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# Research Activities on Fast Reactors in Switzerland

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## 1 Future Electricity Supply Mix Options

The current domestic Swiss electricity supply is primarily based on hydro power (approximately 61%) and nuclear power (about 37%). The contribution of fossil systems is, consequently, minimal (the remaining 2%). In addition, long-term (but limited in time) contracts exist, securing imports of electricity of nuclear origin from France. The total yearly net electricity generation by domestic power plants in the hydrological year 1993/1994 was 62.9 TWh; the domestic demand was 51.0 TWh (including 7% losses). During the last two years, the electricity consumption has been almost stagnant, although the 80s recorded an average annual increase rate of 2.7%.

The future development of the electricity demand is a complex function of several factors with possibly competing effects, like increased efficiency of applications, changes in the industrial structure of the country, increase of population, further automation of industrial processes and services. Under the basic assumption of economic growth, two possible electricity demand level cases were postulated by VSE (Association of the Swiss Utilities): a high-growth demand case corresponding to a yearly increase of 2% from year 1995 to year 2010 and 1% from year 2010 to year 2030, and a low-growth demand case corresponding to a yearly increase of 1% from year 1995 to year 2010 and 0.5% from year 2010 to year 2030.

The electricity generating systems whose capacity, according to VSE, is largely secured are herewith referred to as the "base" supply and is predominantly hydropower.

Due to decommissioning of the currently operating nuclear power plants and expiration of long-term electricity import contracts there will eventually open a gap between the postulated electricity demand and the base supply. The assumed projected demand cases, high and low, as well as the secured yearly electric energy supply are shown in Figure 1 for the period of interest.

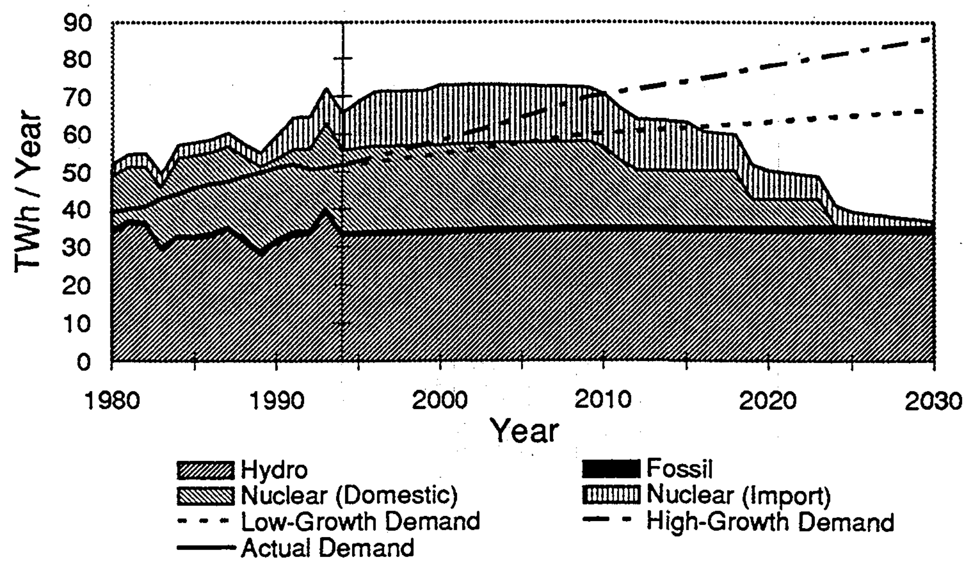


**Fig. 1:** Electric energy demand cases considered by VSE and the secured yearly electricity supply for the period 1995-2030.

| Supply mix options | | System shares in the cold season to cover the gap of electric energy |
|---|---|---|
| 1 | Conventional thermal | 50% CC(gas); 25% CC(oil); 25% Coal |
| 2 | Nuclear | 100% Nuclear domestic |
| 3 | Mix Nuclear/Gas | Today's installed nuclear capacity; rest of supply CC(gas) |
| 4 | Import 100% | 10% CC(gas); 30% Coal; 60% Nuclear |
| 5 | Import 50% | Import: 10% Coal; 40% Nuclear.<br>Domestic: 25% CC(gas); 25% Nuclear. |
| 6 | Conventional thermal + PV | as Option 1 with PV substituting 5% |
| 7 | Mix Nuclear/Gas + PV | as Option 3 with PV substituting 5% |

