SWEDISH DEFENCE RESEARCH AGENCY

FOI-R--0835--SE
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Progress Report

Kristina Wahlgren (Editor)

WEAPONS AND PROTECTION DIVISION
Annual Report
2002

WEAPONS AND PROTECTION DIVISION
SE-147 25 TUMBA, SWEDEN

The Swedish Defence Research Agency

FOI is an assignment-based authority under the Ministry of Defence. It has more than 1200 employees, of whom around 850 are university educated research scientists, and is one of the leading institutes in Europe for applied research. Its annual turnover is around one billion Swedish kronor (100 million Euro).

FOI consists of seven research units, directorate and staff, as well as a common administrative unit.

Administration	Aeronautics, FFA	C2 Systems	Defence Analysis
FLSC	Management	NBC Defence	Sensor Technology
	Systems Technology	Weapons and Protection	

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The cover picture: ”Shock testing a coastal corvette somewhere in the archipelago near Stockholm”
Photographer: Bertil Sandberg

Contents

FOI Weapons and Protection Division

Director until 2002-09-30:
Dr Bo Janzon, M.Sc. (Eng.Phys.), Ph.D. (Med. Sci.)

Director 2002-10-01:
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Deputy Director:
Mrs Carin Lamnevik, M.Sc. (Eng. Phys.)

Deputy Director:
Ralf T Holmlin
M.Sc. (Dir. of Res.)

FOI Weapons and Protection, Area of Activity:

- Energetic Materials
- Rapid mechanical and energetic processes
- Mechanical/dynamic properties of materials

especially applied to

- Weapons, munitions and warheads
- Their effects and protection against effects
- Weapons effects and vulnerability of platforms, vulnerability of man

including, also for the needs of the civilian society:

- Risk and process analysis
- Fire initiation and evolution, including smoke spread
- Sensitivity testing of explosives

FOI Weapons and Protection, Vision:

To be one of the World's leading research institutes within our area of activity!

Business Idea

We are a knowledge unit of the FOI.
In a dialogue with our customers, we perform

- Research
- Development
- Studies and analyses, and
- Sell knowledge

within our area of activity

Most important products

- Research results
- Competence transfer
- Analyses and advices
- Future and Threat prognoses
- Technical and Systems solutions and base data
- Development
- Education
- Testing

Research

- Physics, Chemistry, Mechanics, Materials and Strength of materials
- Close interaction between theory and experiments
- High competence in modelling and simulation
- Highly advanced, superfast measurement equipment
- Good contacts with Universities etc. (KTH, UU, CTH, LTH, LiTH, LuTH, and abroad)

Energetic Materials Department

Head of Department:
Dr. Henric Östmark, M.Sc. (Eng. Phys.), Ph.D. (Phys. Chem.)

The Energetic Materials Department conducts basic and applied research within the area of explosives and propellants and their ignition, as well as technical development and specialized small-scale production. We also act as expert advisors to the armed forces concerning explosives, propellants, ignition systems, mines and ammunition safety. The goal for the department is to be one of the world's leading research organizations in our field of expertise.

The department staff consists of 30 persons, 19 of whom hold academic degrees (10 Ph D, 9 M Sc). A positive sign is that 40% of the staff is women. We also have an extensive co-operation with the Royal Institute of Technology and Stockholm University: 5 graduate students. During the year we have had three visiting scientists from DSTA in Singapore and one from QinetiQ in UK, working in different areas.

Among our customers are the Swedish Defence Forces (FM), the Swedish Defence Material Administration (FMV), the Swedish Rescue Services Agency (SRV), DSTA/DSO in Singapore, GICHD in Geneva, Nexplo Bofors AB, Saab Bofors Dynamics and Bofors Defence.

The Energetic Materials Department has a number of national and international co-operation projects, e.g. The Royal Institute of Technology (KTH), Stockholm University (SU) US (Department of Defense Project Agreement NO. SW-N-96-1505 "Synthesis & Characterization of "Green" Energetic Materials and Formulations for Rocket Motors and Warheads") and US (Department of Defense, Defense Advanced Projects Agency, Washington D.C., Project agreement NO. TRDP-US-SWD-98-0001, High Energy Density Materials), UK (DERA, "The uses of ADN in formulations containing PolyGlyn or PolyNimmo"), Finland (DFRIT), Netherlands (TNO Prince Maurits Laboratory, IA 13 "FOX-7"), France, Norway and Germany. In April 2002 a new long-term co-operation project with DSTA in Singapore was started.

The Department has been responsible for a number of courses and lectures on explosives chemistry and explosives safety, e.g. an annual high explosives course (3 parts of 3 days each with about 35 participants from the defence industry, FOI, Police, and other Government authorities), and one annual lecture series at the Royal Military College (FHS) on "Chemistry; high explosives and propellants" (25 hrs). Apart from the activities mentioned above, a large number of presentations and laboratory tours for visitors both from Sweden and from the rest of the world have taken place.

Ongoing activities are described under work in progress.

Warhead and Propulsion Department

Head of Department:
Dr Torgny Carlsson,
M.Sc. (Eng. Phys.),
Ph.D. (Opt. Eng.)
Ass. Prof.

The Department of Warheads and Propulsion offers scientific competence in application areas of essential importance for the Swedish defence, such as warhead technology and detonics, propulsion, launch techniques for guns, underwater warheads, RF-warheads (microwave weapons) and Computational Continuum Mechanics (CCM).

All our research activities aim to be based on integration of theoretical, experimental and numerical competence in basic physic fields, such as combustion physics, detonics, electrophysics, fluid mechanics and continuum mechanics. We also thoroughly follow the international development within our fields.

The department has access to excellent facilities for test of warheads, underwater events, detonics, propulsion, etc. which are frequently used for testing of, among other things, all types of propulsion system components, new explosives and warheads.

The department has extensive collaboration with universities, research institutes and industry, both in Sweden and abroad.

The department has 33 full time employees, 22 of whom hold academic degrees (8 PhD, 14 MSc or similar). Besides these there are other researchers associated to the department, mainly PhD students at Swedish universities.

During 2002 the department has produced 70 publications, mainly FOI-reports and articles in international journals and conferences.

Ongoing activities are described under work in progress.

Protection and Materials Department

Head of Department:
Michael Jacob, M.Sc. (Chem. Eng.), Ph.D. (Chem. Eng.), Assoc. Prof. (Chem.)

The Department of Protection and Materials had 20 employees at the end of the year, and of these 16 are researchers and 4 technical and administrative staff. The personnel constitute a fine mix between experienced and recently recruited persons.

The research at the department is based on integrated experimental and theoretical work concerning materials and construction structures, with the main aim towards protection against rapid dynamic deformations and fire. The department consists of four research groups:

- **Fire** - theoretical and experimental research in the fields of fire and smoke propagation and protection.
- **Fortification** - fortification in terms of large scale testing and impact experiments, and risk analysis.
- **Materials** - synthesis and characterisation of materials, and dynamic material properties.
- **Simulation** - finite element calculations for prediction and understanding of rapid dynamic events.

The department has several ongoing national and international collaborations with universities, institutes of technology and research institutes. During 2002 a large number of projects have been carried out and presented as reports and publications, and at symposia and conferences around the world.

Ongoing activities are described under work in progress.

Armour and Survivability Department

Head of Department:
Ralf T Holmlin, M.Sc. (Dir. of Res.)

The Department ”Armour and Survivability” employs, at the turn of the year, 25 persons. During 2002 three newcomers, one with PhD in Solid Mechanics and two Masters of Engineering were employed, one person retired and one left for another department.

The “Armour” group of the department consists of 14 persons, working mainly on the projects “Ballistic protection”, “Lightweight armour” and “Active protection”. Ten of them are scientists and four are technicians who support the experimental part of the work. Four of the scientists are working actively on their PhD’s under supervision of Prof. Bengt Lundberg, who combines his position as Professor of Solid Mechanics at Uppsala University with a part-time position as adjoint Director of Research in the department.

The “Survivability” group consists of 8 persons, comprising the projects “Assessment of effect and vulnerability” and “Weapons effects on humans”.

Two persons are involved in the Swedish Armed Forces´ studies to define requirements to meet future tasks, especially the needs connected with Peace Support Operations, PSO. These studies are, at the same time, an essential basis for our research in the technical projects mentioned above. Directing the project ”Scalable effects”, previously called “Adaptable effects” and even earlier “Non-lethal weapons”, is a part of this work.

Ongoing activities are described under work in progress.

Work in progress

New Energetic Materials

Our work with new energetic materials includes activities in a variety of different areas, ranging from quantum mechanical and thermo-chemical calculations through, among others, synthesis, analysis, sensitivity testing, characterization, scale-up, formulation, to testing in generic applications. In the following, some selected examples of activities performed and results achieved during 2002 are presented.

A large study regarding calculations on density and heat of formation by quantum mechanical methods has been performed. This has worked quite well for both densities and heats of formation. Aided by the calculations we have been able to identify several synthetic target molecules. Preliminary synthetic studies have been encouraging and a patent has been filed. The chemical reactivity of FOX-7 has been investigated and the compound has shown reactivity towards nucleophiles at high temperatures. The acid-base properties of FOX-7 have also been investigated. Research on new synthetic routes to CL-20 has been undertaken. This has led to the preparation of several new highly energetic compounds, which are being patented.

