CONCEPTUAL DESIGN FOR THE INJECTION OF TRITIATED EFFLUENTS INTO DEEP GEOLOGICAL FORMATIONS

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ABSTRACT

According to the Fourth Amendment to the German Atomic Energy Act in 1976, the Government of the Federal Republic of Germany is responsible for the establishment and operation of repositories for radioactive wastes, such as disposal facilities for tritium-containing water, coming out from reprocessing plants.

The Federal Government has declared that it considers the disposal of tritiated effluent in suitable, deep-lying geological formations as the preferred solution. Alternative methods are the cementing of tritium effluents for disposal and so-called in-situ solidification. The "Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH" (DBE) is on the way to design a concept for a deep-well injection facility for the disposal of tritiated effluents by order of the Federal Ministry for Research and Technology.

For the injection of tritiated effluents, a deep-lying porous rock stratum is to be used, on the safety and operational requirements on corresponding systems for both surface and underground installations.

From an economic standpoint, the most favorable approach involves the transport of HTO effluent via tank truck/lorry and an intermittent operation of the deep-well injection facility with a duration of about four weeks each year.

Associated research and development work concerning the propagation behavior of miscible liquids in a porous medium, has revealed that the difference between the density of the tritiated effluent and that of the formation fluids exerts a considerable influence on the establishment of the displacement flood front.

INTRODUCTION

In a reprocessing plant for spent nuclear fuel elements, tritiated effluents are produced. These effluents are slightly radioactive and cannot be released to the environment for reason of radiation protection (Table I). The output rate for tritiated effluent amounts to about 1 000 m^3/a.

There are essentially three possibilities for the management and the final disposal of tritiated effluent:

- injection into porous deep-lying geological formations,
- cementation into drums and disposal
- in-situ solidification.

In the Federal Republic of Germany, the injection into deep-lying geological formations has been designated as a reference concept and is being pursued with priority.

The Federal Ministry for Research and Technology has commissioned the DBE with the planning of a facility for the deep-well injection of these effluents.

The suitability of the plans for the final disposal of tritiated effluents in deep-lying geological formations shall be demonstrated with reference to location, radiological protection, the standpoint of safety engineering and in accordance with legal requirement.

EXECUTION OF THE PROJECT

The project is to be executed technically in the form of three partial projects:

- general planning
- design conception, and
- course planning independent of location.

A "work break-down structure" is shown in Fig. 1.

The objectives of the general planning include:

- the definition of basic principles, development of guidelines, and specification of boundary conditions, for orientation of the project realization,
- a compilation of the current status of knowledge, on which the underground disposal of tritiated effluent is based, with reference to the work hitherto conducted by the Nuclear Research Center at Karlsruhe (KfK),
- the elucidation of fundamental safety and technical aspects,
- the recognition of possible information gaps from a comparison between the problems involved and the status of current knowledge,
- execution of required research and development work, and
- execution of variational planning, by means of which the technoeconomic consequences can be derived from the safety specifications.

TABLE I

Nuclide Spectrum of Tritiated Effluent (HTO)

Nuclide	Concentration in Bq· m^{-3}	Limit in Bq· m^{-3}	RTI
H-3	3,7 E+12	7,3 E+6	5,1 E+5
Sr-90	3,6 E+6	8,9 E+2	4,0 E+3
Y-90	3,6 E+6	4,5 E+4	8,0 E+1
Ru-106	1,8 E+5	2,6 E+4	6,9 E±0
Rh-106	1,8 E+5	2,3 E+5	3,6 E+1
Cs-134	1,6 E+6	1,9 E+4	8,4 E+1
Cs-137	5,6 E+6	3,4 E+4	1,6 E+2
Ba-137 m	5,3 E+6	4,8 E+3	1,1 E+3
Ce-144	1,4 E+5	2,6 E+4	5,4 E±0
Pr-144	1,4 E+5	5,0 E+3	2,8 E+1
Pu-241	1,7 E+4	5,0 E+5	3,4 E-2
I-129	4,1 E+5	4,1 E+2	1,0 E+3
Am-241	1,1 E+5	8,4 E+3	1,3 E+1
Cm-244	5,9 E+5	1,6 E+4	3,7 E+1
Pu-238 -239 -240 -242 -244	9,1 E+2	9,8 E+3	9,3 E-2