**Table 1:** Definition of the supply mix options assumed by VSE to cover the future electricity gap.

For these 7 supply mix options and for the base supply life cycle analysis (LCA) to evaluate the total amounts of greenhouse gases (GHG) were performed (Fig. 2)

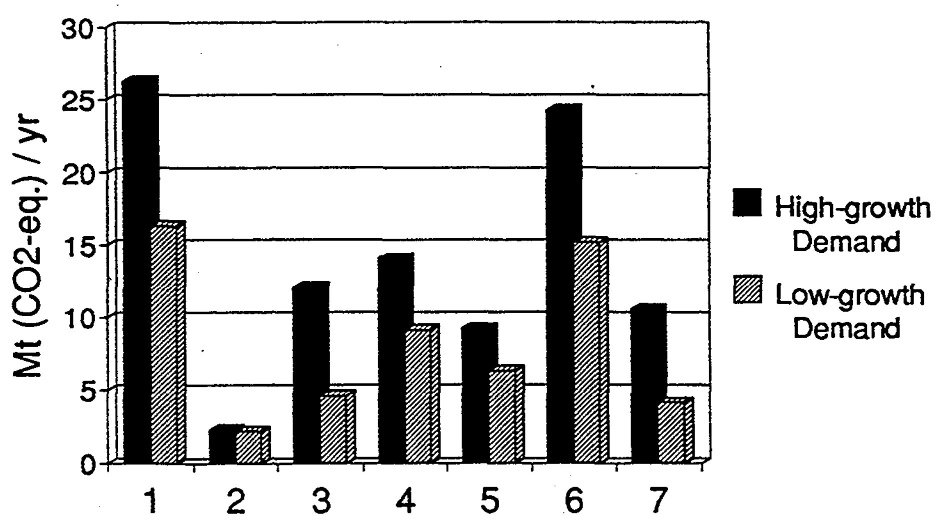


**Fig. 2:** Greenhouse gas emissions for the 7 supply mix options of the high- and low-growth demand cases in year 2030.

In Figure 3 the total GHG-emissions in Switzerland are compared with those due to the electricity production. The GHG emissions are naturally only one criteria among several others to decide on the future supply mix in Switzerland. A complete documentation of this subject is given in Ref. [1].

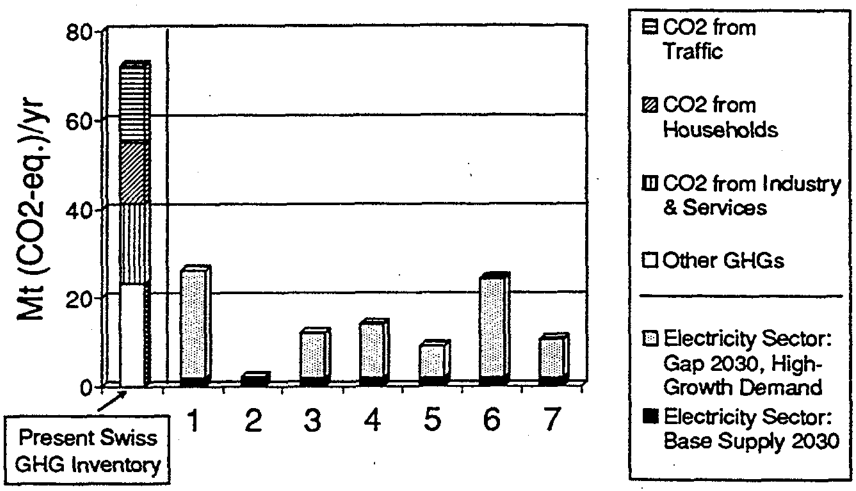


**Fig. 3:** Comparison of the present Swiss GHG emission inventory with LCA results for high-growth demand case options for year 2030.