Composition B has been used for more than half a century in a number of different applications. This high explosive formulation is well known, has shown good performance, is castable and is manufactured from relatively inexpensive raw materials. However since COMP-B is impact sensitive, reacts violently during cook-off testing and shrinks when cured, the interest in finding low-sensitive, castable (plastic bonded) replacements with at least the same performance is high. As a base material for such new formulations we have chosen to use FOX-7 (1,1-diamino-2,2-dinitroeten). During 2001, a PBX-composition with 70% FOX-7 and 30% energetic binders (e.g. polyGLYN and butyl-NENA) was developed. Cook-off and detonation tests indicate that this is a low sensitivity composition. However, the composition has bad mechanical properties and therefore a new binder based on polyGLYN and GAP was applied resulting in a more elastic formulation with better low-temperature properties. Figure 1 shows the result of a detonation test on NaCl (inert reference) COMP-B and our FOX-7/GAP composition. It is clearly seen that the FOX-7 / GAP composition is very insensitive and the performance of this new composition is nearly equivalent with COMP-B.

Figure 1: Detonability test on NaCl (inert reference), COMP-B and FOX-7/GAP

For the purpose of broadening the potential use of FOX-7 a burn velocity study on a FOX-7 based propellant has been conducted. Compared with today's LOVA-gun propellants it had a higher burn velocity but with a similar pressure exponent.

ADN (Ammoniumdinitramide) is a promising high explosive with a potential use in several different types of applications. Since ADN is not compatible with the majority of curing agents, one of our main challenges is to find a suitable curing agent. This year some progress, including burning of a smokeless ADN-based rocket propellant in a test engines, has been reported and this work will definitely continue.

Figure 2: Burning of a smokeless ADN rocket formulation

ADN mixed with aluminium was tested during 2001 and found to be a very promising and a very high-performing underwater explosive. During 2002, the casting method has been developed further, and the manufacturing equipment has been improved which facilitated a safer, more reliable and easier charge production.

The long-range research perspective on new energetic materials is focused on substances more or less dependent on new principles for storage of chemical energy. It is known today that this type of substance has a theoretical potential performance at least 100 - 500 % better than today's explosives. The possibility to synthesize N_4 has been studied by us for several years. So far tetrahedral N_4 has not been detected. During 2002 a new possible synthesis route was identified from calculation. Since the detection limit for N_4 in the used equipment is rather high, a substantial amount of work in this area has been concentrated to the introduction of alternative detection methods including Mass Spectrometry, Surface Enhanced Raman Spectroscopy and Laser-Induced Fluorescence. During last year the ion N_5^- (pentazolate) was successfully included as a target substance in our work toward high energy density materials. During a preliminary test this ion was detected with a mass spectrometer by collision induced decomposition of an aryl- pentazole, see figure 3.

The analysis of explosive substances has increased in importance during the last years due to an increased need in detecting and analyzing explosives both in industrial processes as well as in hidden objects such as mines or Improvised Explosive Devices (IED). We have developed an HPLC method which can be used for the analysis of nearly all common explosives in one analysis, see figure 4.

Mine detection and neutralization

Mine Clearance and De-mining are important issues on many levels for Sweden. For several years, research and development in the area of ammunition and mine clearance has been performed by FOI.

Since explosives are a common factor for all mines and unexploded ordnances (UXO), explosive detection can be used as confirmation of a mine or unexploded ordnance. It should therefore be natural to have chemical sensors for detection of explosives in the toolbox when performing mine clearance and de-mining operations. Our research is focused on development of vapour phase sampling devices, air sampling methods, and analytical methods for soil sample analysis.

The only sensor for detecting explosives in common use today is the mine detecting dog. Results from our research support the Swedish Armed Forces training and development program for explosive detecting dogs (mine, bomb and weapon dogs).

Most of the buried landmines contain trinitrotoluene (TNT), which can migrate from the mine to the surrounding soil and air. The amount of explosive molecules that enter the air phase is extremely low, since most molecules will remain in the soil. Due to this, there is a great demand for highly sensitive and selective detection methods. A method for extraction and analysis of TNT and related compounds in soil samples has been developed by FOI.

Through the Swedish Rescue Service Agency, we are able to visit mine-affected countries and countries with test fields for mine clearance. These places represent different types of environmental and climatic conditions, and soil and air samples have been taken and analysed for the migration study.

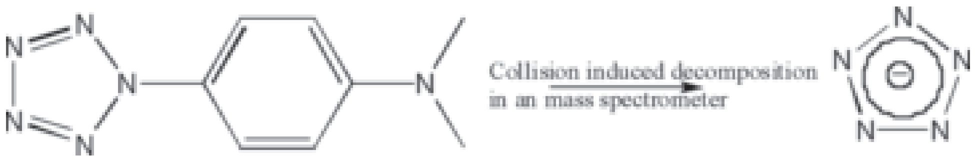


Figure 3: *Mass spectroscopic detection of pentazolate(N_5^-)*

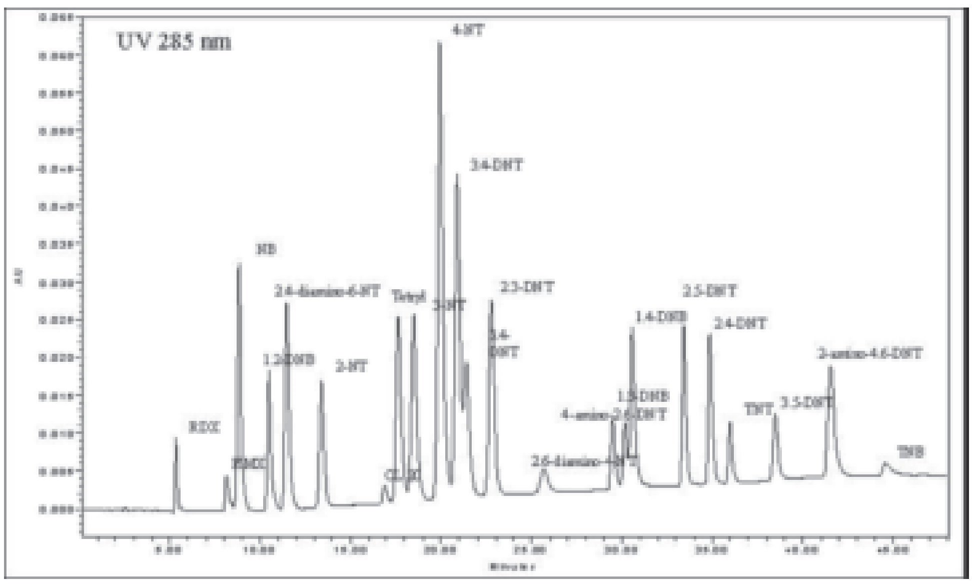


Figure 4: *HPLC Analysis of Explosives*

In a project sponsored by the Geneva International Centre for Humanitarian Demining (GICHD), the Mechem air sampling system used for mine detection with dogs was evaluated. Using this technique, air samples are collected above the surface of roads and subsequently analyzed by specially trained explosive sniffing dogs. In addition to the evaluation of the Mechem system, the sampling procedure was improved by development of new filter/adsorbent and sampling equipment. Determination of methods for storage and procedure for the introduction of filter content to the dogs has also been performed. To verify the content of explosives on the sampled filters, chemical methods for analysis of explosives were developed.

In all soils bacteria live on organic material. These bacteria are very important for maintaining the ecological balance of the environment. This idea of mine field detection is based on the ability of bacteria to adapt themselves very quickly to changed environmental conditions. If a new substance is introduced in a certain environment, and if the bacteria can use this substance as nourishment, the bacteria will quickly change their metabolism in such a way that this new substance can be absorbed, broken down and included into the metabolism of the bacterium. Substances related to explosives such as TNT and DNT contain a lot of nitrogen and carbon and are therefore an attractive source of nutrition. When the bacteria detects those substances in the ground they change their metabolism in such a way that those substances can be broken down. The process behind this is a synthetization of enzymes capable of breaking down those substances diffusing out into the soil. The ultimate objective is to use the natural metabolism of the bacterium, but substituting a protein with the capability of fluorescence instead of the enzyme that breaks down TNT or DNT. This fluorescence can then be detected using UV-illumination and an optical detector. This work is done in collaboration with the Department of Biochemistry and Biophysics at Stockholm University and FOI Division, NBC-Protection.

During 2002 some new types of Thermite charges for neutralization of mines and unexploded ordnance of different sizes have been developed. Tests with the charges are planned for the beginning of 2003.

Demilitarisation and risk analysis

Explosive-contaminated waste is generated during all stages in the life cycle of ammunition, from production to demilitarisation. Today, this waste is disposed of by open burning, resulting in uncontrolled emissions to the environment. Our work in the demilitarisation area aims at increasing recycling and reuse of both explosives and metals, and on finding safe and environmentally friendly methods for disposal of non-reusable explosive-containing waste. During 2002, several such methods have been identified and examined.

Accidental explosions pose a serious threat to all parts of society. In the risk analysis team, the expertise of the energetic materials department is utilised along with risk assessment methodology to identify, assess and reduce explosion hazards. During 2002, several companies as well as government agencies have consulted the risk analysis team.

Propellant surveillance and ammunition safety

During 2002, members of the Energetic Materials Department have taken part in advisory boards concerning explosives, ignition trains and safety. We have also participated in NATO workgroups such as AC310 SG 1 and in NIMIC.

A vital part of the ammunition safety work is propellant surveillance with the purpose of preventing accidental ignition of ammunition, and stopping unnecessary demilitarisation of ammunition based on nitrocellulose. During 2002, 1918 samples of the stabiliser content in ammunition have been analysed. The energy evolved from samples held at 65 °C during 13 days has been measured for 448 samples.