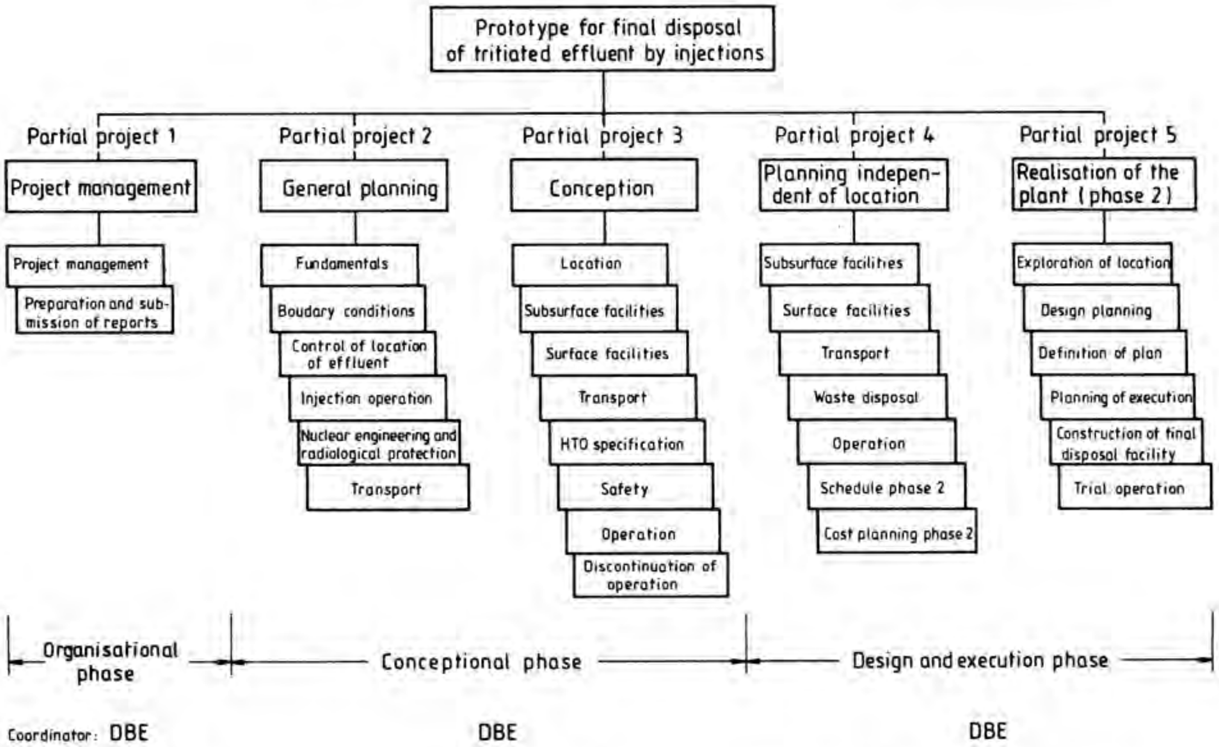


Fig. 1. System structure of the project development for the prototype plant for the final disposal of tritiated effluent by injection.

In the design phase for the plant, the objective is to apply the method employed by the petroleum industry for the injection of saline effluent into porous strata to the disposal of tritiated effluent, as well as supplementary conceptual planning in the field of nuclear engineering. The conception of such an injection plant encompasses the entire system, including radiation protection, safety, geological, technical, and economic aspects. With the use of the results of the variational planning and comparisons, the overall system is to be optimized.

