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Titel

CONCEPTUAL DESIGN OF AN AUTOMATED SHIELDED DIRECT ACCESS STORE FOR RADIOACTIVE SAMPLES

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1. INTRODUCTION

In the process of post irradiation examination of nuclear fuels and construction materials the destructive examination phase is responsible for the creation of large numbers of small size specimens, either for metallographic analysis or chemical analysis.
For a number of reasons these items have to be stored for appreciable lengths of time, varying from months to some years.
This at least has been the experience over many years at ECN.
This is explained by appreciable time delays often occurring between the production of an item and the start of its chemical analysis, by time lags involved in the execution of metallographic or chemical analysis and reporting these on the one hand and judgment and appraisal on the other hand.
Many times a re-examination is called for.
Also the final report on the findings may lead to additional questions being raised on behalf of the client.
Sometimes it has been found or hoped that conservation of items to an indefinite future may enable investigators to apply as yet undeveloped investigational methods.
Therefore there is in a hot cell facility at any time a demand for the unearthing of items within a heterogeneous collection which have been produced in a distant past.
This fact by itself would not be an argument in favour of a direct access store, were it not for the fact that, according to our experience, there is no possibility of storing the items in any systematic way in collective packages. They seem to be produced at random and to be recalled at random.
This same situation holds true for a book lending library where the demand and the return of books in terms of titles or subjects is random.
Collective storage has been practiced at LSO for twenty years in steel cans within shielded storage holes and lately in specially built shielded storage casks.
A single can, in its turn, may contain any number of subpackages.
This means that the retrieval of any specific item may require the turnover of the entire content of a collective package. We have found this method to be very laborious.
We came to the conclusion that the solution to the problem would be to make each individually registered item individually accessible.

In the next chapter a conceptual design will be given of a stand-alone shielded facility for the storage of 2480 items, which may be connected to any number of hot cell working stations and which stores according to the direct access principle.
In the application of the system within the LSO, the metallographic cell line (F) and the chemical cells (G1/G2) will be linked to a store of this nature.

2. RADIO PROTECTION CONSIDERATIONS

The definition of the radioactivity level of the items to be stored is of necessity somewhat arbitrary.
It has been recognized that in order to obtain a direct access store concept which can find application as a stand-alone device it should be linked with the facilities to be served by preference by means of a pneumatic conveyor.
As the cost of installatien of shielded conveyor pipes in existing buildings over great distance is prohibitive, we have calculated under which condition unshielded piping would be feasible.

It can be shown that a radioactive source moving along a straight line at a uniform speed of V_0 cm/sec, will deliver an integrated dose D rem, per shot fired, to an observer which is located at a distance of a cm from an infinite length of piping, according to the following expression:

$$D = \frac{\pi \cdot D_0'}{a \cdot V_0}$$

D_0' being the dose rate of the unshielded source in rem/sec at unit distance, in stationary condition.

An observer situated at the end of the unshielded pipe will receive half the dose (provided that no shielding obstruction interferes with this 'ideal' situation).
Consideration has furthermore been given to the fact that the shuttle will not move at uniform speed, neither at the station of departure nor at the station of destination.
If one assumes that in both cases the flight of the shuttle is uniformly

accelerated over a part of its trajectory, either positively or negatively, one can calculate the ratio R, which is defined as:

$$R = \frac{\text{dose } (a, V_0) \text{ at accelerated speed}}{\text{dose } (a, V_0) \text{ at uniform speed}}$$

It can be shown that R is given by the following expression:

$$R = \left[(\pi/2 - \varphi_2) + (\mathrm{tg}\ \varphi_2)^{+0.5} \int_0^{\varphi_2} 2 \cdot (\mathrm{tg}\ \varphi)^{-0.5} \cdot d\varphi \right] \frac{2}{\pi}$$

φ_2 is the angle (in radians) subtended by the part of the trajectory where the motion is accelerated, as shown in figure 4.

If one assumes $a = 200$ cm and $V_0 = 1000$ cm it can be shown that R reaches a value of 3.73 at an angle φ_2 of 75 degrees which does not increase significantly beyond that angle.
However, in practice it will generally be possible to design the piping lay-out at the terminal location in such a way that an observer, i.e. the cell operator, will not be in the sight of the accelerated part of the trajectory.
For example, in the case just mentioned the length of the non uniform speed trajectory is 746 cm (acceleration 669 cm/sec^2).