A test series with the purpose of collecting reference values for the ammunition surveillance of the Torp 62 warhead explosive has been conducted.

Research on Warhead Technology

The research in this field is focused on development of more effective warheads and exploration of new weapon effects.
In order to characterise inert materials and to evaluate the performance and sensitivity of high explosives, accurate and non-intrusive experimental techniques are needed. Most detonation and shock wave experiments are more easily interpreted if the process is quasi-static. Such quasi-static conditions can be obtained by impacting the target by a flying plate, generating a sustained shock wave. A plane wave gun, used for accelerating flying plates, have been installed and instrumented at our site and will constitute a valuable tool in future shock wave experiments.
A new method for measuring detonation front arrival times using fiber optic probes has been developed. The method utilises the fact that a strong light pulse is generated in the fiber when a detonation front is passing. The rise time of the signal is almost instantaneous and is only limited by the fiber width. The high time

resolution makes this method well suited for measuring detonation velocities.
Flash X-ray photography is a standard tool in high-speed research. Conventional X-ray systems use intensifying screens and photographic film. Recently, a new digital X-ray system was purchased to improve the image qualities and is now operating at a regular basis. The system has been used for, among other things, aerosol spreading studies and for examining jet formations in shaped charges.

To utilise new high performance explosives in shaped charges, there is a need to develop new forming techniques to use new liner materials such as molybdenum and tungsten. The Spark Plasma Sintering (SPS) technique is an interesting alternative to traditional techniques to manufacture high density and fine grained liner materials. Initial efforts have been devoted to manufacturing molybdenum using spark plasma sintering with promising results and these will continue in 2003.
New computational tools permit accurate simulations of shaped charge jet formations. These tools make it possible to optimise the design of a warhead with respect to liner design, wave shaper, initiation points, etc. A series of experiments have been conducted on a shaped charge with a hemispherical liner to investigate how the jet velocity and penetration ability depends on the initiation point. Excellent agreement between the calculated and measured jet shape and tip velocity was obtained, as can been seen in figure 5.

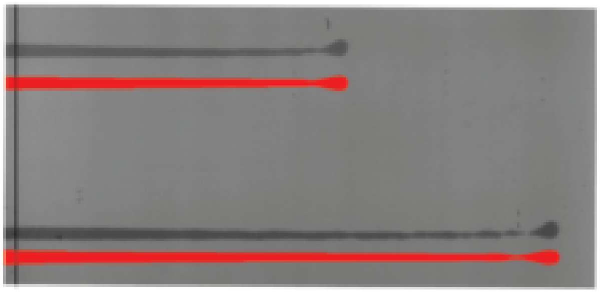


Figure 5: Digital flash X-ray image of a shaped charge jet. Calculated jet formation is overlaid in red.

Research on Propulsion

Today's propulsion systems are required to produce a larger and more rapid release of energy from smaller and more compact combustors, to cope with the demand for increased speed and range, and a wider operational envelope. Associated with these requirements are higher temperatures, increased heat transfer and thermal load, the increasing danger of combustion instabilities (leading to performance deterioration and excessive mechanical loads), and frequent off-design operation. For current and future propulsion systems the following five major criteria are important:

- increase the speed and range of vehicles and weapons,
- obtain the maximum combustion efficiency and stable operation,
- increase safety,
- understand and subsequently minimise combustion induced instabilities,
- comply with environmental constraints.

The research on propulsion is focused on three areas: Pulse Detonation Engines (PDEs), high-speed combustion and ramjets. Although these activities are somewhat disparate, they do interact heavily. For instance, the measurement techniques studied in high-speed combustion can be used in the study of PDEs and ramjets. The ability to obtain detailed results from high-speed combustion is also very important as a mean to calibrate the numerical methods being developed in the computational physics branch of the project. And obviously, these numerical methods are of great value when aspects of all types of propulsion are studied. The ultimate goal of the PDE part of the project is to design and build a successful air breathing PDE, an effort that is based on both theoretical and practical work.

This engine has several very attractive features, e.g., high specific impulse, a wide speed range, and a simple design. However, in order to realise these advantages a few obstacles - of which the most fundamental one is the initiation of the detonation (more often than not requiring thousands of Joules in order to be successful) - have to be resolved. Here this difficulty is attacked both with theoretical and experimental work. The standard mathematical model governing these phenomena is impossible to solve analytically, and the numerical treatment of it results in problems which cannot be solved with the computers (or methods) of today. Therefore, the theoretical work has been focused on finding models of adequate complexity for the available computer resources. While being simplified it is hoped that these models will still being able to provide answer to some of the questions at hand. That is, the numerical results of these simplified models indicate a possible way to resolve the problem of the initiation of the detonation, but due to the simplifications introduced in the model it is extremely important to study the problems experimentally. To that end efforts to construct a PDE based on the theoretical findings were started. Since this new engine consists of several key components that had to be designed from scratch, this is an elaborate endeavour, which were not fully completed during the year. However, it is anticipated that the engine will be tested in the first half of 2003.

In the ramjet field the objective is to exemplify performance and the possibility of and conditions for regulation of mass-flow.

For high-speed combustion, the goal is to utilise non-intrusive diagnostics techniques enabling us to perform experiments and computations on complex propulsion systems. An experimental facility for studies of high-speed combustion using Schlieren, interferometry and Laser induced Fluorescence (LIF) techniques has been installed and integrated with the instrumentation. The facility has also been adapted to manage combustion of hydrogen from a safety point of view. Experiments have been performed where a jet, originating from the combustion of a hydrogen/air mix in a cavity with a small "exhaust-hole", was studied. In cooperation with Luleå Technical University holographic interferometry has been used to study propane-air turbulent jet-diffusion flames. Using ray tracing the CFD-model was used to simulate the light propagation through the flame. On this basis, schlieren as well as the interferometrical experiments could be simulated, showing good agreement when compared to experiments, see figures 6 and 7.

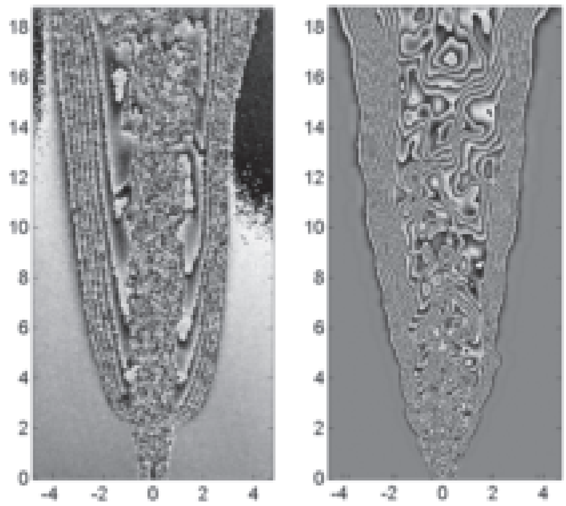


Figure 6: Comparison between phase maps of interferometrically achieved images. Experimental (a) and simulated (b) refraction index contours for a C_3H_8/air diffusion flame.

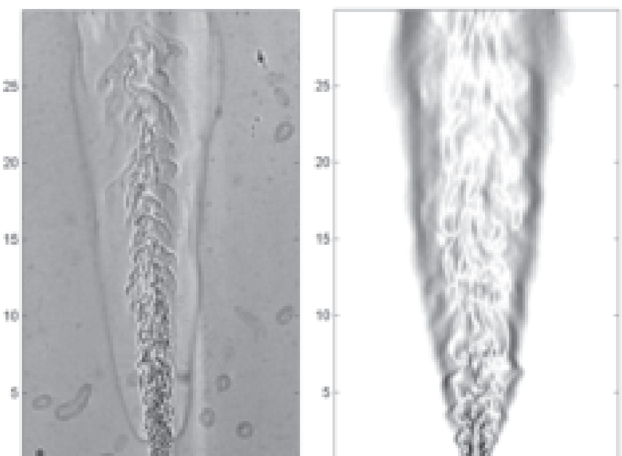


Figure 7: Schlieren images, experiment (a) and simulated (b) for a C_3H_8/air diffusion flame.

The RAM-jet is an interesting concept for future propulsion systems. A proposal for mass flow control of RAM-jets has been proposed. Different softwares for this purpose have also been evaluated.

In addition to the above-mentioned projects, aging-control and testing of rocket engines for the Swedish defence, the Swedish Space Corporation and other customers have been performed.

Research on Computational Physics

The use of scientific computing in the field of military research has proven extremely useful, and will play an ever increasing role in simulation based procurement, when designing or modifying equipment, or when investigating new application areas. In addition, scientific computing is used as a fundamental tool to examine and analyse physical and chemical phenomena relevant to key science and technology areas. Due to the increasing complexity of modern military systems many aspects are coupled which require simultaneous analysis from different disciplines and many such studies can only be undertaken using scientific computing. The field of scientific computing is based on mathematical modelling of physical and chemical processes, numerical methods, computer technology and programming. Models usually consist of partial differential equations (e.g. the Navier-Stokes equations describing fluid flow or the Maxwell equations describing electrodynamics) which have to be solved numerically due to their complexity. The intricacy of the underlying model and the desire to include more complex phenomena promotes the need for development of advanced computational models, numerical methods and software, as well as access to very fast computers with large memory and storage. During 2002 the computational physics group has been active in a number of different projects in a number of application areas, a few of which will be summarised below.