## 2 Physics Aspects of Pu-Burning Fast Reactor Configurations

### Introduction

Several countries worldwide have decided to take effective steps for managing the long term growth of their plutonium stockpiles, thus making the maximum use of the energy source present in plutonium and reducing the long term toxicity and proliferation risks associated with stored stockpiles. Various studies have demonstrated that fast reactor cores can be designed to burn the degraded plutonium resulting from LWR multi-recycle; nevertheless, the required modifications of conventional fast cores tend to alter their overall physics and safety behaviour. Within this framework, a major experimental program is undertaken at the MASURCA facility at CEA Cadarache in support of the CAPRA (Accrued Consumption of Plutonium in Fast Reactors) project [2]. The CIRANO program [3] which provides experimental data on mock-up configurations of Pu-burning cores, is primarily aimed at validating nuclear data and methods used to model the novel features of plutonium burning reactor cores: Replacement of radial and axial blankets by reflectors consisting of stainless steel and sodium, higher Pu-enrichment, degraded Pu-vector, and more heterogeneous core design. The ongoing collaborative program between CEA in France and PSI in Switzerland supports the validation and qualification of the ECCO/ERANOS deterministic code system [4] developed at CEA for accurately predicting operating and safety-related physics parameters of plutonium-burning advanced fast reactors. This scheme of calculations, which is based on the JEF-2 evaluation, is compared with other deterministic code systems, such as the PSI system MICROX/TWODANT, and with the continuous energy Monte Carlo reference method, using additional data evaluations. The ECCO/ERANOS predictions are also compared with measured values, provided by the CIRANO program, of reactivity, central spectral indices, sodium void worths, reaction rate traverses, as well as neutron and photon heat depositions along the radial and axial directions.

### System Description and Results

Neutronic analyses, including coupled neutron/photon calculations and sensitivity studies to methods and data, are performed for the first two cores in the CIRANO experimental program, namely ZONA2-A and ZONA2-A3 [5]. The ZONA2-A core is the first ever totally plutonium-fueled core built in MASURCA. It contains $UO_2PuO_2$ rodlets with about 25 % Pu-enrichment, and Na rodlets. The core is axially and radially surrounded by a breeding region (blanket) consisting of natural $UO_2$ and Na rodlets, itself surrounded on all sides by a stainless steel shield region. The ZONA2-A core as such constitutes the starting reference point for the changes outlined above. These changes have begun with the replacement of the radial and axial fertile blankets surrounding the core by sodium/steel reflector assemblies.

The second configuration analyzed, ZONA2-A3, forms an intermediate step in this process, as the radial fertile blanket, but not the axial one, has been replaced by sodium/steel elements. This replacement results in reduction of the critical radius (reflector gain), significantly higher flux and heat deposition rate in these sodium/steel elements than in the original radial blanket, and therefore in larger complexity of the physics phenomena involved. The correct collapsing of cross sections in the reflector, modelling of resonance shielding and back scattering into the core, as well as determination of gamma sources, are particularly difficult because of the enhanced role played by structural material resolved and unresolved resonances in the whole fast energy range, and by anisotropic cross sections.