The amount of fuel which can be safely admitted in a shuttle depends besides on the specific gamma dose rate from the following additional factors:
a. the frequency of the flights
b. the integrated dose which may be delivered to the inhabitants of the building
c. the integrated dose which is consumed by workers when recovering a jammed shuttle.

We shall examine the last factor first.
Jamming of a shuttle in the transport pipe may occur when the latter has been damaged by an external cause, which can never be entirely excluded. If one ensures that the piping is installed over the entire trajectory in such a manner that it is readily accessible and also is supproted well away from building surfaces, it will technically be possible to install a hydraulic shear at both sides of the jammed shuttle.

We assume furthermore that the dose incurred in the shuttle rescue operation shall be limited to 0.2 man-rem.
It can be shown that in general the dose incurred in the process of approaching and leaving the workspot is negligible in comparison with contribution of the actual on site operation to the total dose.
The degree of accessibility of the piping influences the admissible mass of the shears considerably. The existence of surfaces suitable for support of this tool is important in this connection. If the piping is supported at not too close intervals a considerable dose reduction can be achieved by choosing the cutting locations further away from the shuttle position. When very favourable circumstances prevail, one can execute the recovery at a distance of 100 cm and in a time lapse of 60 seconds.
This will require further substantiation by mock-up demonstration. For the time being we shall proceed from this assumption, however.
The 0.2 man-rem limit assumed earlier then limits the dose rate of a shuttle to 33 $rem.cm^2.sec^{-1}$.

In order to determine what this means in terms of the amount of fuel which can be allowed within a shuttle we have based ourselves on fuel elements as they are discharged from the GKN nuclear power station at Dodewaard. The irradiation conditions of these elements are such that a calculation of the unit dose rate by means of the program ISOSHIELD II yields the following data:

Decay time	D_0'	Decay power	Burnup
(years)	($rem.cm^2.sec^{-1}.cm^{-1}$)	($Watt.cm^{-1}$)	($MWD.cm^{-1}$)
.5	6.72	0.067	0.26
1.0	3.28	0.042	0.26
1.5	2.39	0.031	0.26
2.0	1.97	0.024	0.26

On this basis the limitations on shuttle recovery outlined above require limitations on the length of fuel rods according to the following table:

Decay time (years)	Maximum length of fuel rod (cm)
.5	4.9
1.0	10.1
1.5	13.8
2.0	16.7

As a criterion for the integrated dose due to shuttle flights delivered to inhabitants of the building we have departed from a target annual dose to any individual to the amount of 10 percent of the maximum annual dose, the latter being 5 rem. If we allow 20 percent of the target dose to be contributed by shuttle flights, ensure furthermore that any individual is normally at least 200 cm away from the pipe, the shuttle speed is 1000 cm/sec and the non uniform motion correction factor is disregarded due to proper lay-out of the terminals, the assumption of 250 single yourney flights per year leads to a maximal value of D_0' of 25.46 rem/cm^2.sec^{-2}. This value is of the same order of magnitude as determined from the recovery operation.

3. DESIGN CHARACTERISTICS

The direct access store will provide 2480 individual positions for shuttles. They will be located within an upright cylindrical geometry, radially orientated towards the axis of the cylinder (figure 1).
The storage locations will be 7.5 cm long lengths of piping, inclined at an angle of 10 degrees downward.
The storage tubes will be assembled in the form of annular units, 80 locations per unit. They will be stacked on top of each other, to a height of 31 units. They will be enclosed within a cylindrical lead shield, which is lined with stainless steel on the inside and carbon steel on the outside.
This shield has an inner diameter of 175 mm, an outer diameter of 225 cm and a height of 180 cm. Its weight is approximately 42 tons.
The top shield consists of steel, 40 cm thick. Its weight is 12.5 tons.