Almost all practical flows are turbulent and hence the simulation of turbulent flow and its diversity of flow characteristics remains one of the most challenging areas in the field of classical physics. Most Computational Fluid Dynamic (CFD) codes used for high Reynolds number complex flows are based on the Reynolds Average Navier-Stokes (RANS) equations together with a turbulence model representing the effects of turbulence on the mean flow. Although RANS correctly predicts the mean flow in many cases, RANS often fails when facing more complex flows. Moreover, RANS is not appropriate when unsteady flow features are of primary concern or when these dominate the flow. On the other hand, Direct Numerical Simulation (DNS), in which all scales are resolved, is currently too expensive. Large Eddy Simulations (LES) present an alternative way of improving qualitative and quantitative aspects of complex turbulent flow predictions for both research and engineering purposes. LES resolves the three-dimensional time-dependent details of the large and medium (i.e. resolved) scales, whereas the effects of the small unresolved eddies are modelled with a subgrid turbulence model. Much of our work is devoted to developing LES for practical flow problems, such as the flow past a submarine. As an example of a simplified problem figure 8 shows the flow past a prolate spheroid at 20 degrees angle of attack and comparison with experimental data.

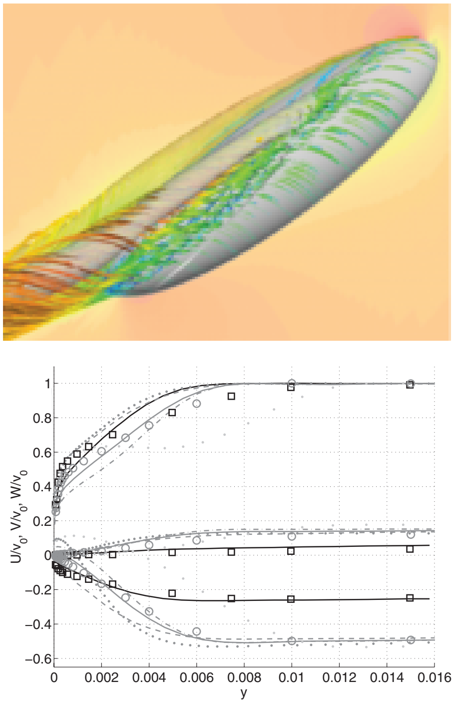


Figure 8: Flow around a prolate spheroid and comparison with experimental data of Simpson et al. 1998 in the boundary layer.

The current trend in chemical propulsion is towards producing larger and more rapid release of energy from smaller and more compact combustors to cope with the demand for increased speed and range of vehicles and weapons with reduced weight, whilst increasing the operational envelope. Associated with these requirements are higher temperatures, increased thermal load and the increasing danger of combustion instabilities leading to performance deterioration and excessive mechanical loads, and frequent off-design operation. In addition, propulsion systems need also to comply with environmental constraints, and producing virtually no signatures. Time-dependent, reactive flow experiments based on numerical simulations with precise control of initial and boundary conditions are ideally suited to address these issues, and supplement the laboratory studies when available. During 2002 a number of reacting flow studies have successfully been conducted, ranging from jet flames to gas turbine combustors, figure 9. In this area one PhD student funded by SBD and enrolled at NADA at KTH is working on high-speed combustion. The work in this area is carried out in conjunction with that in Propulsion.

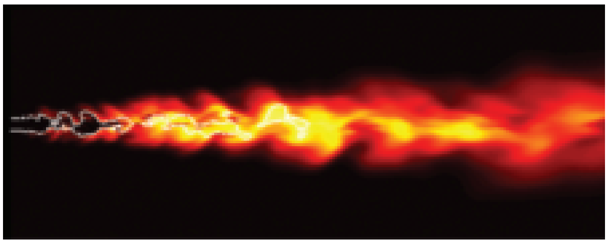


Figure 9: Turbulent jet flame.

In order to handle problems involving flows in a temporally developing geometry we are developing a family of computational methods that can handle a wide spectrum of problems ranging from control surface effects on ships and aircrafts to weapons effects of shaped charges. Our effort in this area includes a PhD project together with the Dept. of Fluid Mechanics at LTH in Lund, and a STEM financed national project on generic studies on energy-related fluid mechanic with fluid-structure interaction. So far we have developed an Arbitrary Lagrangian Eulerian (ALE) method, and in collaboration with LTH a Volume of Solid (VoS) method has been developed. This research area is very wide and in order to form a competitive and sufficiently application oriented research group around these issues a collaboration has been initiated with the division of Aeronautics, who are also interested in developing methods of this kind.

In collaboration with the departments of Hydroacoustics and Naval Sensor Systems at the Division of Systems Technology the multidisciplinary project Underwater Signatures has been formed. This project aims at investigating underwater signatures from surface ships, submarines and torpedoes, and contains both applied and fundamental research issues. The computational physics group has during 2002 been involved in investigating the mechanisms behind near field acoustics and wakes behind submarines. The methods used are generally based on LES, and the developments of signature-prediction models are therefore closely linked to the development of advanced flow simulation models.

With the shift of the perceived NBC-threat from large-scale actions to terrorist actions in urban areas, the demands for detailed simulations of dispersion in a complex geometry have become of much higher priority. Contaminant Transport (CT) treats airborne pollutants released in industrial accidents, smoke, as well as chemical/biological/radiological agents released in war situations or terrorist attacks. The main applications envisioned include: (i) detailed modelling of critical situations for site defence, sensor placement, and threat analysis, (ii) model development to treat the interior and exterior of building complexes simultaneously, and (iii) treating tunnel and subway systems coupled to the external airflow over large areas. FOI is currently in the process of developing the necessary basic models for time-dependent three-dimensional simulation flow, turbulence and dispersion within confined quarters or in the neighbourhood of urban areas using LES. This development is carried out as collaboration between groups at the divisions of NBC-protection (coordinator) and Weapons & Protection.

Research on Underwater Explosives and Effects of Underwater Warheads

The Warhead and Propulsion Department includes a group that carries out theoretical and experimental research regarding, among other things, clearance of mines, warheads, underwater detonics and high-speed vehicles. The research can be divided into fundamental research and applied research and is carried out within several projects. The main customers are the Armed Forces and the Defence Materiel Administration, FMV. Through the close coupling between developing computational tools and experiments it is possible to assess ship vulnerability regarding underwater detonations and signatures. New types of adaptable underwater warheads are being developed and have showed promising results. High-speed torpedoes are, at right conditions, covered by a large cavity wich might be controlled, in size and form, by the engines reaction products. It is desired to simulate these phenomena in order to predict such a vessels resistance and manoeuvrability. This could give insight to some of the aspects of the threat and explore the possibility to use such a device. A first simulation with a wing shaped model has produced quantitative results, which agrees well to available experimental good results, see figure 10.

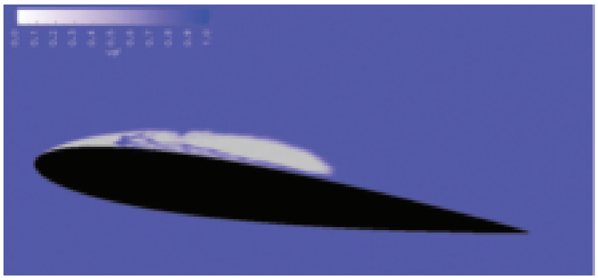


Figure 10: Cavitation on a wing section.

Work is done to develop new cheap pressure gauges that will be characterised in terms of linearity, accuracy, and repeatability. The main benefit with these devices is the ability to measure the pressure closer to or even inside the gas bubble. In the area of weapons effect, interest has turned to the new sandwich materials which has emerged in recent years in naval vessels. Simulations have been performed which, when compared to experimental results, showed that it is possible to reduce the experimental costs by using simulations as a first tool to determine what kind of combinations that work best, see figure 11.

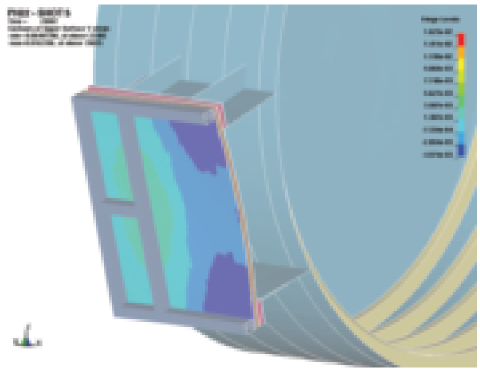


Figure 11: Simulation of a sandwich panel exposed to an underwater explosion.

Clearance of mines has always been an important area but lately, due to the emerging international role of the navy, it is necessary to find and destroy many different kinds of mines in a secure way. One way of doing this is to use a small shaped charge that is able to penetrate the shell material of the mine and supply enough kinetic energy in order to initiate the explosive charge. The shape of the projectile is best determined by simulation where it is possible to screen many different kinds of shapes. The key aspect though is to get necessary data of the explosive that make it possible to determine whether the mine has detonated.

Research on HPM Warheads

The High Power Microwave (HPM) weapons research incorporates theoretical and experimental studies of selected subtechnologies for warheads emitting microwave pulses intended to disturb or destroy electronic equipment. It also involves studies of HPM warhead concepts and an evaluation of the technological possibilities and limitations of such warheads.

A four-year investigation of high voltage generation using an experimental tabletop system called TTHPM was completed during 2002. The TTHPM system, shown in figure 12, consists of an intermediate storage inductor, an opening switch (electrically exploding wire fuse), and a closing switch (spark gap). This work has been summarised in a final report and a brief overview of the system. Experimental results and a simulation model were presented at the European Pulsed Power Symposium in Saint Louis, France, in October 2002.