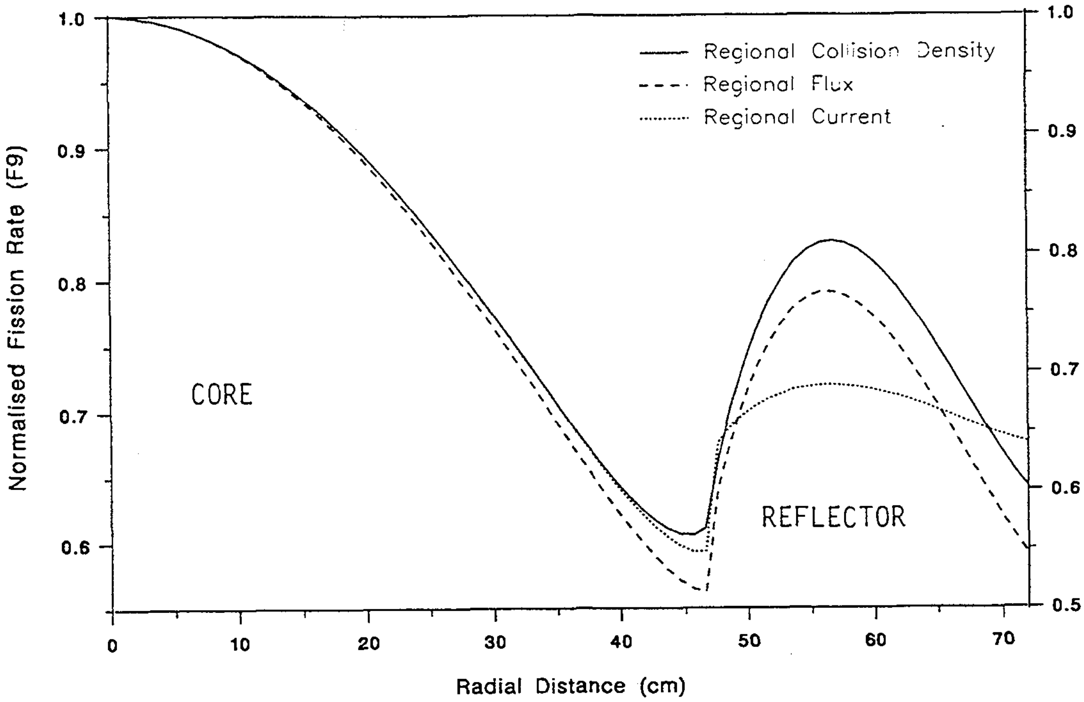


**Fig. 4:** ZONA2-A3 axially centered Pu239 fission rate radial profiles using different homogenisation procedures in the cell calculation

Globally, consistency between deterministic, stochastic, and experimental results is achieved for both configurations. The MICROX/TWODANT predictions of experimental values, using a small number of broad groups, became more satisfactory after the original procedures of homogenisation of anisotropic cell cross sections in space (with either regional fluxes or currents), as well as the generation of fission spectra for individual actinides, were improved. As the previous figure shows, the use of the new homogenisation method (with regional collision densities) leads to higher computed fission rates of $^{239}Pu$ in the radial reflector region of ZONA2-A3. These rates are in much better agreement with the experimental values [3].

Despite these improvements, some unexplained discrepancies between deterministic, stochastic, and experimental results are still noticed. In particular, because the computed reflector gain appears to be mispredicted by all methods, the effect of using different sets of iron data in the various regions is evaluated. In the following Table 2, relative variations of the reactivity of ZONA2-A3 are given in Δk/kk' in %, with respect to the reference k, the JEF-2 value.

| $^{56}Fe$ Data from | Radial Reflector | Axial Blanket | Core | All Regions |
|---|---|---|---|---|
| JENDL-3 | – 0.22 | – 0.03 | – 0.11 | – 0.39 |
| ENDF/B-VI | – 0.20 | – 0.01 | + 0.02 | – 0.23 |
| BROND-2 | – 0.41 | + 0.07 | – 0.07 | – 0.59 |

**Table 2:** Reactivity Variations for ZONA2-A3 in Δk/kk' in %, k is the JEF-2 Value

This table and additional detailed analysis indicate strong sensitivity to both the level and fine shape of the iron cross section: The computed reactivity and radial power distribution are particular sensitive to the elastic scattering cross section between 100 keV and 1 MeV, with the maximum at 300 keV.

## Conclusion

The first results of the CIRANO experimental program are providing valuable information about Pu-burning fast reactor configurations. Collaborative work between PSI and CEA on current experiments is continuing with particular emphasis on code validation and qualification. Efforts are concentrating on unexplained discrepancies observed between calculated and measured reaction rate traverses across the core/reflector interface and sodium void worth. The CIRANO program will provide further experimental information on fast reactor configurations characterised by a variable plutonium isotopic vector and higher enrichment levels. Measurements of heat deposition rates will be analyzed to broaden the range of application of the code systems. This additional experimantal information will be used to assess the quality of methods and data for calculating Pu-burning fast reactor configurations.

