internal reliability. The combined adjustment increases the sensitivity with which the observations can control each other, a very important factor for blunder detection. However, such a combined adjustment is a non-linear problem and sufficient accurate initial values for all unknown network parameters (object point coordinates, parameters of exterior and interior orientation, etc.) have to be calculated beforehand. Additional tools are necessary beside the combined adjusted program to solve this problem. Thus the following major software components are needed for the orientation and transformation toolbox:

- reseau correction;
- relative orientation of two images or two direction bundles;
- absolute orientation (7-parameter transformation) between two 3-D point fields;
- spatial resection for images and theodolite bundles;
- spatial intersection for images and direction bundles;
- combined adjustment program to process all available measurements appropriate and simultaneously; and
- analysis program for the combined adjustment results.

A toolbox known as the *CAP (Combined Adjustment Program) software package*' (Hinsken, 1989, Cogan et al. 1992) containing a lot of components needed is available on the DOS-market for IBM compatible PC's. This has been ported from the DOS-environment to the UNIX-environment of the Silicon Graphics HAZMAP workstation.

The CAP software package offers considerable flexibility for the adjustment of a general photogrammetric multi-station network which can be simultaneously combined with various types of geodetic observations (see list above). Additional features of CAP are:

- free net adjustment;
- deformation analysis;
- camera calibration;
- rigorous error propagation based on the normal equation inverse;
- statistical analysis including blunder detection;
- singularity-free parameterisation for the rotation parameters; and
- algorithms for minimisation of storage requirements and computing time.

In addition, the combined adjustment had to be extended to model the special imaging geometry of a general video theodolite (e.g. Wester-Ebbinghaus 1988a,b). This extended functional model consists of an iterative solution that adjusts the initial observations for a resection to produce the station exterior orientations. This is achieved by converting image observations of conjugate points into directions (horizontal and vertical angles) by ignoring the camera-telescope offset initially. These directions are used in conjunction with initial values for the 3-D coordinates of the observed points inside CAP which provides a new exterior orientation along with adjusted 3-D coordinates. These new values are used to produce new directions which are then both fed back into CAP to produce another set of exterior orientations and 3-D coordinates. This loop is continued until CAP can produce a solution under strict convergence criteria.

### The CAD interface

In trials to date the CAD modeling system used has been the Plant Design Management System (PDMS) from CADCentre Cambridge. This sophisticated tool is normally used by process engineers during plant design and enables a full functional model of plant components in association with a corresponding geometrical description.

The data acquisition requirements depend very much upon the characteristics of the spatial display and analysis methodologies to be employed. Traditionally line drawings describing the construction on individual pieces of equipment and general plant layout have been employed for construction and installation. Increasingly the spatial information implicit in these two dimensional representations is being manipulated in 3D