Switches are critical components in the generation of high voltage pulses with short rise time. The electrically exploding opening switch constitutes a compact and controllable technology, but consumes a substantial amount of the available energy. Another drawback is that this type of switch is inherently non-repetitive. The parametric dependence of current level and switch opening time on parameters such as wire dimensions and number has been quantified.

The TTHPM work has emphasised that consideration of the electric insulation in high voltage generating systems is extremely important. Several modifications of the original system were made to avoid electric flashover. Use of insulating dielectrics and a meticulous design are deemed very important for compact HPM warhead constructions.

A pulse transformer based on transmission line technology, shown in figure 13, using a specially manufactured Semicon cable has been constructed and incorporated into the TTHPM system. This was done as a Master thesis project in collaboration with Uppsala University. The purpose of the semiconducting layer is to distribute the electric field, thus minimising the insulation thickness and weight. The voltage amplification factor of the constructed transformer is about four, see figure 14. This transformer technology is considered as very interesting for many future constructions of high voltage generating systems for HPM applications.

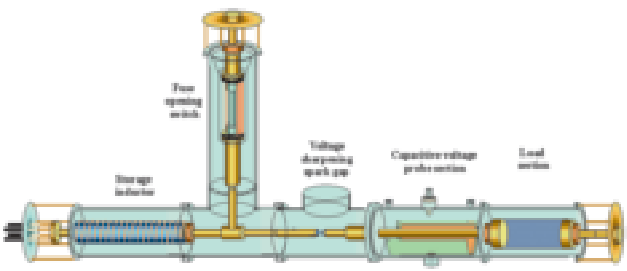


Figure 12: Components of the TTHPM experimental system for research on high voltage pulse generation

Figure 13: High voltage transmission line transformer based on cable technology.

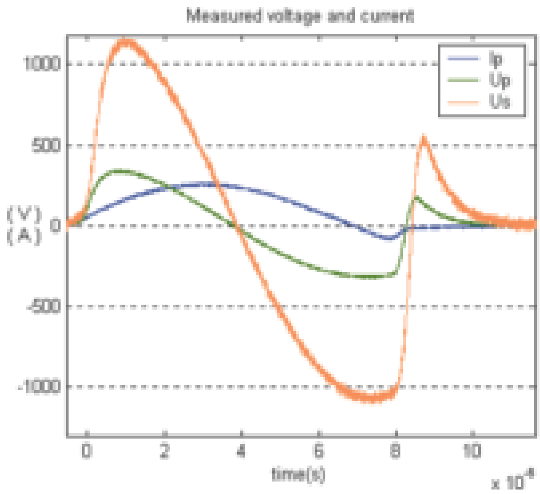


Figure 14: Typical current and voltage traces using model transmission line transformer. The voltage amplification factor is about 4.

Equivalent circuit models of the TTHPM system have been implemented in the circuit simulation programmes PSpice and ATP-EMTP. Such models are very useful tools for making parametric studies and investigating modifications to the system as well as diagnosing problems such as electric flashover inside the TTHPM system. The ATP-EMTP model was presented at two conferences during 2002.

FOI has sponsored two studies of critical pulsed power components for HPM applications at Uppsala University. Both were conducted as Master thesis projects.

An accurate mathematical description of the operation of a spark gap is essential for the prediction of the spark gap function as a closing switch in a high voltage generating system. The study consisted of recording the voltage time dependence during experiments with different spark gaps, and fitting of the data to empirical expressions used in ATP-EMTP simulations.

A study of fast capacitor charging was performed, investigating the possibility to overcharge capacitors to energy levels significantly above the nominal value. This is of interest for compact applications using the capacitor as an intermediate storage and pulse-shaping component.

The study of microwave radiation sources was continued during 2002. This includes refinement of the measurement technique and experiments with a laboratory source. Simulation of radiation from short spark gaps has been analysed. The time dependence of the current is identified as a critical parameter for the operation of a spark gap as a radiation source.

Project members have participated in an industry headed feasibility study for a planned RF/HPM demonstrator. The work performed at FOI Weapons and Protection includes overviews of explosives driven flux compression generators, components for electric energy storage and pulse shaping, and MILO and Vircator microwave sources.

Lectures on HPM technology have been given at the Swedish Defence College (FHS) and the Army combat school (MSS). The lectures include overviews of the research and technology area and present some possible concepts for HPM warheads on different platforms. An example of such a warhead based on TTHPM system components is shown in figure 15.

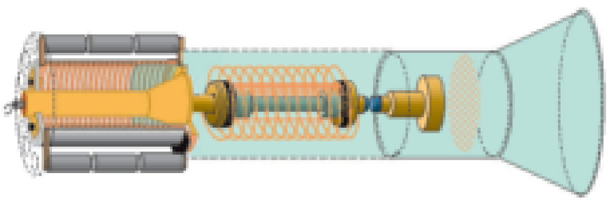


Figure 15: Possible HPM warhead design based on an explosive generator, storage inductor, electrically exploding wire fuse, spark gap closing switch and a vircator microwave source.

Research on Launch Techniques

The current activities are mainly focused on electrothermal-chemical (ETC) launch techniques. The objective of ETC is to utilise electric energy to improve the performance of conventional propellant guns in terms of increased muzzle energy. The higher muzzle energy can be used for carrying a greater payload or obtaining a higher muzzle velocity. By supplying electric energy to stimulate the combustion of the propellant the loading density may be increased well beyond what is feasible in conventional charges and the pressure profile can be tailored. The combustion of a solid propellant is stimulated by leading an electric current through the flame. Electric energy is then supplied to the flame via resistive heating. Part of this thermal energy will be transferred to the unburned propellant and added to the energy released by chemical reactions in the flame. The evaporation and thereby also burning of the propellant can in this way be increased.

To be able to better understand how the combustion is affected by supplying electric energy, experiments are performed in a closed vessel. The combustion is thereby performed at constant volume and it is possible to calculate the propellant burn rate from the pressure recordings at different amounts of electric energy supplied. The electric energy is supplied from a 300 kJ pulsed power supply (PPS) consisting of four modules with capacitors that can be charged to individual voltages each with separate serial inductances. Each module can be switched with different time delays.

When the electric energy has been discharged from the PPS an electric discharge occurs in the flame after a time delay that depends on the electric properties of the flame. By doping the propellants with KNO_3 the initial electric conductivity of the flame has been increased resulting in a reduced variation in time delay of the discharge. This has made pulse forming possible by sequential switching of the four PPS modules. The discharge can then be managed by varying the pulse form and proceeds in a more controllable manner. A more controlled discharge has a lower discharge power, which means that it can be more extended in time. In experiments with discharges more extended in time an increased propellant burn rate has been observed as can be seen in figure 16. This strongly indicates that it may indeed be possible to control the propellant combustion by conducting a current through the reaction zone.

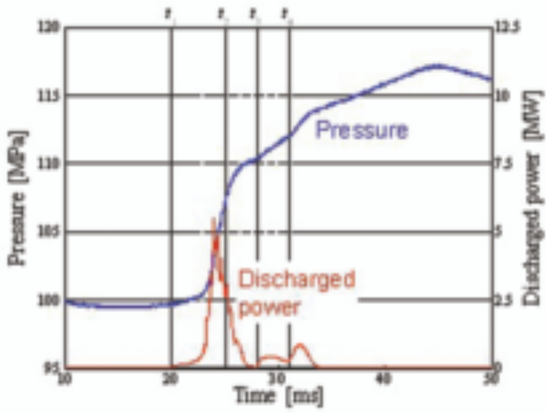


Figure 16: Pressure/time recordings and discharged power from closed vessel experiments with the four PPS modules charged to 4, 1.5, 1.5 and 1.5 kV.

Research on Brilliant Munitions

The research is focused on the integration of multi-sensor technology with adaptive warheads (see the chapter on Warhead Technology). The aim is to study concepts of such combinations that enable one missile to be able to defeat a spectrum of targets with optimal effect. There is also a goal to be able to hit the target at a specified area, for instance disabling the engine so the targets manoeuvring capabilities cease.

The work is limited to the attack phase of the missile, meaning that the target has been discovered and classified. The first step in this project is to identify the target and to identify a hit-point. In order to do these studies research on manoeuvring and precision guiding is also incorporated.

Three main areas of sensors are presently studied: Millimetre-wave radar, Infrared imaging and laser-radar.

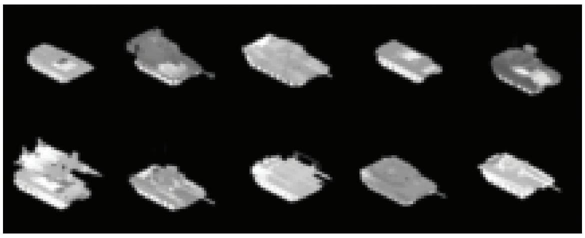


Figure 17: Computer models of different targets used in this project. These are high-resolution cad-models and are used to generate data for all three sensors. In this figure they are shown textured as infrared emitting targets.

The sensor research has been theoretic, complemented by some real measurements of different kind of vehicles, se figure 17. In order to identify and classify our own and enemy targets, information about the targets characteristic radar-signatures has to be known. This has been done by performing radar-signature computations with FOPOL on all targets, shown in figure 18. The seeker is modelled with a frequency of 94 GHz, it approaches the target at a height of 300 meters, and data is collected at 17 distances from the target from 8 kilometres to 500 meters. The targets have been observed from all aspects with a resolution of 5 degrees.

In both these areas measurements on real targets has been performed, see figure 19. From these measurements 3D-models have been created, see figure 20.