## 3 Swiss research relating to residual heat removal in Fast Breeder Reactors

### Introduction

The LMFBR-related thermal-hydraulics research programme in Switzerland consists of experimental and analytical investigations on the mixing between two horizontal fluid layers of different velocities and temperatures.

The main purpose of the experimental part of this programme is to investigate the thermal-hydraulic phenomena in horizontal mixing-layers with particular attention paid to the effects of Richardson number (experiments in a wide range of velocity and temperature differences between the two streams) and Prandtl number (use of two fluids water and liquid sodium). For mixing layers with different temperatures, buoyancy forces influence considerably the intensity of mixing. Stratification is therefore an important phenomenon for heat exchange between sodium streams of different temperature in the upper plenum of FBRs under decay-heat-removal conditions.

Further development and adaptation of suitable computer codes for mixing layer calculation represent the analytical part of the programme. To accurately predict the flow fields and temperature distribution in the pools a satisfactory validation of codes, based on a reliable experimental data base, must be performed.

### Short review of achieved results

In the first phase of the programme experiments with water were performed in a test-section made of acrylic glass (WAMIX I experiment). Visual observations of flow primarily lead to a better qualitative understanding of the phenomena in the developing mixing layer.

From the different experimental techniques tested, the laser sheet technique, using luminescent dye diluted in water was found to be a very efficient method to investigate generation, formation and interaction of vortices.

The mixing-layer thickness as a function of important parameters (distance from the splitter plate, Richardson number and velocity ratio) was determined and semi-empirical correlations for their calculation were given.

In order to investigate the formation of streamwise vortices (visualisation by a moving laser sheet) a conveyer system was used. It was found, that with increase of Richardson number (e.g. increase of the temperature difference between the layers) the formation of vortices is suppressed and the growth of mixing layer reduced.

The experimental results were used for comparison with codes, particularly with direct numerical simulations of the code FLOW-SB [6]. Extensive work of the WAMIX experiment was also related to the design of sodium experiment NAMIX, leading to decision to build a test-section with homogeneously-turbulent inlet flows.

A survey of the WAMIX tests together with main evaluated results was given in [7] and [8]. Complete results of the first investigation phase as well as their analysis are summarised in [9].

The main objective of the analytical work is to check the ability of general-purpose fluid dynamics codes (like FLOW3D [10] or ASTEC [11, 12]) to reproduce (with reasonable accuracy) the overall development of stratified mixing layers at various Prandtl numbers and to provide a code for a direct numerica1 simulation (modification of code FLOW-SB).

Up to now, most of the work has been carried out with the code ASTEC (calculations of velocity profiles in the flow conditioning part of the test-section and investigation of the effect of channel wall inclination on mixing-layer development). Particularly important was the participation of ASTEC as well as FLOW3D in different benchmark calculation tasks.

A survey of this work was presented at the international "Computational Fluid Dynamic Services (CFDS)" conference [13]. Some results were also included in a contribution to NURETH-6 [7].

Very good progress has already been achieved adapting the pseudo-spectral code FLOW-SB for the direct numerical simulation (DNS) of stratified mixing layers. Many modifications have been successfully implemented, particularly important to mention the possibility to visualise flow structures and temperature fields. A number of interesting calculation results on mixing-layer development with 2D and 3D models were compared with experimental as well as with the results of other numerical calculations [8, 14].

**Progress report 1995**

In 1995 the experimental work has been concentrated on preparation of second phase of investigation in water (WAMIX II) and providing a comparable testing arrangement in sodium (NAMIX experiment).

To carry out systematic measurements of local velocity and temperature as well as their fluctuation in WAMIX test-section, a new instrumentation (laser Doppler and hot wire anemometry) was chosen and ordered. Some modifications on the water loop and test-section were also made in order to allow the application of the new measuring techniques.