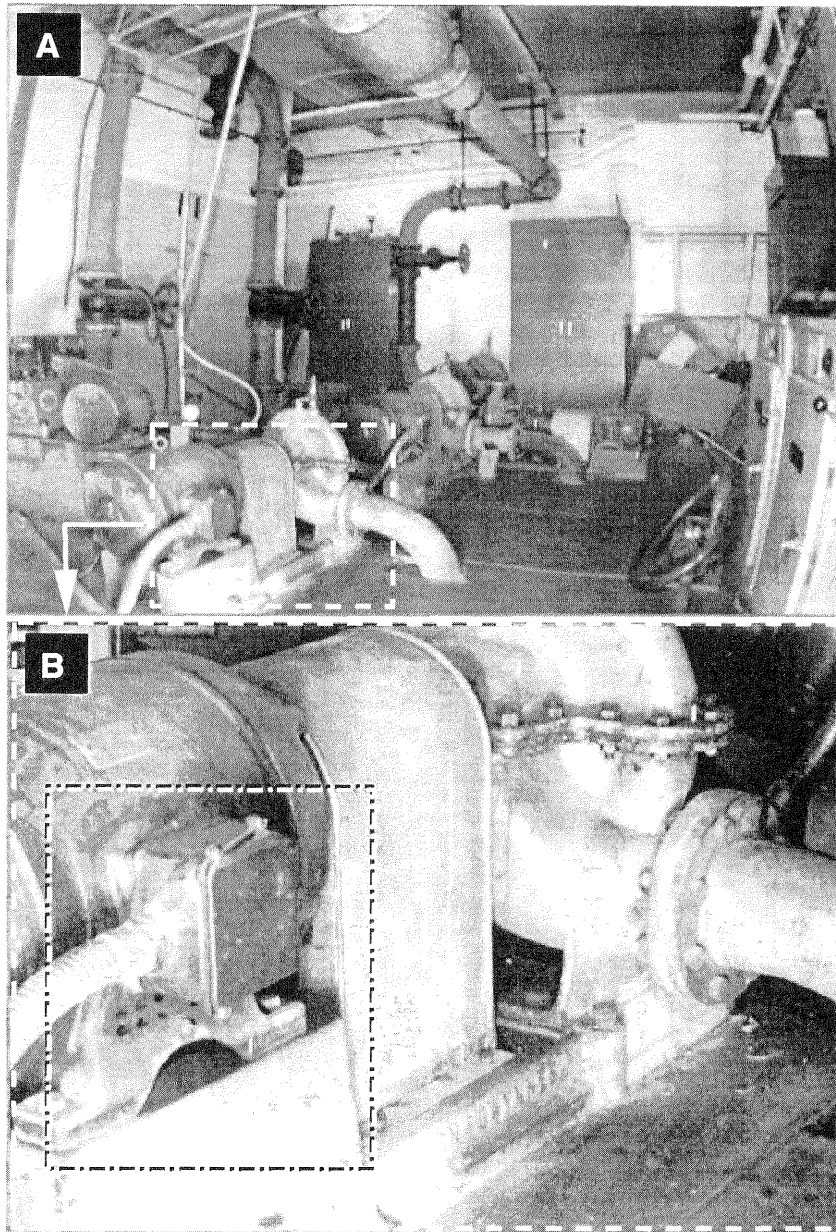


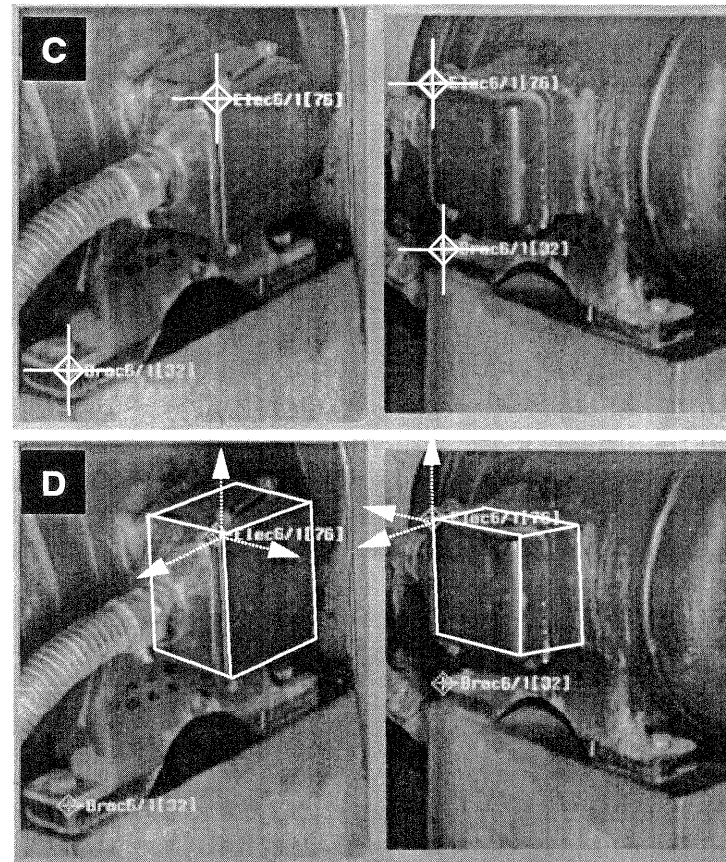
Figure 6 Image selection and measurement.

A. 'Context' image: used during acquisition to indicate the regions of interest that should be viewed by the measurement camera. Also used to index full resolution images (B).

B. Full resolution measurement image. Region of interest tile shown.

C. Two region of interest tiles (from different imaging stations) shown on a software paste board. Conjugate observations yield 3D coordinates of two relevant points on the item of equipment.

D. Injection of a wireframe solid modelling primitive onto the paste board. One corner of the primitive is shown 'locked' to a conjugate observation.



CAD systems. These systems are referred to as solid modellers, their internal data structures hold a description of the bounding volume or surface of the physical entities in a planned or existing environment.

Internal solid representation strategies fall into two categories

- surface or B-rep where the bounding interface is held or
- Constructive Solid Geometry (CSG) in which logical operations are applied to a set of primitives.