One of the storage locations assumes an exceptional position because it serves as the point of entry and departure for any shuttle, as it forms part of the terminal of the pneumatic conveyor, which is in the shape of a shielded blister exterior to the main shield.
The store is equipped with a programmable, though otherwise simple, manipulator which is supported in the upper structure of the store.
The manipulator provides for vertical, rotational and radial movements.
The motions are derived from stepping motors which are controlled by a LSI 11/23 minicomputer.
The manipulator hand will be simply a hollow pipe stub with a suction cup at one end.
On arrival of a shuttle the pneumatic terminal will ensure insertion of the shuttle in the associated intermediate storage position.
The manipulator arm will already by on its way to this position, grip the shuttle and will subsequently transport it to its final location. This may be a predetermined location or a floating location depending on the philosophy which has not yet been fixed in this respect.

The concept will have to satisfy in addition the following requirements:

a. containment of the atmosphere within the store,
b. a negative pressure with respect to the environment,
c. parking of the manipulator in idle time outside the radiation field,
d. ability to view interior of store by closed circuit television,
e. ability to deal with shuttles which have inadvertently dropped on the bottom,
f. provision for maintenance of a contaminated manipulator arm,
g. provision to unload a shuttle from a failing arm prior to retrieval of the latter.

In order to deal with the situation under e. one may either consider manual control of the manipulator or provide for the introduction of a normal hand operated manipulator arm in an emergency. The first solution will require a more sophisticated hand. Therefore we are inclined towards the latter approach.

Because of the fact that the items will be individually packed in shuttles the number of these required is substantial and their price will therefore substantially contribute to the overall cost. It is important therefore to design these on a basis which allows mass manufacture.
The shuttles must satisfy the following requirements:

a. designed towards minimal cost,
b. closure designed towards minimal cell handling effort,
c. closure to be safe in flight and landing,
d. improper closure to lead to automatic rejection when attempting transmission,
e. overall mass minimal,
f. provision of an external unique identification mark.

4. THE CONTROL SYSTEM PHILOSOPHY

Because the storage system will have to be used by more than one user it is required that it shall not assume the character of a lucky dip. The control system is therefore required to provide a record of the material movements.

Therefore each item must be identified with a unique name. The identification code will be similar to the one employed since 7 years within the context of our computerized general fuel materials accounting system [1]. Within this system any item is characterized by the following elements:

a. an alphanumeric name, up to 20 characters in length,
b. a set of two coordinates, expressed in 4 digits each,
c. a geometry descriptor, which is either 'AX' or 'RS'.

(It is not at present envisaged to couple the present accounting files directly to the computer files of the system under consideration).

The system will therefore require the following files:

a. a library file containing the defining parameters of all known items. This file will be generated and updated by the LSO accounting officer.

b. a location file. This file will contain the parameters of the previously mentioned file and in addition the station designation (two alphanumeric characters) and the shuttle identifier (10 alphanumeric characters). It will be generated by the accounting officer and be updated by the program.

c. a file of 2480 authorized shuttle identifiers. This file will be updated by the accounting officer.

d. a file containing a listing of executed transactions, with associated date and time as obtained from the internal system clock. This file will be generated by the program.

Whenever an item requires a movement within the system the cell operator is required to type in the following data:

a. item name,
b. item coordinates,
c. item geometry descriptor,
d. station of origin,
e. station of destination,
f. shuttle identifier (only when sending towards the store).

In the case of an item being recalled from the store it is already within a shuttle of known identity. Therefore no shuttle identification needs to be supplied by the operator.
Once the shuttle has been recalled its identifier will be automatically dissociated from the item it carried.
Any item sent to the store will require an additional re-association entry with a shuttle identifier on behalf of the operator.

It may be argued that some effort has to be spent by the operator in defining his requirements. However, it will be realized that it is precisely the same information he is required to enter on forms at present.

The output of the transaction file will be distributed at regular intervals to the operators and to the accounting officer. It will enable him to update the general files.

Further requirements of the control system are the following:

- to prevent having more than one shuttle in the line at any one time,
- to lock the system in the event that a shuttle has arrived at the store's termnial but subsequent deposition at its end position was not completed,
- to prevent operation of the air blower if a terminal in a cell has not been closed with respect to the cell atmosphere,
- to prevent transmission from a cell if the radioactivity level of a shuttle exceeds a maximum value,
- to verify, upon receipt of a shuttle at the store, the coordinates of the next available empty storage location and to verify whether the manipulator has actually reached the internally calculated coordinates of that location,
- to lock the system in the event of an improperly closed shuttle being loaded in the terminal,
- to issue an audible alarm in the event of a shuttle not having arrived if its dispatch has been registered.