After determination of some details of NAMIX test-section design (particular tests with water i.e. WAMIX experiment, were made to clarify these details), the construction was started parallel to work needed to provide other components of experiment. Particular attention was put to define the process control system and its interaction to the data acquisition system.

Participation on Benchmark exercises was continued also in 1995. Velocity and temperature distribution for vertical buoyant jets were calculated with FLOW3D. This work started already in 1994, was performed for a benchmark meeting, organised by the IAHR Working Group on Advanced Nuclear Reactors Thermal Hydraulics [15]. After the meeting additional comparisons were made at PSI. It was found that the FLOW3D predictions are in closest agreement with the experimental results of all the codes using $k - \varepsilon$ model [16].

The analysis of stratified mixing layers at different Ri and Pr numbers was continued with the code FLOW-SB. Particular attention was paid to entrainment and mixing in the layer. The calculation for air and sodium has been finished, that for water is under way. The results were reported at the EUROMECH 339 conference [17].

As examples of these results Figs. 5 to 7 are added here. The non-dimensionalized times at which the isosurfaces are shown correspond to characteristic times, when the flow has reached a large degree of three-dimensionality and therefore ribs are visible. The important parameters which influence the results are initial conditions (deterministic and random distribution of velocity perturbations), temperature difference between the flows (Ri - effect) and the choice of fluid (Pr - effect).

The combination of deterministic and random initial conditions simulation corresponds well to the observations in experiments. The effect of stratification can be seen by comparing Fig 5 and 6. The baroclinic torque (i.e. torque produced by density gradients normal to the gravity direction) plays an important role in stratified cases because it influences the vorticity level. Cross-section cuts show that in stratified cases the vorticity is weakened .

Based on the comparison between the results for air and liquid sodium (of particular interest) at Ri = 0.05 (compare Figs. 6 and 7), it can be concluded that besides stratification also the high thermal conductivity of sodium suppresses the growth of the mixing layer.