Some systems are a hybrid of both representations. In a B-rep modeller a cuboid could be described in terms of a vertex list or a relational list describing the lines between them. Description of an 'approximate' cube is an easy matter of displacing one or more vertices to their measured positions, the object is likely to be no longer a cuboid. CSG systems usually use primitives that are made up of combinations of simple half-spaces, for example a box would be considered as combinations of orthogonal planes. The modification to 'as measured' involves manipulating the size and orientation of the cuboid to the best fitting representation, which will still be a cuboid. The high density of data acquired from laser scanning systems is more suited to the first type of representation, particularly where the exact nature of the surface is relevant.

However, CAD models of process plant also represent the function of plant items. Thus such systems must also be capable of modeling the functional, as well as geometrical, relationships between equipment items. In many circumstances a fairly nominal surface description of any plant item may be all that is required and the emphasis will switch to the accurate location of plant items within a cell and their correct functional connections.

The Plant Design and Management System is a software environment that allows the design and specification of both nominal and as-built representations of process plant. Civil engineering structures and pieces of equipment are described in terms of CSG combinations of a set of primitives. Any combination is allowed but potential clashes between items of equipment and walls or other items or equipment / pipework can be detected. Thus correct functional connectivity can be rigorously tested. The layout of pipework is controlled both in terms of connection geometry and function. The items of pipework are positioned along a direction known as the constrained centre line. This direction can be changed by the introduction of elbows and bends. The former is a piping component with a limited number of directional attributes, e.g 45° or 90°, the latter is an unrestricted attribute of a small section of pipe.

### 3.0 SYSTEM TRIALS

The system has been deployed on two trial missions. In both cases the prototype system was deployed on stable

tripods and targeted control points were provided by theodolite intersection techniques. These trials form part of the proof of concept stage of the HAZMAP trial and more demanding simulations will be completed by the third quarter of 1992. Details of the first trial are given in the paper by Chapman and Deacon (Chapman and Deacon, 1991) and will not be repeated here, the second trial attempted to produce a full PDMS model of a single cell of a Hydraulics Laboratory at UCL. The site was chosen as it was felt to mirror some of the complexity of a typical process plant or reprocessing cell which had been commissioned for a few years and thus attracted realistic amounts of clutter and debris.

The cell comprises a single room of dimensions 7m x 4m (Figure 6) containing pumping and associated equipment.

#### Calibration.

The context and measurement images were calibrated using the method described in Section 2. Images of a pair of targets were acquired at different sensor orientations. A total 25 images were used to make a virtual 3D target field of 50 points. The location of the centres of the targets was determined in each image using a centre of gravity image processing filter.

The camera calibration was tested by re-calculating the directions (horizontal and vertical angles) of the telescope centre to the two targets used in generating the control field. The targets were observed with a number of different telescope directions during the calibration stage. The calculated angles, which ideally should be identical to the theodolite readings, had a variation of 0.02 gon and a negligible mean value difference. With distances to the targets registered at 2573mm and 5335mm, the average error in the calculated target positions was about 0.2mm. The observed and calculated values are summarised below:

Observed - independent of camera			
Near target:	distance (mm)		2573.00
	horizontal (gon)		307.5739
	vertical (gon)		101.3908
Far target	distance		5335.00
	horizontal		304.0156
	vertical		100.2017

Calculated			
Near target	Range	Mean	Stdev
h:	0.0206	307.5724	0.0054
v:	0.0181	101.3907	0.0048
Far target			
h:	0.0201	304.014	0.0049
v:	0.0160	100.202	0.0041

In order to check the electronic stability of the imaging subsystem the unit was left acquiring images of the calibration targets for a period of 24 hours. During the first hour images were captured every 60 seconds. For the following 23 hours images were captured at 10 minute



intervals. The graph below shows the displacement of a target measured by a centre of gravity image processing operator. The results show relatively larger horizontal instability due to line jitter (Dahler, 1987) but no significant warmup effects or long term drift.

**Localisation of the camera stations**

The HAZMAP camera was deployed at four locations (stations) within the cell (1191..1194 in Figure 8) and image mosaics acquired under remote control (Figure 6 shows a mosaic from station 1193 and a typical example of the HAZMAP paste board). Targeted control points were observed by the Leica ECDS system with 17 control points being used for the localisation of the HAZMAP remote measurement unit. RMS error for the ECDS control was better than 1mm.