The objective of the planning independent of site selection is the preparation of the optimized concept for an injection plant at the design planning level to whichever extent possible and expedient. Thus, it is to be ensured that the concept for the facility is examined for its feasibility, and that factors ensuing from the planning also are taken into account during the selection of a site.

BASIC PRINCIPLES FOR THE PROJECT

Analysis of Possible Accidental Scenario

An Analysis of know cases of damage to injection wells has shown that they occur very seldom, as referred to the total number of more than 10 000 injection wells throughout the world. Erroneous geological valuations in the strict sense, or insufficient exploration, have resulted in some failures. The corrosion of casing and injection strings due to aggressive aqueous chemical effluents has thereby also contributed to the damages. Insufficient injection depth has likewise led to individual failures.

Research and Development Work Concerning the Propagation Behavior of Miscible Liquids

In the course of the project, the boundary conditions necessary for reliably investigating the propagation of tritiated effluents in a porous medium under reservoir conditions with the use of analytical models are being studied at the Institute of Petroleum Engineering at the Technical University of Clausthal, West Germany. On the part of the oil industry, sufficient experience with the propagation of nonmiscible liquids is available, but not with the propagation of miscible liquids such as tritiated effluents and formation water. Effects such as mixing, displacement, diffusion, retnetion, and decay of radioactivity, as occur during and after the injection of radioactive effluents, are not taken into consideration by the analytical models employed by the oil industry.

Preliminary results indicate that the difference between the density of formation water and that of the tritiated effluents exerts a substantial influence on the size of the mixing zone, and thus on the establishment of the flood front.

FACTORS AFFECTING THE SEARCH FOR A SUITABLE SITE

For the injection of fluids, three types of reservoirs can in principle be employed:

- porous rock,
- fractured rock, and
- karstic rock.

After a comparative consideration of the three types of a reservoirs on the basis of a catalogue of criteria, a decision has been reached in favor of the porous medium as reference reservoir. The catalogue of criteria comprises:

- ability to control the propagation of the effluent,
- low velocity of propagation,
- nuclide retention capacity,
- sorption capacity,
- pressure conditions prevailing during injections, and
- explorability of the reservoir.

In the selection of a site for the final disposal of tritiated effluent by injection, the following factors must be assessed:

- proximity of the injection facility to the reprocessing plant (transport),
- depth of the horizon for injection, and effects of the HTO in the event of failure,
- tectonic structure of the region,
- basic seismic stresses prevailing in the region,
- proximity to oil reservoirs, mineral deposits, ground-water reservoirs, spas and thermal springs,
- special characteristics of a reservoir horizon decisive for its suitability,
- demands imposed on the overlying impermeable rock stratum, and
- environmental protection.

DESCRIPTION OF THE FINAL DISPOSAL FACILITY

The overall final disposal facility is subdivided into two partial facilities:

- the subsurface facilities, and
- the surface installations.

Subsurface Facilities

The underground facilities encompass the following systems (Fig. 2):

- injection well and pump for injecting the tritriated effluent (including shut-off valves),
- reservoir: section of the porous formation for receiving the tritiated effluents and the overlying impermeable rock stratum as a first barrier, as well as the underlying impermeable shale stratum,
- observation reservoir: porous formation situated above the first overlying impermeable stratum, and a second impermeable stratum as a second barrier,
- monitoring well for the observation reservoir, including shut-off valves,
- monitoring of groundwater, and
- as dictated by the location, possibly monitoring of the tritium propagation through the reservoir formation by means of boreholes.

  Such wells are necessary for the exploration of the locality, in any case. As a precaution, one of these wells can be maintained on standby for use as an injection well, if required.

The final disposal facility has been conceived in analogy to a double-containment system. In the event of failure of the overlying impermeable stratum (thick shale stratum as first barrier), the ascent of tritiated effluent into the observation reservoir is recorded by means of the measuring process to be carried out in the observation well. Upon occurrence of this case, the injection of tritiated effluent is discontinued.