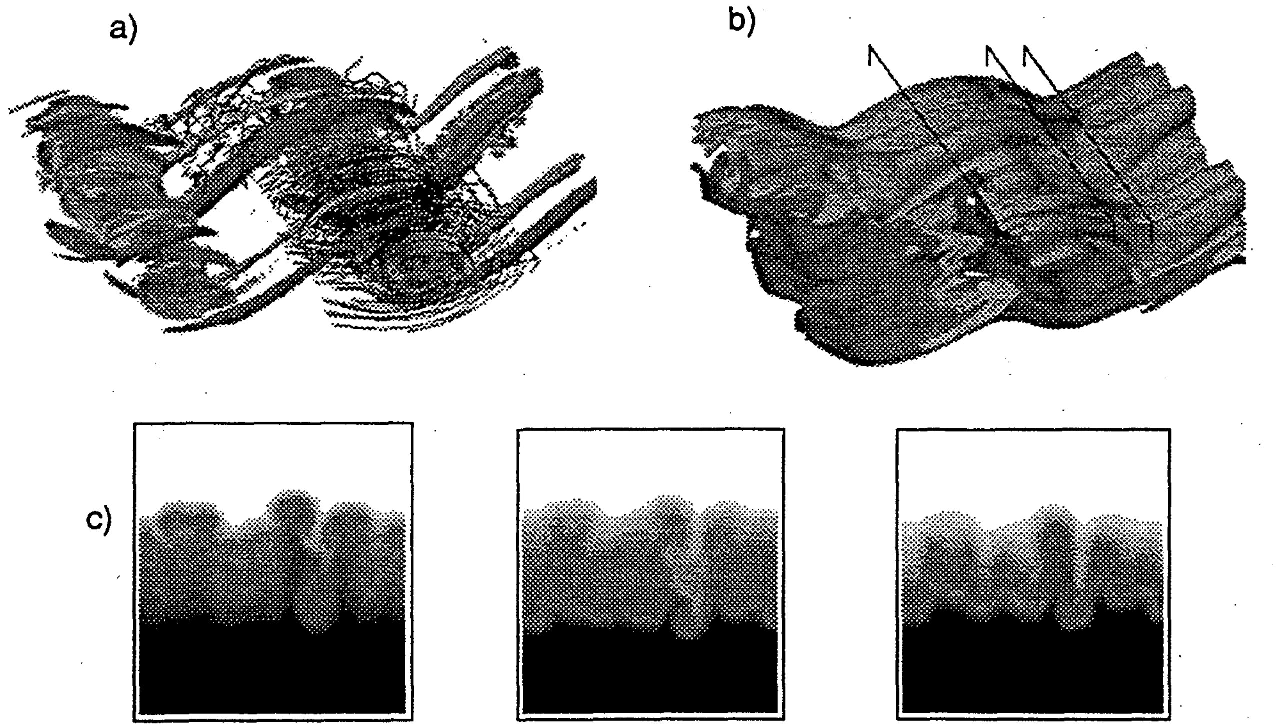


**Fig. 5:** Unstratified mixing layer calculation with combined deterministic and random initial conditions for air simulation at Richardson number Ri = 0.00.
Vorticity isosurfaces (see a), passive scalar isosurfaces (i.e. surfaces with equal marker substance concentration; see b), and cross-sectional cuts of the passive scalar (see c), at different streamwise locations (as marked in b) are given.