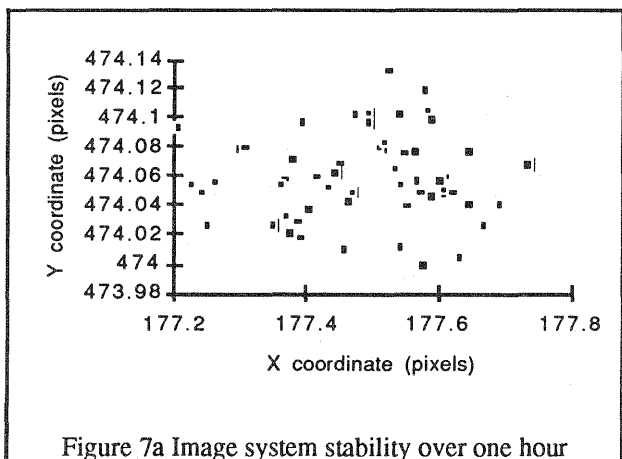


Figure 7a Image system stability over one hour

The results of the space resection using an extended functional model for the hybrid camera used in the remote measurement unit are summarised in Table 1. In addition to the 17 fixed ECDS control points scattered around the room 7 additional observations were made to natural targets within the images to strengthen the geometrical solution.

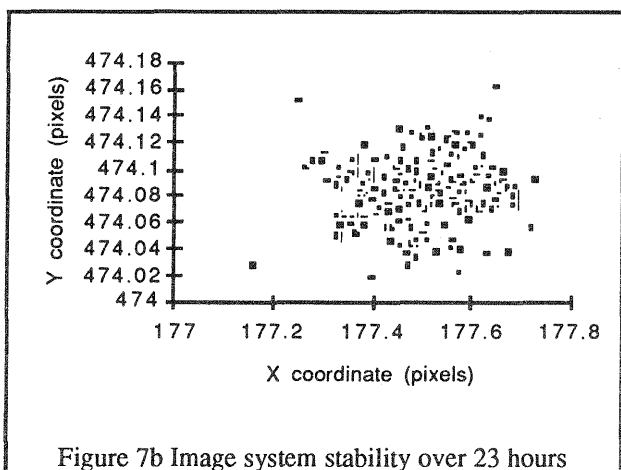


Figure 7b Image system stability over 23 hours

In this trial the camera/instrument calibration was determined by pre-calibration and initial values for the station locations were well known. This meant that the

extended functional model for the hybrid camera converged with little difficulty. However the 4 station setup simulates the weak geometrical network design which has to be expected in the real environment. Using his network an internal accuracy for the point determination within the combined adjustment in object space of  $\pm 2\text{mm}$  (standard deviation in each coordinate direction for the new object points within the combined adjustment) appears to be achievable. By strengthening the network (by observing object points from 3 rather than 2 stations) an accuracy of less than  $\pm 1.0\text{ mm}$  seems to be achievable. The external accuracy (difference between ECDS measurements and photogrammetry) is approx  $\pm 2\text{mm}$ .

Station	Station coordinates (mm)					
	X	se	Y	se	Z	se
1191	7498.17	0.36	54356.05	0.36	19586.26	0.36
1192	7514.36	0.31	51431.05	0.34	19595.78	0.34
1193	9925.09	0.32	49754.92	0.31	19576.59	0.34
1194	9605.49	0.26	51358.23	0.31	19608.68	0.28
Mean		0.31		0.33		0.33

Station	Station Rotations (Gons)					
	Omega	se	Phi	se	Kappa	se
1191	399.8289	0.02	399.9290	0.02	53.8785	0.01
1192	399.9850	0.01	399.9368	0.01	107.0346	0.01
1193	0.1025	0.01	0.0520	0.01	156.8036	0.01
1194	0.0142	0.01	0.0174	0.01	299.0222	0.01
Mean		0.01		0.02		0.01

Trials to test the convergence of the extended functional model when station and object coordinates are only approximately known continue. However, since the reduction to centre computation is a simple function of distance an alternative solution is the direct measurement of object point ranges by pulsed laser EDM.

However, the system has converged to a unique solution when these initial values were displaced by up to a metre and rotated by up to 30 gons. These values depend upon the strength of the control framework and investigations are continuing in this area as well as in the stability of free net adjustments with few or no known object locations.