The first requirement demands sensing of an empty terminal at the point of destination. This will be done with pneumatic sensors (fluidonics). Additionally it will be required to assess whether any shuttle despatched previously is still underway.

The manipulator grip, being a suction cup, will be able to perform as a sensing device in its own right, as the loss of vacuum during the transfer from the arrival position to the final location within the store will be indicative of the loss of the shuttle. Thus the second requirement outlined above may be fulfilled.

In order to fulfill the third requirement the manipulator arm has to be provided with position encoders.

5. AN ALTERNATIVE CONCEPT

An alternative to the concept outlined above is shown in figure 2. The manipulator in this case has been reduced to four bent pipes assembled together in the form of an inverted 'tree' which are simply extensions to the pneumatic transmission tube.
In this concept the store is divided vertically in four levels, each level being served by a separate branch of the pipe tree.
The purpose is that thus a shuttle can be deposited and retrieved directly to and from its position in the store by an appropriate branch.
The tree rotates around its axis of symmetry by means of a motor drive with angle position encoder and also can execute a translation over a range of 45 cm in the vertical direction, with position encoding.
This concept requires the introduction of a four way diverter between the transmission line and the stem of the tree. Each of the four branches terminates in an extensible section, which consists of 2 coaxial metal bellows and a cone shaped mouthpiece. When the branch pipe has reached its desired position, the mouthpiece moves towards the mouth of the storage location by applying pressurized air to the bellows assembly (figure 3).
It should be noted that the division of the store in four levels to be served by individual pipe branches serves the purpose of limiting the required vertical travel of the 'manipulator' to one fourth of the range which would have been required if only one pipe branch had been installed. This enables the transmission pipe to be coupled to the store by means of a short flexible pipe section, which can easily be guided into the required shape.

It should be noted that all the components requiring maintenance are situated in an accessible location outside the topshield.
In the arrangement shown the four way diverter forms a part of the stem. It is situated within the bearing plug.
Immediately preceding this diverter is another diverter which selects the cell to be connected to the store. In figure 2 it has been sketched in the form of a linear slide with four piping inputs. Depending on the actual application this diverter may be installed elsewhere in the building of course.
By assembling the manipulator pipe branches in such a manner that they are in one plane, it is possible to extract the manipulator from the store through a relatively narrow slit in the topshield, which is normally closed by means of a steel insert (not shown).

This alternative appears to be very attractive for a number of reasons:
a. economical to manufacture,
b. no vulnerable nor radiation sensitive components within the store,
c. no risk of shuttles dropping to the bottom.

If any doubt should persist about this, this situation can be dealth with by shaping the bottom of the store in such a way that a shuttle will be guided to an extraction point from where it can be collected in a shielded pot.

With so many advantages there must be at least one drawback, according to the 'law of conservation of misery' and we shall try to identify it in the very near future.

6. COST ESTIMATE (ALTERNATIVE VERSION)

1. Cylindrical lead shield, thickness 25 cm, encased in stainless steel inner- and mild steel outer liner: weight 42 tons, steel topshield: weight 12 tons	Hfl. 150.000,--
2. 'Manipulator arm' and drive unit, inclusive of diverter	Hfl. 30.000,--
3. 2 Pneumatic conveyor terminals	Hfl. 10.000,--
4. Roots air blower	Hfl. 10.000,--
5. Pressure control system	Hfl. 10.000,--

6.	Position encoders and other sensors	Hfl. 15.000,--
7.	LSI 11/23 128 K computer, inclusive 1 20 Mbyte disk drive, 1 floppy drive, 2 terminals, 1 printer	Hfl. 42.500,--
8.	CAMAC crate + controller stepmotor drivers and parallel input output gates	Hfl. 40.000,--
9.	2480 shuttles	Hfl. 125.000,-- - * 250.000,--
10.	Shuttle storage locations	Hfl. 25.000,--
11.	Software development + installation	Hfl. 100.000,--
12.	Closed circuit TV system	Hfl. 10.000,--
13.	Piping + electrical wiring installed	Hfl. 20.000,--
14.	Auxilliary containment and shields for manipulator maintenance	PM
15.	Design	Hfl. 200.000,--
	Total expenditure	Hfl. 787.500,-- → 912.500,--

*The cost may be drastically reduced to approximately Hfl. 10.000,-- if use can be made of commercially available deep drawn cans.