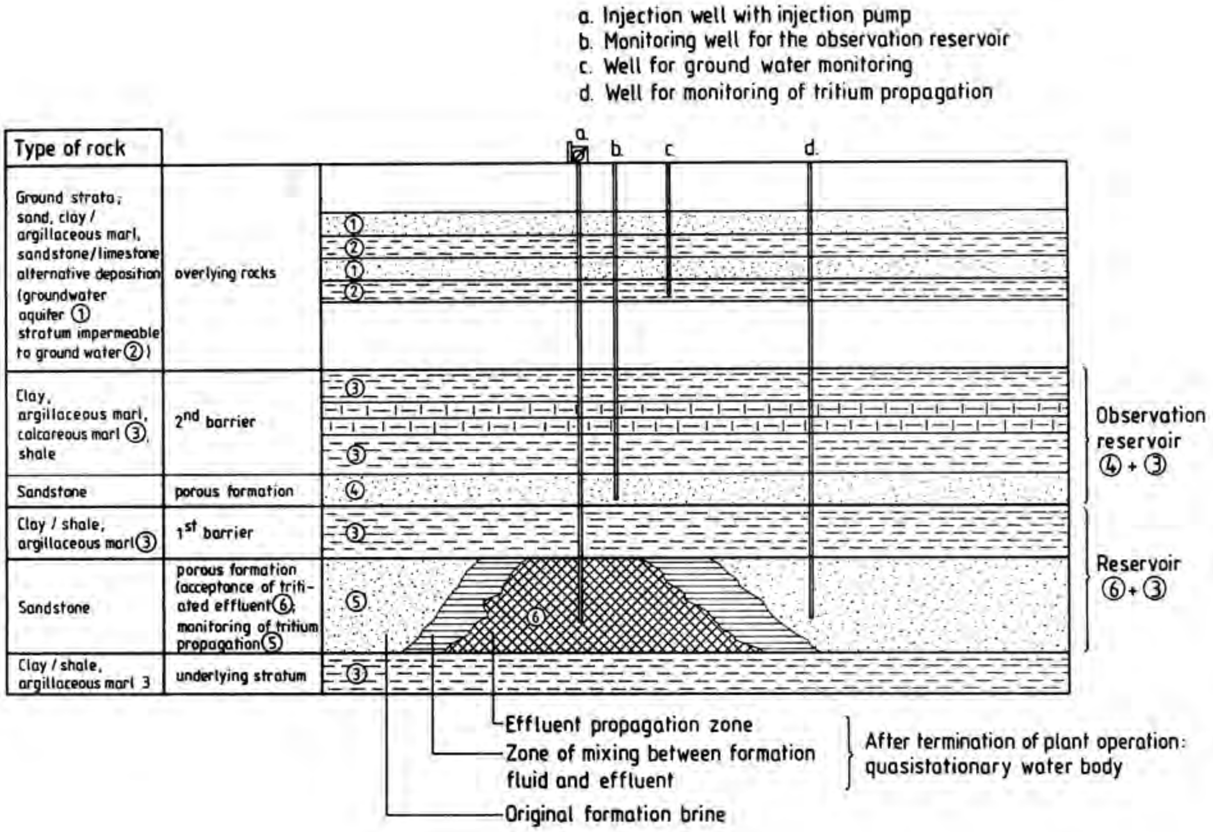


Fig. 2. Schematic Diagram of a Facility for the Final Disposal of Tritiated Effluent by Injection into a Porous Reservoir.

Through the appropriate choice of casing system and cementation of the annuli, it is ensured that the control wells satisfy the demands of a multi-barrier system.

The description of the subsurface facilities shows that the impermeable rock strata overlying the second barrier are not viewed as a further barrier and do not constitute a part of the final disposal facility. This assumption is based on the results of propagation calculations for the migration of tritiated effluents through the overlying rock of a model sedimentary formation with average flow conditions and a shale stratum which does not extend over the entire area under consideration. These results do not indicate any radiation exposure beyond the water path. Examples of arrival times and yearly doses as functions of the depth of origin for the nuclide I-129, which is subject to practically no sorption at all, are presented in Table II.