**Construction of CAD model.**

**Equipment** In a large construction project representations of 'standard' items of regularly used equipment would be generated by a member of the design team. Examples would include pumps, storage tanks and air coolers. These can then be replicated and positioned as appropriate within the site model. In upgrading an existing model to as-built it is necessary

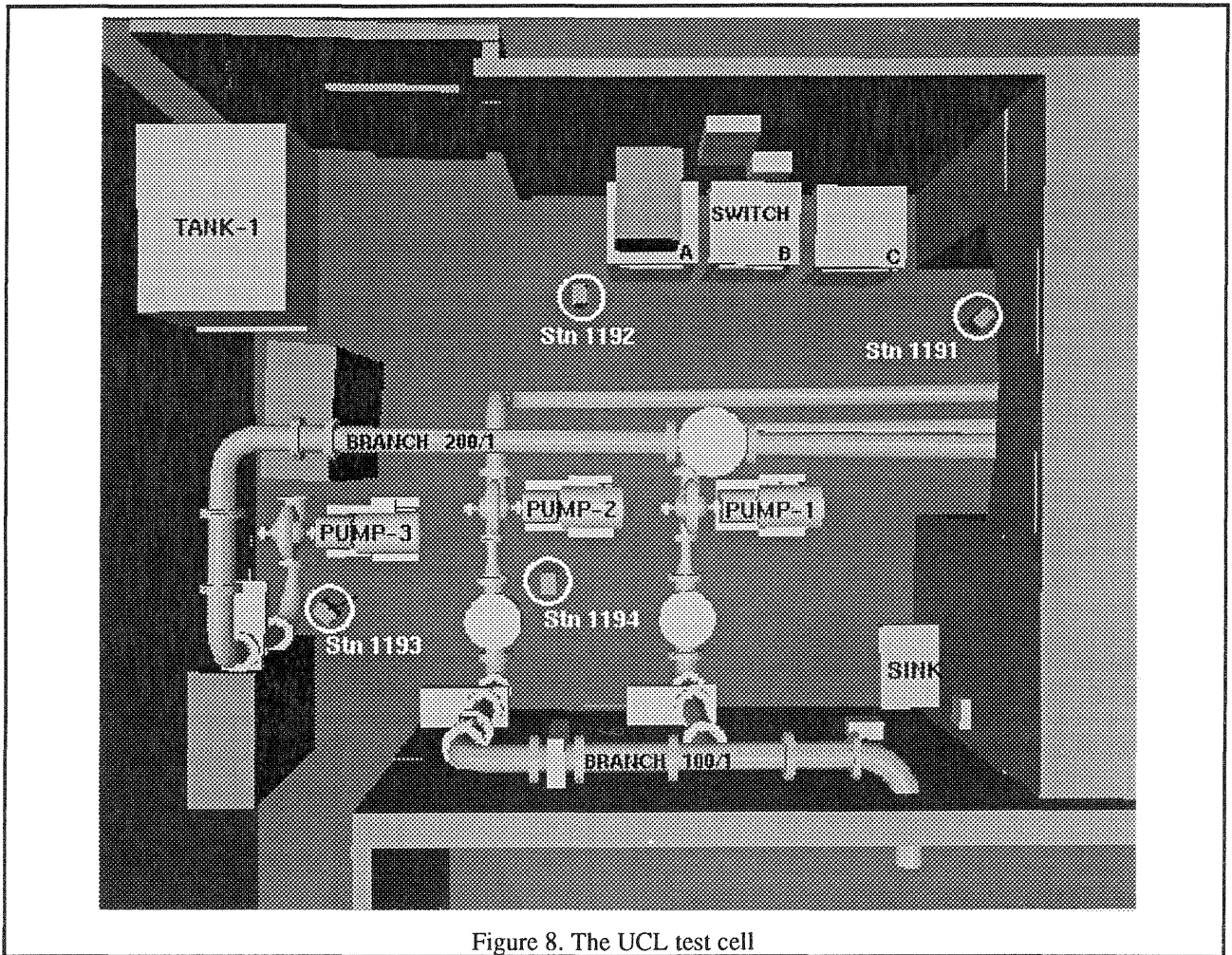


Figure 8. The UCL test cell

to identify and measure features on the item of equipment in both the real scene and the CAD model. Our modelling trial involved the construction and positioning of **all** items of equipment as no existing nominal representations were available. Figure 9. shows the PDMS representation of the pump unit in Figure 7. The position of the construction points is marked by 10mm or 5mm cubes centred on the observed location of a corner or fitting. The impeller cover is only representative of the actual shape, PDMS would **not** normally represent a surface such as this exactly. Instead it would be only in terms of a representative boundary. The interface between the equipment and pipework is by means of nozzles. These *belong* to items of equipment but can *connect* to pipe runs.