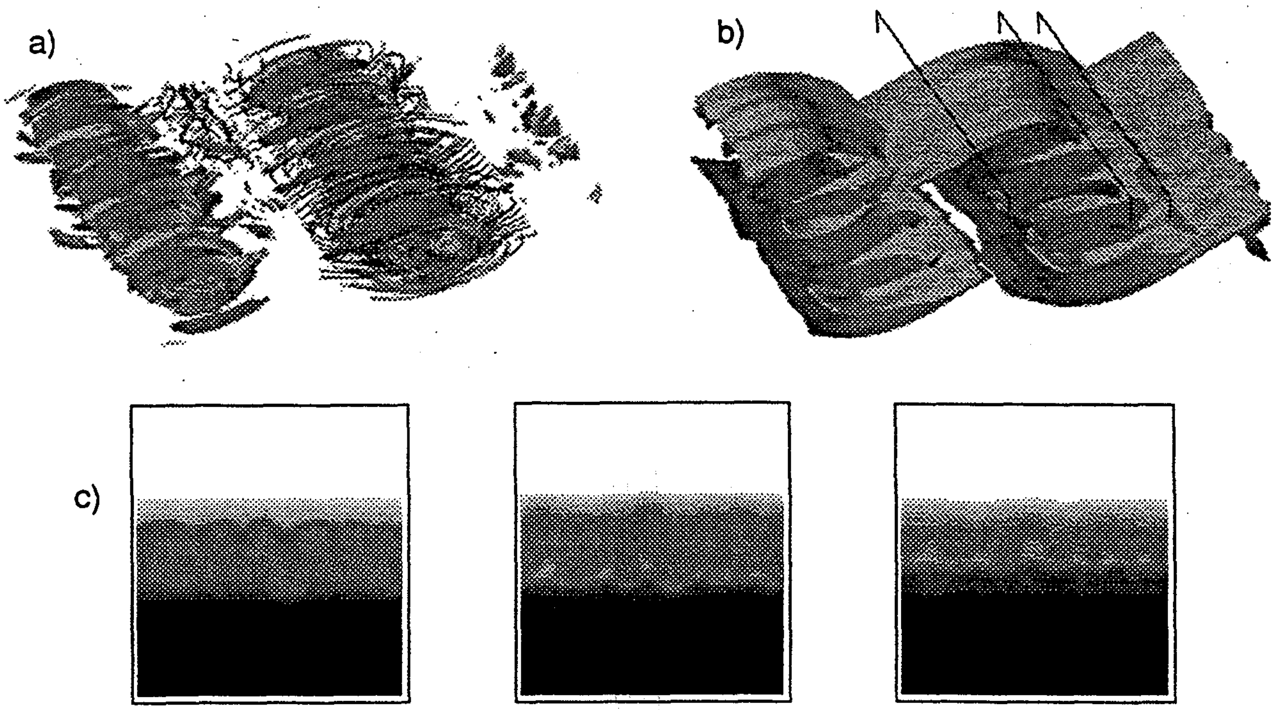


**Fig. 6:** Stably-stratified mixing layer calculation with combined deterministic and random initial conditions for air simulation at Richardson number Ri = 0.05.
Vorticity isosurfaces (see a), passive scalar isosurfaces (i.e. surfaces with equal marker substance concentration; see b), and cross-sectional cuts of the passive scalar (see c), at different streamwise locations (as marked in b) are given.

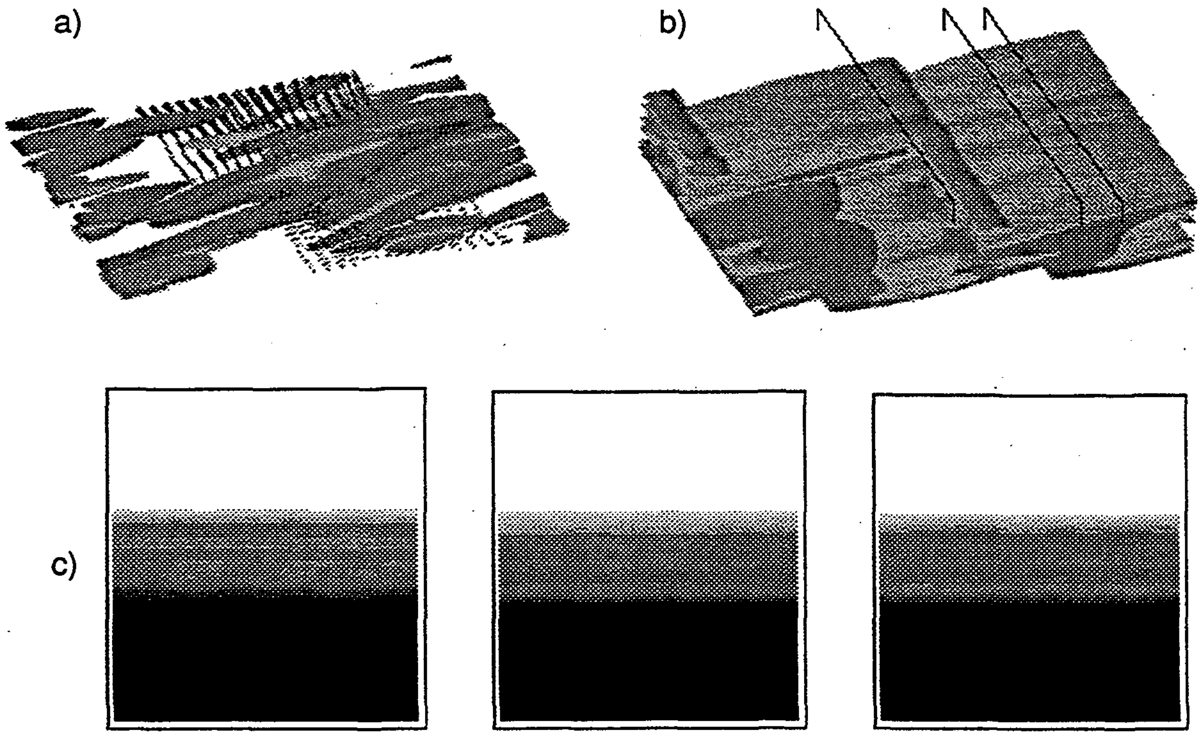


**Fig. 7:** Stably-stratified mixing layer calculation with combined deterministic and random initial conditions for liquid sodium simulation at Richardson number Ri = 0.05.
Vorticity isosurfaces (see a), passive scalar isosurfaces (i.e. surfaces with equal marker substance concentration; see b), and cross-sectional cuts of the passive scalar (see c), at different streamwise locations (as marked in b) are given.

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