In the infrared area research is directed at using arrays so that identification of the target is possible. Some of the work in progress is shown in figure 21, using multi-spectral techniques to enhance the details on a target. Target approaches have been done in a simulated environment with both infrared and laser-radar seekers, see figure 22.

In the case of laser-radar and conventional radar there is a modulation of the reflected signal due to the vibration spectrum the target emits when the engine is running and when it moves. This vibration spectrum is unique and can also be used for identification of the targets.

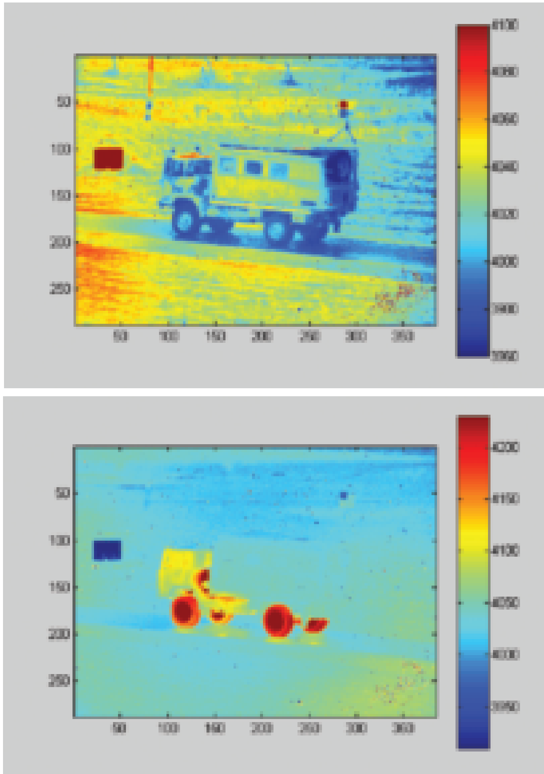


Figure 18: An IR-image of a truck taken with a camera with a spectral bandwidth of 1.5 to 5.2 mm. The upper picture is with a band-pass filter of 1.55 to 1.75 µm, and the lower picture with a band-pass filter 4.55 – 5.2 µm.

Figure 19: The upper picture is a scanned image of an MBT using a laser-radar. In the lower picture the background information (red) has been cancelled out.

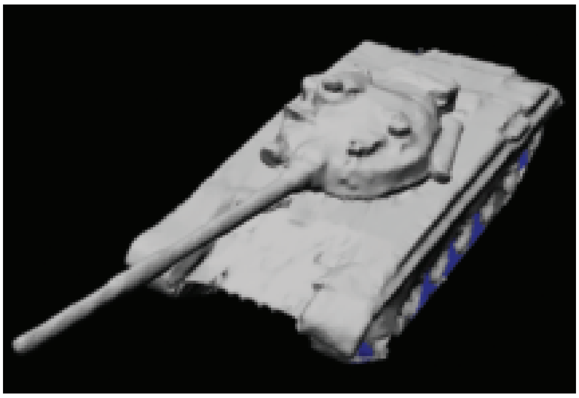


Figure 20: A computed 3D-model of the MBT, from the image data in figure 19. Some inconsistencies remain due to low resolution scanning (blue).

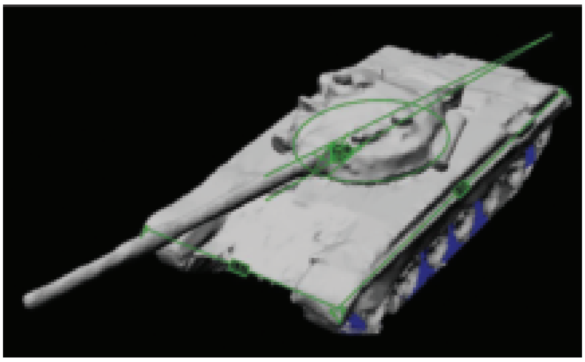


Figure 21: The computer has performed measurements on specific parts of the target. Target length 6.69 m, width 3.57 m, the turrets radius is measured to be 1.22 m and the elevation of the gun is 3.68 degrees. An aiming- and hit-point can now be determined.

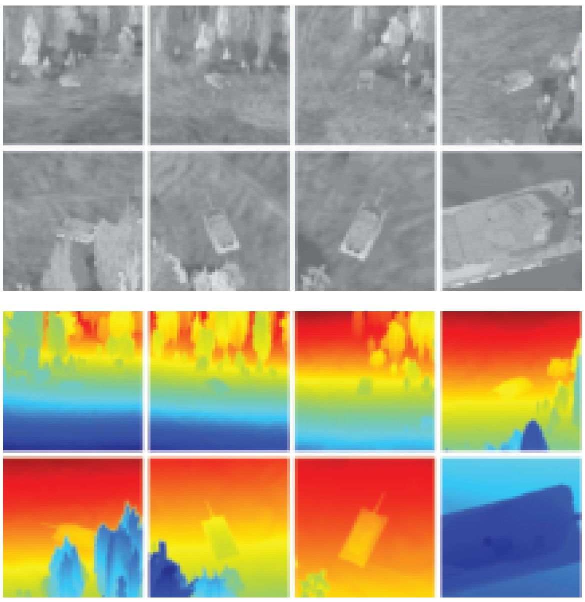


Figure 22: The upper two rows shows a simulated, spirally approach of an infrared seeker towards a target. The lower two rows shows the same way of approach but with laser-radar seeker, here the distances in the images are colour-coded.

Fire

Fire research activities have been focused on small-scale studies of ignition behaviour of materials and model-scale room fire experiments. The latter included fire growth studies in a single compartment with combustible linings, see figure 23. Of particular interest was to map how the fire development depended on the type and size of ignition source used. Extensive measurements were performed to document the different cases of fire development and the experimental data will, among other things, constitute a basis for future comparisons to simulation models.
Further activities have mainly included a number of Hot Smoke Tests in order to evaluate the current level of protection against smoke spread in buildings and meeting places. These tests were performed according to a previously developed non-destructive test method. One of the evaluated premises was the assembly hall in the house of Parliament.

Figure 23: Flashover in model-scale fire test.

Fortification

During the year the work with ammunition storage for the Singapore Defence continued at the shooting-range of Älvdalen. One large test and a lot of pre-tests were performed concerning mixed storage of HE and propellant. The large test indicated without any doubt that for storage of propellant together with HE, the propellant must be classified as mass detonated explosives.
Full-scale tests in a rock tunnel have also been performed, at the shooting-range of Älvdalen, in order to study the propagation of blast wave in tunnel systems. This project started 1995 and during this year phase 10 was performed. The effects of different sizes of holes in a barrier were studied. The objective of this study was to verify that protection for certain equipment can be achieved behind a barrier that is not completely closed. A charge of 125 or 625kg of AnFo was detonated at different distances from the barrier. The pressures were monitored in the whole tunnel system, but the research was focused on the effects behind the barrier.

Late in the year an inquiry from Singapore started an intense workperiod with the manufacturing of a blast chamber of steel plates. A number of tests were performed in the blast chamber in the beginning of December, with the purpose of studying the combined effects from blast wave and fragments on the walls. The results were delivered before the end of the year.

Under contract with the Headquarters of the Swedish Armed Forces the Protection and Materials Department has continued the work initiated 2000, in cooperation with Norway (FFI and FLO), with the mutual purpose to further develop the risk analysis model AMRISK. Individual and collective risk for the general public (third person) in the vicinity of ammunition storage in the case of a detonation is calculated with AMRISK.

Mitigation of effects from accidental detonations in ammunitions storages has been performed with water as main energy absorbing agent. The water mitigation investigation focussed on registration of the distribution process of the water just after detonation of a high-explosive, with the aim to find the optimal distribution of containers in a storage facility, in order to reduce the hazardous area around a storage. The work was performed under contract with the Headquarters of the Swedish Armed Forces.

The Protection and Materials Department tested materials and combinations of materials, which are part of the covering of a fortification in ground, exposing them to shaped charges, see figure 24. As a result from the tests a preliminary proposal of a model for penetration of shaped charges in materials, which are part of the covering of fortifications in ground, has been given.

Figure 24: Photo from before a test with shaped charge against concrete, and after the test where each segment is inspected concerning damage and penetration.

During 2002, a model has been proposed for protection of military units with stationary or mobile behaviour. The model contains information of infrastructure constructions such as bridges, tunnels and other constructions in rock, which can give protection for military units from weapon attacks and detection, in a program/system that handles GIS (Geographic Information System) and databases.

Work has been conducted, under contract from the Headquarters of the Swedish Armed Forces, regarding movable fortifications. The aim with the project is to provide protection from small arms fire and fragments, with a low cost and low weight structure that can be easily assembled and dismantled without the use of special tools and equipment.

Materials

During 2002 the production of new armour materials with the Spark Plasma Sintering (SPS) technique has continued.

The work on Functionally Graded Materials (FGM) in the titanium-titanium diboride (Ti-TiB_2) system is in progress. The differences in thermal expansion between titanium and titanium diboride caused crack formation during sintering, despite a zone with graded composition of the constituents between the pure phases, however two crack-free samples with very thin layers have successfully been produced.

Further investigation on Ti-TiB_2-composites, has showed that a composite has better mechanical properties than pure TiB_2.

The mechanical behaviour of a tungsten heavy metal alloy (WHA) with potential use as a kinetic energy penetrator has been investigated during 2002. The WHA is a composite consisting of tungsten grains (92.5 w%) embedded in a matrix of Ni, Fe and Co. Dynamic mechanical properties related to tensile loading are measured at strain rates up to 400 $°s^{-1}$ and at temperatures from 20 °C to about 500 °C. From the experimental data parameters for the constitutive equations developed by Johnson and Cook (J&C) as well as Zerilli and Armstrong (Z&A) are determined. These equations, which relate flow stress to strain, strain rate and temperature, are frequently used in hydrocodes for calculation of impact phenomena such as penetration. The J&C model is semi-empirical while the Z&A model is based on dislocation dynamics and takes the crystal structure into account.