**Pipework** Modelling of pipework requires a (i) a specification of pipe type and (ii) pipe *nominal* bore. The layout of the pipe run is described in terms of a linked list of piping items. Figure 10 shows piping components positioned on the constrained centre lines of two pipe branches. The orientation of the top branch was determined from the relative position of the centres of the two flanges A and B. In order to place an additional component a point along this line must be determined. This can be done by measuring the 3D coordinates of a single point on the circumference of

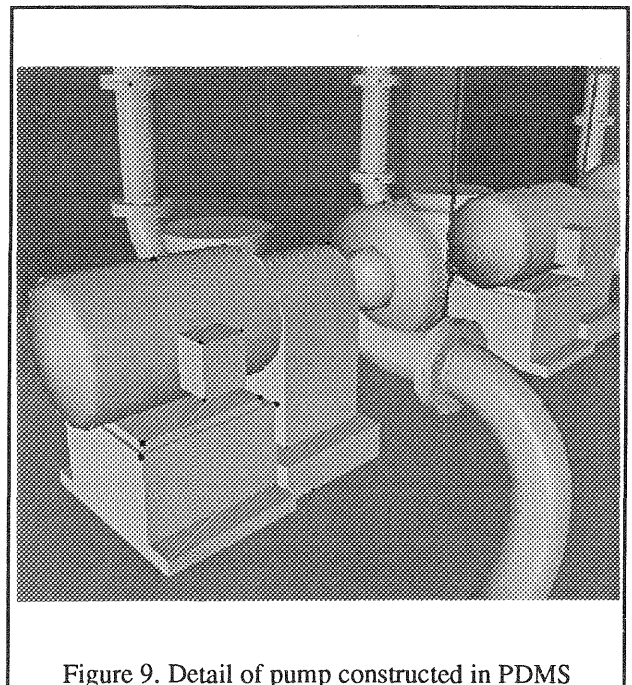


Figure 9. Detail of pump constructed in PDMS

the interface between two flange. PDMS can then be used to determine the distance along the centre line to the normal plane defining the interface of the flanges.

Thus quite complex pipe runs can be constructed by the combination of accurate determination of the orientation and single point measurements at flange pairs.

The orientation of each piping component is described in terms of the 'arrive' and 'leave' vectors. It is the relative difference in the leave vector of the previous element and the arrive vector of the next component that must be within tolerance for the pipe to be valid. The integrity of pipework is checked by a data consistency checker. This is why the bends that are allowed along a section of pipe are so important. Without them it could be impossible to construct an as-built representation without relaxing *all* piping misalignment tolerances.

Valve gear can be positioned in a similar manner to other more simple piping components. Figure 11 shows the PDMS representation of a valve and the parameters that are determined from the catalogue. One flange measurement is sufficient to position the valve but an additional measurement of handle location is necessary in order to set the orientation relative to the centre line.

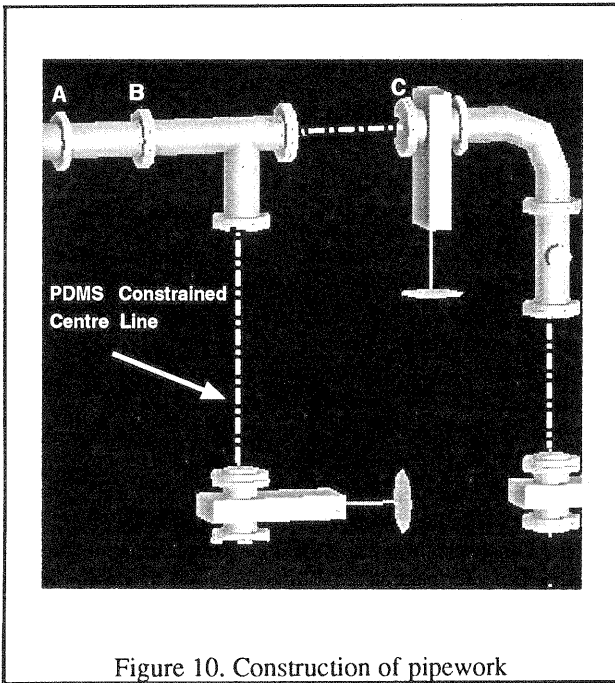


Figure 10. Construction of pipework

**Primitive modelling** The modelling described above depends upon *single point transfer*. If solid primitives are injected and manipulated to fit the objects visible in the scene then these are transferred to PDMS in terms of a constructional macro that describes in high level terms the size and orientation of the individual primitives. This type of modelling can be useful where the exact details of an item of equipment are not relevant. The object can be described in terms of a simple collision volume.