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[1] Debets, P.C. and H.J. Wervers
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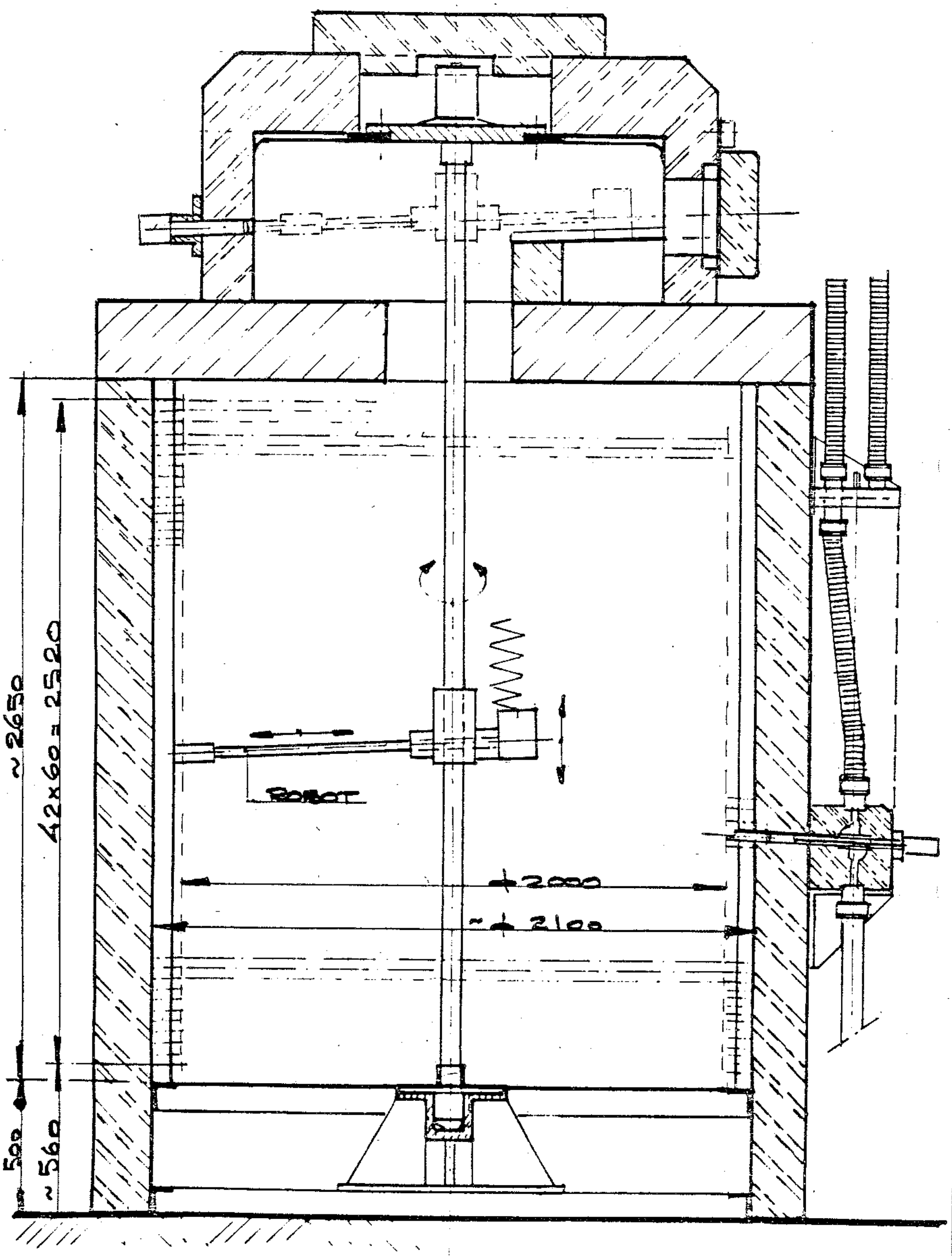