From the extracted models isothermal and adiabatic flow stress curves are calculated and compared to experiments and available literature data. At high strain rates or high temperatures the J&C model deviates about 5-10 % from experimental results, while the

Z&A model shows a better agreement with the collected data. It should be emphasised that the Z&A model used in this work is developed for materials with body centred crystals whereas the WHA is a composite with both face centred- and body centred crystals.

Sweden joined an international project "Ballistic performance of different low cost Titanium alloys" 2002. Titanium has long been recognised as an effective material for ballistic protection. The titanium alloy traditionally considered for such applications is aerospace grade Ti6Al4V, an alloy with high quality requirements demanded for the aerospace applications. Unfortunately, the very high cost of this material has limited the use of titanium for armour applications. The objective of this project is to compare the ballistic performance of different low-cost titanium alloys with the reference aerospace Ti6Al4V grade and hence determine the influence of material quality of protection capability.

Simulation

Modelling of materials subjected to weapons effects has been a major area of interest for many years and several material models to describe the material behaviour at high pressures and high strain rates have been developed. However, it is not until recent years, with the development of both advanced concrete models and new numerical solution methods, that it has become possible to model the behaviour of concrete targets during projectile penetration with acceptable results. The possibility to use numerical simulations to predict the effects of conventional weapons on protective structures is evaluated in the project *Structural protection for stationary/mobile tactical behaviour*.

Numerical simulations of steel projectiles penetrating concrete targets have been performed with the use of Autodyn version 4.2 with the advanced RHT concrete model implemented. With the latest developments in material and numerical modelling it is possible to use such advanced material models together with alternative element formulations. Thus, both Lagrange and Smooth Particle Hydrodynamics (SPH) formulations of the problem were considered and simulations were performed in 2D and 3D. A ballistic benchmark test series from 1999 with steel projectiles impacting concrete targets was used as a reference case. The computational time for a 3D simulation increases compared to a corresponding 2D calculation. The development of parallel processors and such systems has increased the possibility to obtain a computer capacity for advanced simulations at a reasonable cost. Thus, a minor test using a parallel processor system consisting of 2 and 4 processors has been tested and compared to single processor calculations.

The simulations with the RHT model show promising results. This model is able to handle most of the cases that are of importance for projectile penetration into brittle materials like concrete. However, extensive experimental work is required to determine the material constants. The parameters describing damage evolution, residual strength and tensile behaviour are difficult to assess and it is necessary to develop new testing methods to determine the two former parameters.

The use of the 3D version of the software allows oblique impact (as well as simulations of yaw and pitch angles) and must be considered a major enhancement of the possibilities to predict the interaction between projectile and target. Unfortunately, there are still software problems using the 3D SPH formulation combined with the RHT material model that need to be solved. One important finding from the Lagrange calculations in this work is that even a very small yaw angle of 1° results in a relatively large effect on the penetration path and exit velocity of the projectile, see figure 25. Thus, efforts must be taken to carefully measure the impact geometry of the projectile in future ballistic experiments. Furthermore, parallel computations using two or four processors can be used to substantially decrease the calculation time.

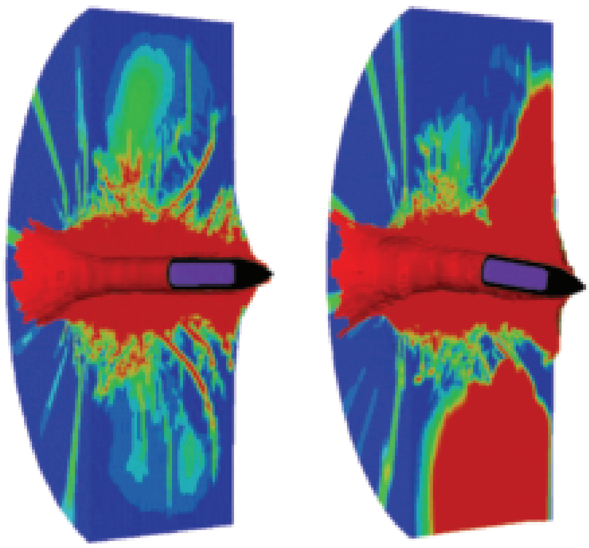


Figure 25: A comparison of the penetration path at normal impact (left) and with 1° yaw (right) at an impact velocity of 459 m/s. The exit velocities are 211 m/s and 186 m/s, respectively.

Research on Ballistic Protection

Research is executed on armour protection for vehicles against heavier Kinetic Energy (KE) threats, mainly consuming and disturbing armour components to defeat long rod projectiles at velocities from 1.5 up to above 2 km/s. Especially ceramic, reactive and active armours have been considered.

The work on ceramic armour has concentrated on studies of the interface defeat phenomenon. Experimental studies to find out the velocity at which the transition between interface defeat and penetration takes place have been carried out on commercially available silicon-carbide materials. The pressure exerted on the ceramic surface by cylindrical and conical penetrators has been modelled as well as the stress-strain state and the crack behaviour of the ceramic material.

The basic mechanisms of reactive and active armour have been investigated by studying long rod projectiles hitting moving oblique plates. A reverse impact technique has been developed (an oblique plate is fired onto a yawed penetrator) which enables well-controlled experiments to be performed and a systematic study of the influence of the angle and velocity of the plate has been carried out. A method for evaluating the flash X-ray pictures from the experiments to enable quantifying the behaviour of the residual penetrator is under development. Parameters for constitutive models for the penetrator tungsten material used in the investigations have been assessed. Efforts to numerically model the residual projectile behaviour, especially fracture, have continued.

A small experimental study on the performance of telescopic penetrators in stationary and moving oblique plates has been carried out.

A review of the terminal ballistic problems associated with defeating ballistic missile warheads were made, see figure 26.

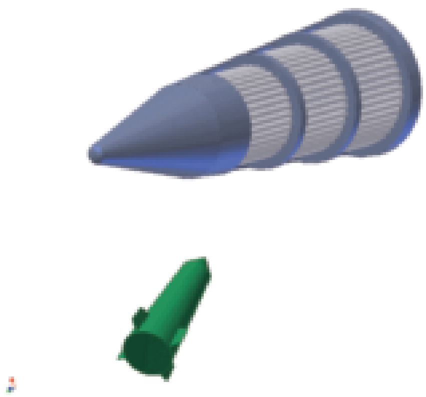


Figure 26: How to defeat ballistic missile warhead

On lightweight armour the work is focused on protection against armour-piercing small calibre projectiles with tungsten-carbide cores. There are a lot of commercial armour products available on the market that can be combined in different ways to offer good protection, but the penetration capability of tungsten-carbide projectiles is so high that new kinds of solutions must be considered to keep the weight of the armour down.

One concept studied is to produce gradient materials where the frontal part is a ceramic material and the rear part is a metallic material, see figure 27. In this type of material, the ceramic is supported and integrated with the metallic part giving less tensile stress in the back of the ceramic. This hopefully also reduces fracture and disintegration of the ceramic and gives us a thin and stiff armour material.

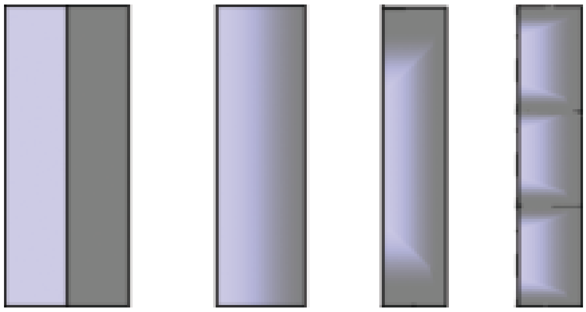


Figure 27: An idea of how to use gradient materials of ceramic (blue) and metall (grey) to accive a thin armour material with multi-hit-capacity.

Spark Plasma Sintering-technique (SPS) is used to produce test bodies of Ti–TiB_2 gradient materials. There are difficulties in producing the Ti–TiB_2 gradient material, i.e. the difference in thermal expansion behaviour between titanium and titanium-diboride can cause cracks in the gradient material during sintering. A large number of layer combinations have been tested, most so far resulting in cracked specimens. In one case, with eight different layers, we succeeded in producing a sample without cracks.

The SPS-technique has also been used to produce test bodies of pure ceramics and whisker reinforced ceramics. Two different ceramic materials, sub-micron alumina (Al_2O_3) and titanium-diboride ($(TiB_2)_{0.95}(Ti)_{0.05}$) have been tested ballistically. The sub-micron alumina is of interest because of the possibility to obtain a transparent material and the titanium-diboride composite is a candidate as front material in a gradient material. In comparison to the Al_2O_3 and TiB_2 commercially available, the SPS produced materials show a small increase in mechanical properties. For both materials, ballistic testing has shown little difference in penetration resistance between the SPS produced and the commercial materials.

Combinations of commercially available products have been studied as well as the influence of geometric disturbances and the influence of the hardness, toughness and energy absorbing properties of the armour material. One effective way of defeating a tungsten carbide projectile is to transfer unsymmetrical forces onto the projectile to make it break up into fragments. The fragmentation of the projectile is so effective that a fibre material can be enough to stop the residual fragments. One example of a weight effective armour design of this type is a thin oblique steel plate in front of a panel of Dyneema.