Surface Installations

Essential factors affecting the design of the surface facilities are:

- the treatment of the effluent,
- the mode of operation of the plant (continuous, intermittent over the year, periodic injection for about four weeks each year),
- the transport of the effluent (truck/lorry, pipeline, railway).

From the standpoint of process technology, the surface installations of the injection plant must be capable of treating the delivered (nitric acid) tritiated effluents in such a way that no damage occurs as a result of corrosion of the plant components and casing in contact with the tritiated effluent, or as a result of incompatibility of the tritiated effluent, or as a result of incompatibility of the tritiated effluent with the reservoir rock and formation fluid (geochemical effects).

During the planning of the structural features, such as processing buildings and exterior installations, the requirements resulting from the means of transport and mode of operation of the plant must be taken into account, besides the process engineering itself.

As a basis for optimizing the plant design, the following have been specified:

1) Treatment of the effluent, subject to the following requirements:

   - increase in salinity to achieve the density of the formation fluid in the reservoir,
   - adjustment of the pH-value to that of the formation fluid in the reservoir,
   - deoxygenation,
   - addition of biocide, and
   - separation of solids.

This conditioning is necessary for the adjustment of the tritiated effluent to the reservoir conditions.

2) Operation during a certain period (about four weeks each year)

   - Periodic operation is the economically most favorable mode of operation.

TABLE II

Time of Arrival and Annual Exposure Upon Injection of 40 000 m^3 of Tritiated Effluent Containing I-129 (concentration: 4.1 · 10^5 Bq· m^{-3}) for various depths of origin

Depth of origin in m	Remarks	Time of arrival of maximum in a	Exposure in mrem
190 to 220	Below the Lauenburger clay	1650 1600	0,4 0,4
60 to 190	Below the boulder clay (glacial till)	200	1,3
15 to 60	"	200	1,2

3) Transport by truck

- Transport via truck/lorry constitutes the economically most favorable alternative (Fig. 3).

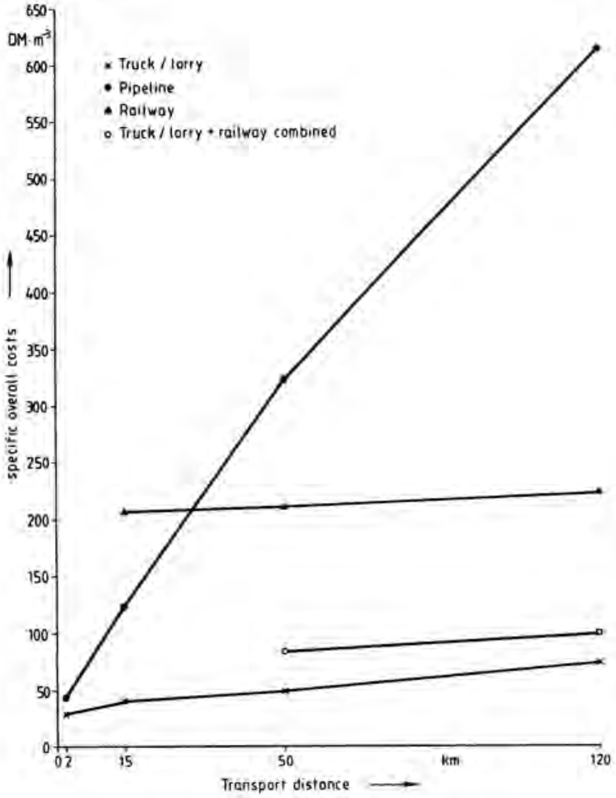


Fig. 3. Comparison for various transport systems

The security and operational installations comprise a number of systems:

- receiving area,
- reaction zone,
- storage of chemicals,
- chemical metering equipment,
- separation of solids,
- surface installations,
- pipe racking area,
- fence and associated installations,
- security installations for the control and restriction of admittance,
- traffic facilities,
- ventilation facility suitable for nuclear installations,
- decontamination equipment,
- measures for protection against radiation,
- instruments for protection against radiation,
- fire-fighting equipment,
- handling of radioactive wastes resulting from operation,
- air-conditioning facilities,
- communications equipment,
- electric power supply,
- lighting facilities,
- water supply,
- disposal of sewage not radioactively contaminated,
- laboratory and associated equipment,
- maintenance and auxiliary equipment, and
- office and social facilities.

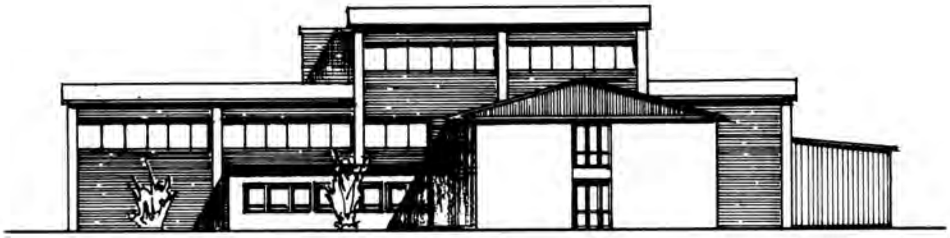
A view of the injection plant is presented in Fig. 4.; a ground plan is shown in Fig. 5.

The air-conditioning facilities have been designed with a three-fold underpressure graduation:

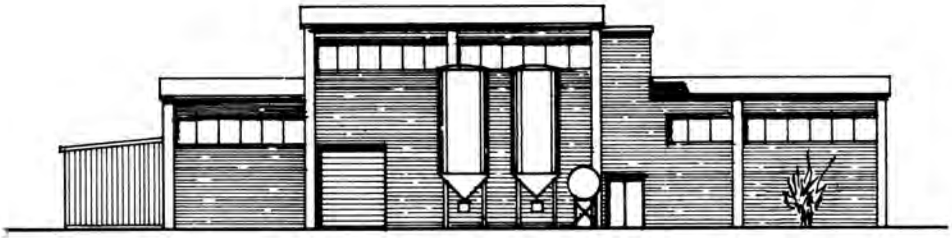
- The highest vacuum prevails at the site of origin of contamination of exhaust air by tritium, that is, directly above the liquid-air interface in the vessels filled with tritiated effluent.
- An intermediate vacuum is to prevail in the workshop and processing area.
- The lowest vacuum is to prevail in the corridors. For a portion of the office and auxiliary building (for example, visitor's room, etc.), no underpressure is to be provided.

The radiation protection areas comprise the control area with the

- receiving area,
- reaction area,
- separation of solids,
- transfer area,
- injection station (mobile shop section),
- workshop,