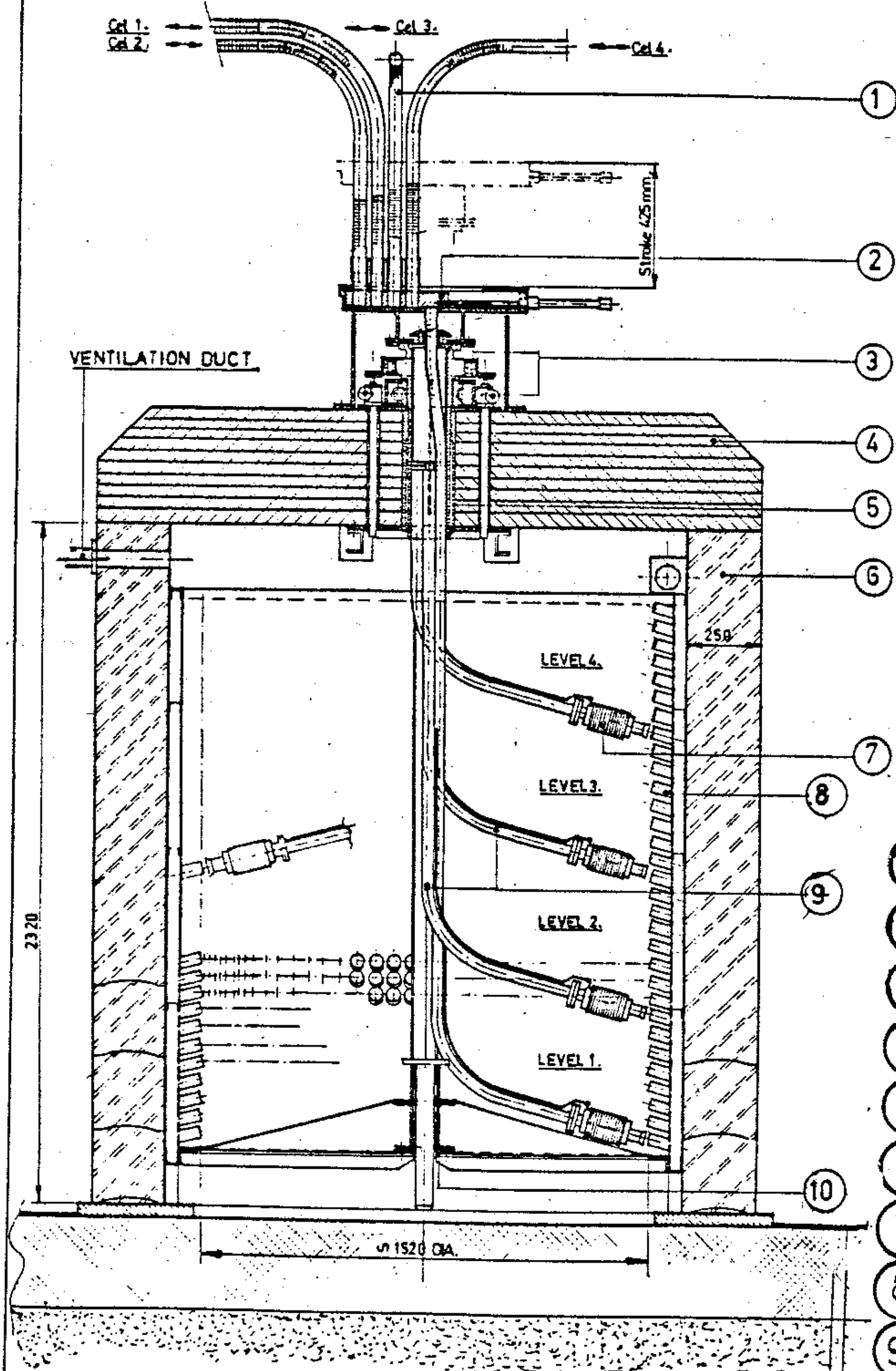
Materiaalkunde-memo 76-19, february 1976.
Presented at the 17th meeting of Hott Laboratory Committee, Casaccia, May 25th - 26th, 1976.