**Precision of model** The precision with which such natural features may be established is highly dependant upon the accurate identification of points in convergent views. This obviously depends upon the nature of the features, however a measure of the overall

precisions of intersected points can be determined by the skew-normal lengths (i.e. the separation, at the point of closest approach, of two directions to a target). A representative sample of intersections in the test scenes shows that the precision of coordinate determination is of the order of  $\pm 3\text{mm}$ .

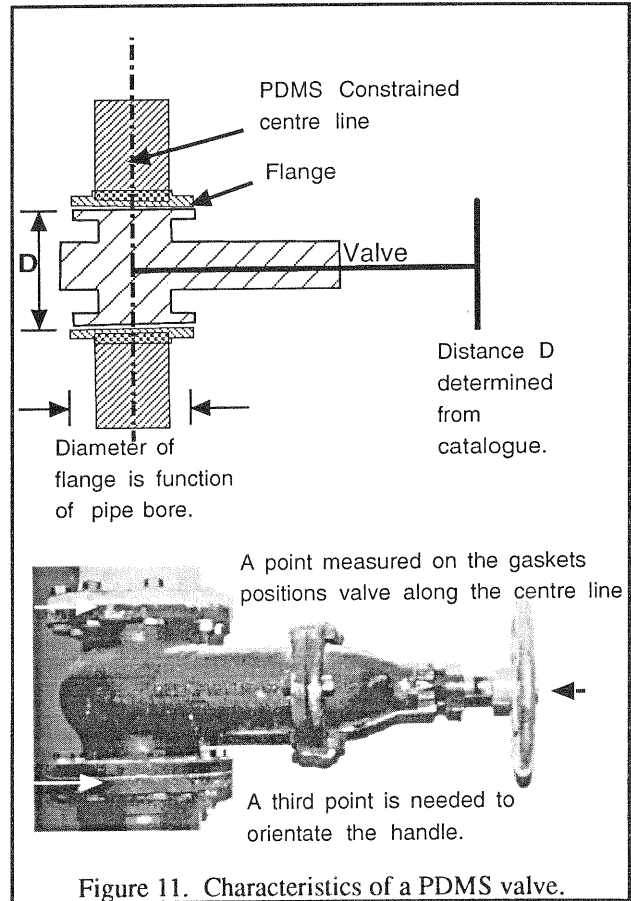


Figure 11. Characteristics of a PDMS valve.

Data from the photogrammetric module passed to PDMS was used for the construction of the model shown in figures 8 and 12. In some situations the geometric fidelity of the model is limited by the fact that the functional models of plant components do not exactly reflect the physical characteristics of the equipment employed within the laboratory. However check dimensions observed by taping between critical plant components indicate that the model is accurate at the centimetre level.

## 5.0 CONCLUSIONS

Trials to date indicate that digital photogrammetry is well suited to the construction of CAD models of process plant. The ability to move switch easily between a photogrammetric measurement capability and the CAD package enables photogrammetry to be as a three dimensional digitiser, the engineer simply measures appropriate dimensions and locations in three dimensions rather than extracting the information from two dimensional plans.

The results are accurate 'as built', rather than 'as designed', models. The complexity of the model depends only upon the patience of the engineer and the costs that his employer is willing to bear. Since a calibrated image archive is maintained on computer disk it can be replicated at will, indexed and archived on to stable media such as CDROM. Thus digital imagery may well form an important component of a plant's lifetime record. Rapid access to the archive means that modelling or measurement may be carried out on a project by project basis with costly CAD reconstruction being only undertaken when appropriate.