SOUTH VIEW

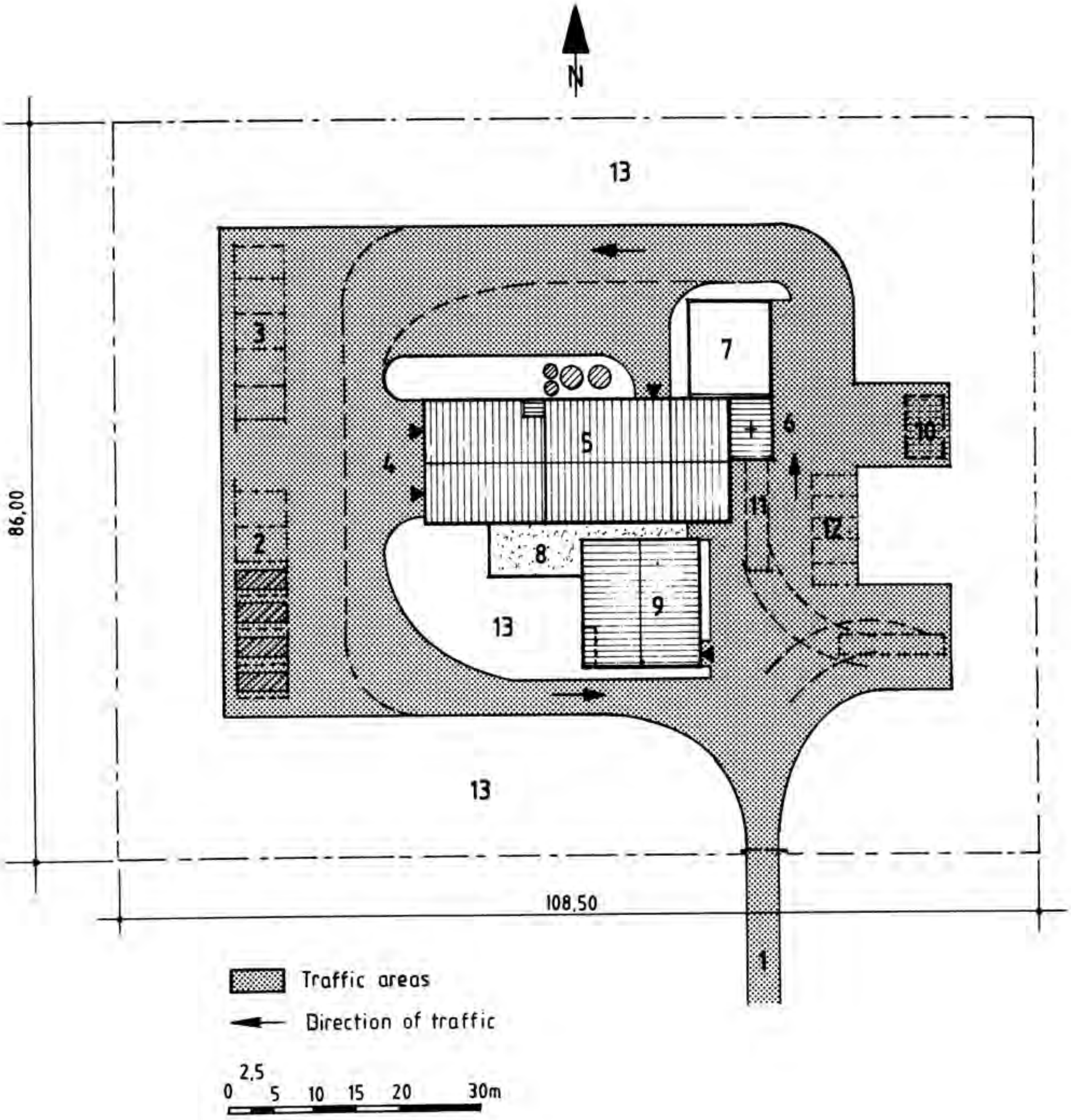


NORTH VIEW

EAST VIEW

WEST VIEW

Fig. 4. Views of the injection plant



LEGEND:

1. Driveway
2. HTO container stand-by (full)
3. HTO container stand-by (empty)
4. Container entrance to injection plant
5. Station building
6. Mobile shop section with injection well
7. Pipe racking area
8. Laboratory building
9. Office and social building
10. Area for storage of the mobile shop section
11. Drilling rig with turning radii
12. Vehicle parking lot
13. Lawn

Fig. 5. Ground plan of the injection plant.

- loading area for radioactive wastes,
- air-conditioning facilities suitable for nuclear technology,
- laboratory for radioactive materials,
- processing and auxiliary materials,
- laboratory for conventional materials, and
- corridor,

as well as the surveillance area with the remaining rooms.

MALFUNCTIONS AND ACCIDENTS

As stipulated by the German Atomic Energy Act, the necessary precautions must be taken for safeguarding against damages in conjunction with the construction and operation of the injection plant, in accordance with the current status of science and technology. In the following, a survey of so-called design failures is presented for the surface and subsurface facilities.