<u>Figure 1.</u> Cross section of a direct access store with simple robot arm



1. Flexible tubes
2. Cell selector
3. Level selector device
4. Mild steel roof
5. Top bearing
6. Lead wall
7. Mouthpiece
8. Storage tube
9. Pipe tree
10. Bottom bearing

Figure 2. Cross section of an alternative design with direct pneumatic insertion of shuttle

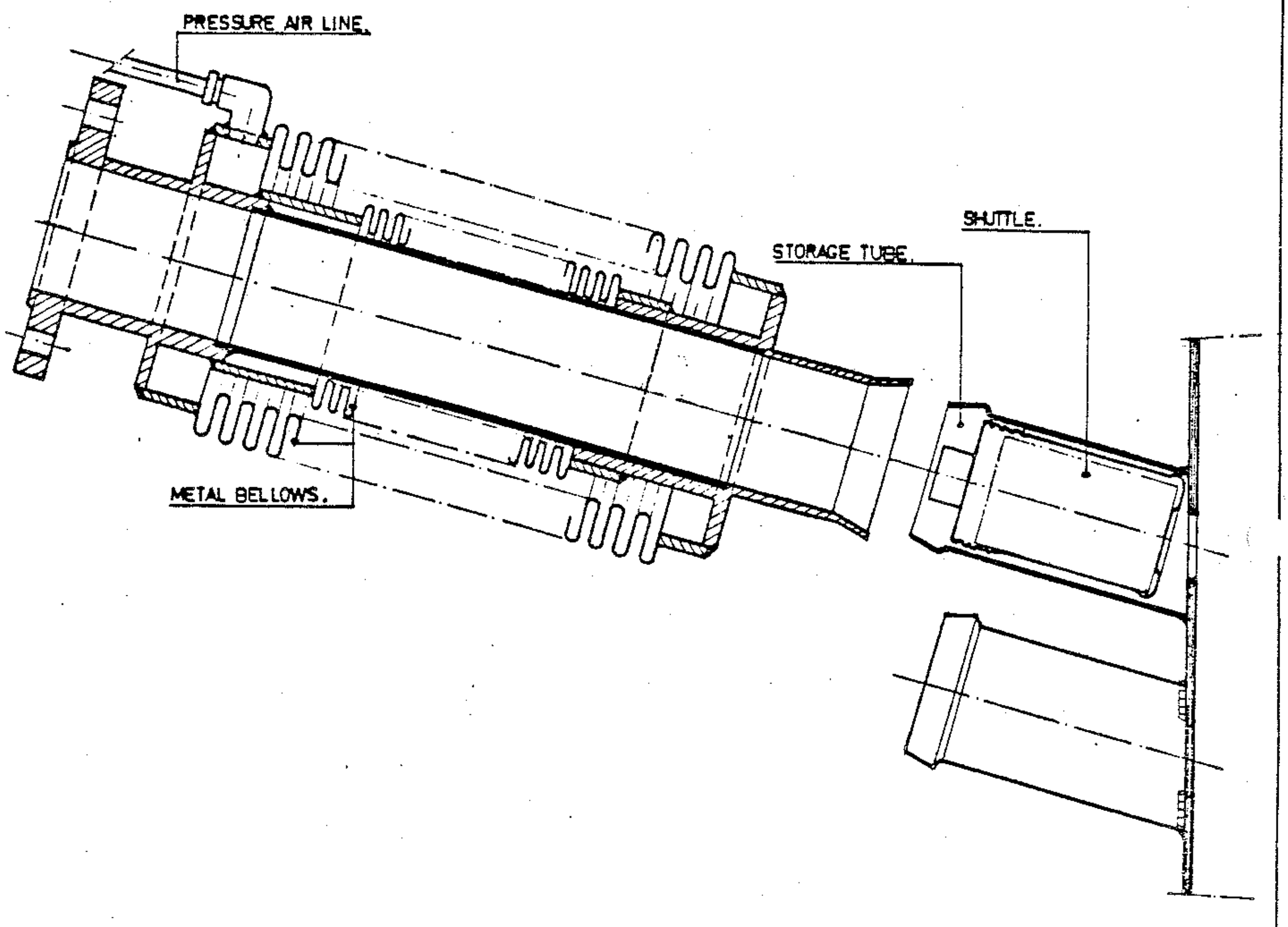
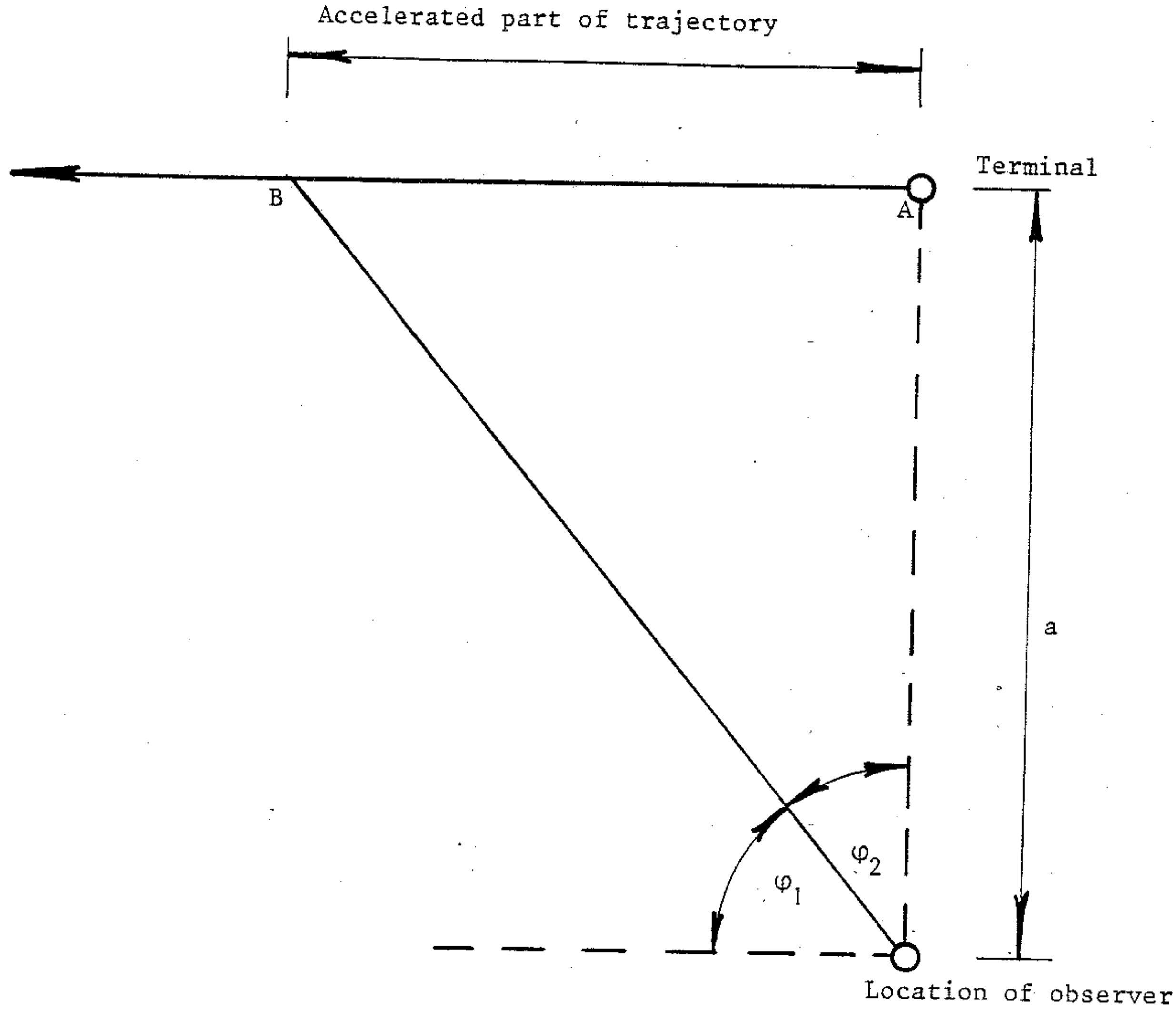


Figure 3. Detail of charge/discharge bellows assembly of alternative design



Shuttle departing from terminal A with velocity = 0 has reached velocity of V_0 cm/sec at point B.

Figure 4. Flight path of a shuttle as seen by an observer