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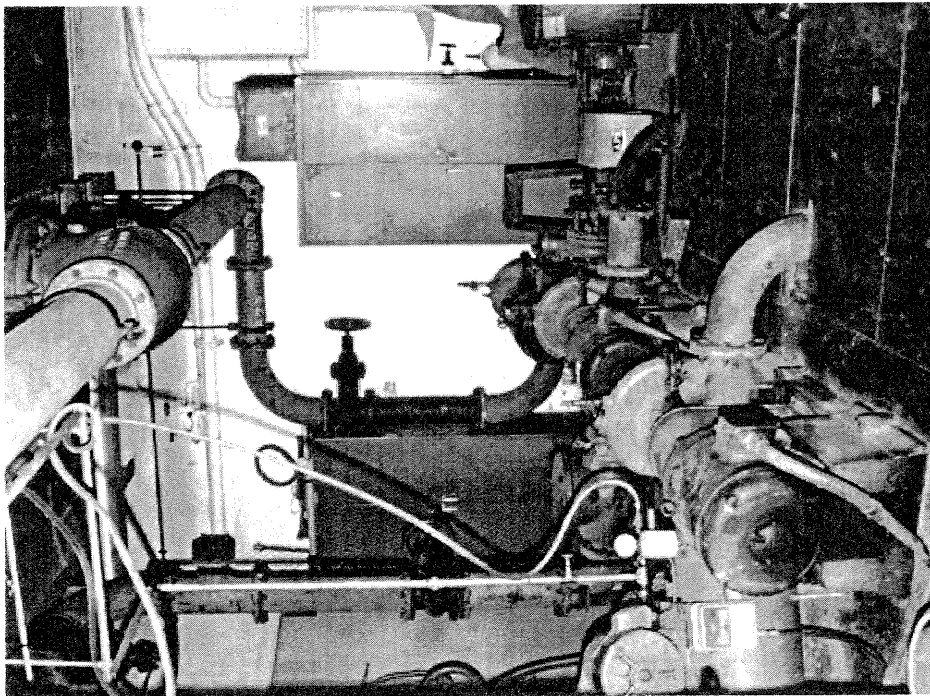
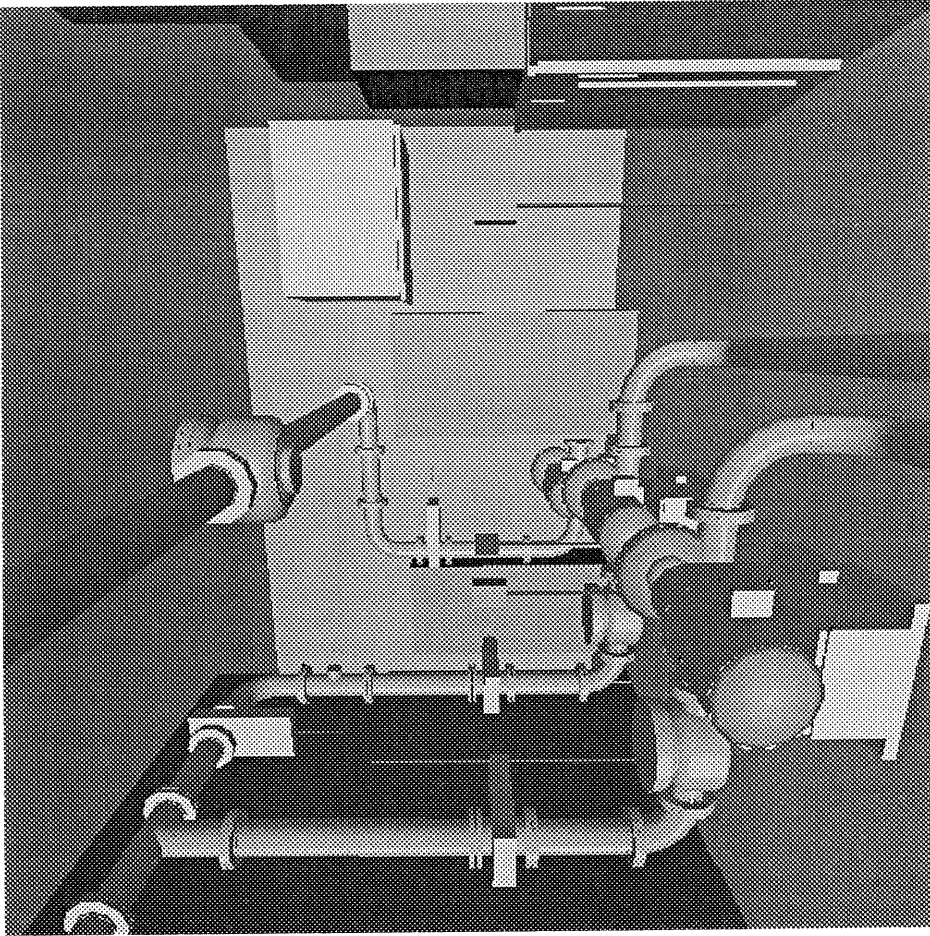


Figure 12. CAD model of test cell