Failures in the Subsurface Facility

During the operational phase, only a single imaginable case of failure could possibly lead to environmental pollution. This would occur only if groundwater were contaminated by tritiated effluent. The events which could result in contamination of the groundwater, as well as their causes and consequent precautionary measures and demands imposed on the design of the subsurface components of the final disposal plant, are compiled in Table III.

Similarly, during the postoperational phase, only this same case of failure could conceivably result in environmental pollution through contamination of the groundwater by tritiated effluents. The event, its cause, as well as precautionary measures and corresponding design of the endangered subsurface components of the final disposal plant, are compiled in the Table IV for this case during the postoperational phase.

Accidents at the Surface Installations

The conceivable accidents which are decisive for the design of the surface installations are compiled in Table V.

CONCLUSIONS

The technical planning operations and the failure considerations hitherto conducted demonstrate that the injection of tritiated effluent is feasible from the standpoint of safety.

TABLE III

Event, Cause, Preventive Measures as well as Component Design for Various Malfunctions or Accidents in the Subsurface Facilities During the Operational Phase

Event	Cause	Preventive measure, design
1. Leakage through the casing (riser and casing strings, including packers	- corrosion of the tubular goods or connections	- Filling of the annulus with a protective fluid (corrosion inhibitor) - Monitoring the annular fill for fluctations in pressure - Use of stainless steel for tubular goods in contact with the effluent - Quality control measures to be implemented during the manufacture as well as installation of the tubular goods (ultrasonic measurements, testing of the tightness of connections) - Monitoring of the ground water by means of observation broreholes
2. Leakage through the cementation (frac)	- faulty cement bonding - low strength values	- Optimising of the cementation programme with respect to the composition of the cement slurries, rheological parameters, placement of centralisers, compressive strength - Inspection of the cement bonding with the use of geophysical measuring techniques, if necessary, cement squeeze - Monitoring of pressure at injection pump - Monitoring of the ground water by means of observation wells - Monitoring of the observation reservoir by means of observation wells
3. Leakage through the overlying, impermeable stratum (barrier)	- undetected fault	- Thickness of the overlying impermeable stratum (first barrier) exceeding 20 m - Monitoring of pressure at the injection pump, with due observation of the reservoir behaviour (formation history) - Monitoring of the observation reservoir by means of monitoring wells - Presence of a second overlying impermeable stratum (second barrier) above the observation reservoir

TABLE IV

Event, Cause, Preventive Measures and Component Design for Malfunctions During the Postoperational Phase in the Subsurface Facilities

Event	Cause	Preventive measure, design
Leakage at the borehole plug	- Injection through neighbouring wells for other purposes without knowledge ledge of the existence of the previous injection well for tritiated effluent	- Optimising of the plugging programme with respect to the composition of the cement slurry, rheological parameters, compressive strength, shrinkage behaviour - Injection of flood water after completion of injection of tritiated effluent; thus displacement of the tritiated effluent from the immediate proximity of the injection well - Installation of so-called bridge plugs - Installation of clay and, if required, asphalt plugs

TABLE V

Compilation of Accidents and Malfunctions Decisive for Designing of the Surface Installations

Accident Category	Event
Collision of transport vehicle without fire	Mechanical effects on the draining line of the transport container, and on the transport container itself
Collision of transport vehicle with fire	Mechanical and thermal effects on the transport container and associated draining line
Fire on vehicle	Thermal effects on the transport container and associated draining line
Failure of a pipeline or other component carrying radioactive fluid	Mechanical effect on the pipeline or other components (pumps, valves, etc.) carrying radioactive fluid
Dropping of transport container during handling or transport	Dropping of transport container during transfer from delivery vehicle to that at the plant
Fire within the plant precincts	Thermal effects on the transport container, associated draining lines, and other pipelines or components carrying radioactive fluid