Low cost titanium as armour material is studied in an international cooperation. Four different materials have been tested against 7.62 mm ammunition and characterisation of the dynamic material properties has been started.

Preliminary tests with unconventional armours using explosives and electricity have been carried out.

We continuously improve the methods for dynamic material testing and numerical simulations, especially on brittle materials such as ceramics. A new computer code, ”KRYP”, is under development to model the influence of the microstructure on the mechanical properties of the material. A scanning of appropriate material and failure models to be used in the Autodyn code for simulations of tungsten-carbide projectiles penetrating oblique plates and ceramics is going on.

Research on Active Protection

Active Protection Systems (APS) are armour concepts where some form of sensor information is used to detect, classify and/or determine time and point of impact of incoming threats, after which these threats are attacked with some form of countermeasure.

The main argument for APS is the capability of reducing or even preventing warhead and projectile penetration capacity even before they reach their target. It seems reasonable that armour concepts making use of some threat information before impact have greater potential for high mass efficiency than those that have no such information at all.

The project is mainly focused on basic research, studying appropriate sensor- and countermeasure systems and following international development within the area. During 2002, research efforts include signal-processing methods for radar sensor systems, availability issues of IR sensor systems and KE countermeasure systems. Simultaneously, APS-adapted weapons technologies are monitored.

A larger effort within the countermeasure part of the project has included numerical and experimental studies of countermeasure launch and interaction with KE penetrators. Part of this work has been the development of suitable experimental techniques. Preliminary results indicate that KE active protection systems, in comparison with passive armour solutions, may result in large weight savings for a given threat level or may be used to enable protection against higher threat levels at equal weight.

Research results give the customer the ability to assess developments within the area and to assess what potential possibilities APS present for the protection of Swedish units in Sweden and on international missions.

Assessment of effect and vulnerability

There is a focus on development of new and extending of existing methods and models for the assessment of effects and vulnerability. Assessment of effects includes the two complementary aspects “effects of conventional weapons on platforms” and “platform vulnerability to conventional weapons”. One ambition is to develop physically based models that describe the interaction between warheads and platforms structures in order to replace older empirical models. The project is also responsible for overlapping basis of judgment within the area of assessment of effects. This involves description of technical threats coupled to protection levels of relevant platforms. Focus is particularly on changing task profiles and environments that are coupled to SAF (Swedish Armed Forces) increasing engagement in international activities.

Issues that have been addressed are:

1. penetration and perforation of rigid, deformable and erodable projectiles,
2. ricochet of spherical projectiles against thin and thick targets,
3. production of secondary fragments from perforation of KE (Kinetic Energy) projectiles and shaped charge jets,
4. fire initiation,
5. buckling criteria for pressure loaded panel structures,
6. piston effects against vessel hulls.

The result of this research is implemented into the SAF computer program AVAL for assessment of effects and vulnerability.

Mathematical models have been developed for the phenomena involved in the addressed issues and these models have been compared to previously existing experimental results. New experiments have been carried out to validate models in issues 2, 3 and 4.

The models proposed have produced realistic results as far as the validation has been carried out so far. The matters in issues 4, 5 and 6 may be introduced in AVAL in the present shape. For issues 1, 2 and 3, extended experimental activities are planned to validate the models. After validation the results may be introduced into AVAL as alternative methods of calculation to those of today.

Cooperation has taken place with TNO (The Netherlands) concerning the phenomena fire and smoke on platforms, and with ARL (USA) concerning the effects of projectiles and fragments on personnel.

Research on Weapons effects on humans

The focus is on the development of new, and the extension of existing methods and models for the assessment of effects of conventional weapons on humans.

Issues that have been addressed are:

1. penetration of projectiles and fragments into simulated biological material (gelatin),
2. penetration into witness packs as a measure of kill probability,
3. evaluation of the computer program ComputerMan from ARL,
4. numerical simulations of the pressure around weapons.

The result of this research is, among other things, implemented into the SAF computer program AVAL for assessment of effects and vulnerability for personnel on platforms (armed land vehicles, fighters and naval ships).

Mathematical models of physical character have been developed for phenomena involved in the issues above. Experimental work has been carried out to validate the models.

The models yield realistic results for the phenomena in question as far as the validation has been carried out so far. Penetration in gelatin is representative for penetration in live biological material, but this is not the case for witness packages. Results from projectile penetration in gelatin show that ComputerMan, which is developed for fragment penetration, cannot be used for assessment of projectile penetration effects in the way it is described in the program manual. The calculated (simulated) pressure around weapons is realistic but requires large computer capacity and is hampered by the difficulty of specifying relevant initial and boundary conditions where these are most important, namely at the muzzle of the weapon.

Information exchange and discussions have been carried out with ARL concerning ComputerMan.

Scalable effects

Research is carried out on scanning fieldable less-lethal technologies as to provide input to the Defence Forces studies of problems concerning activities and rules of engagement in Peace Support Operations (PSO) in different scenarios. Policies and decisions on if and when this type of effects should be permitted are very important for further work in this field.

Within the framework of the Defence Forces studies, concerning e.g. “Future Artillery”, a wide area of weapon effects will be of interest. These effects will be tailored to the target and environment in terms of armour, weak points, risk of collateral damage etc.

During 2002 we have made some experimental studies on cal. 60 and 12-Gauge rounds.

We have participated in the European Working Group on Non-Lethal Weapons (EWG-NLW) together with Austria, Germany, the United Kingdom, Italy, the Netherlands, Russia and Switzerland, see figure 28. The group is preparing the “2nd European Symposium on Non-Lethal Weapons” in Ettlingen, GE, in May 2003.

The project participates in two Nat Working groups (LG/3 Toe and HFM-073/TG-012).

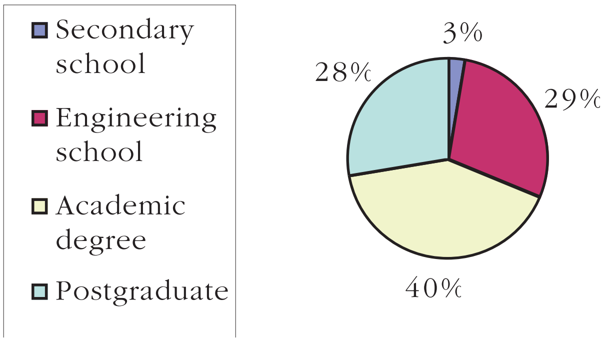
Figure 28: Example of non-lethal weapons

Organisation, management and personnel

The Division consist of four departments, Energetic Materials, Warheads and Propulsion, Protection and Materials, Armour and Survivability.

The Division employs about 115 persons. It is served by a unit of FOI's Administrative Division, in total about 25 persons. This unit comprises mess and housekeeping, mechanical workshop, service units, field and construction service, transports and heavy machinery.

Personnel, education



Location and facilities

The Division is located at the Grindsjön Research Centre, about 40 km south of Stockholm.

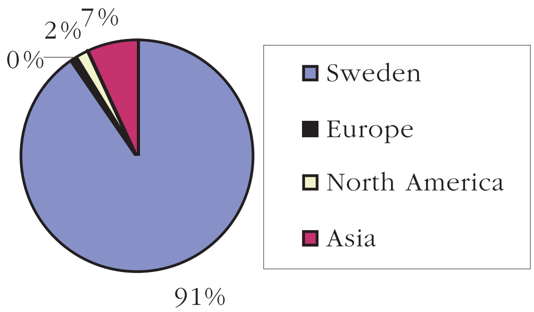
Facilities at the Grindsjön Research Centre are:

- 7,5 km², 23000 m² buildings
- Test sites (max 600 m risk radius)
- Chemistry Labs
- Terminal Ballistic Building
- Laser Lab
- Detonics Lab
- EM Weapons Lab
- H E and Propellant factories
- Propulsion Lab
- Sensitivity Labs
- Materials and Chemistry Labs
- Materials Testing Lab
- Concrete factory

Other facilities:

- Test Site Muskö: Underwater explosions
- Test Site Älvdalen: Large explosions, rock tunnels
- Test Site Märsta: Blast tunnel 40 x 1.6 x 1.2 m
- Test Site Rosersberg: Full-scale fire testing facility

Most important markets



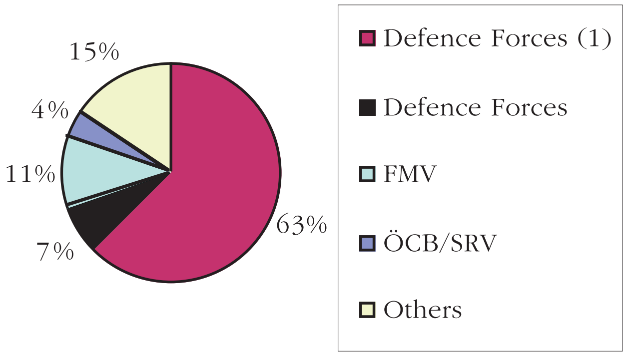
Memberships and participation

The division was a member of:

- The International Ballistics Committee (IBC), represented by Dr. Bo Janzon
- The Aeroballistic Range Association (ARA), represented by Lars Gunnar Olsson
- WEAG CEPA 3 Materials and Advanced Structures. Swedish Representative was Dr. Michael Jacob
- WEAG CEPA 14 Eneregetic Materials. Swedish Representative was Dr. Bo Janzon
- "ENERG" – a sub-group to CEPA 14, and an informal coordination forum between FOI and ICT i. FhG, Germany; PML/TNO, Netherlands; SNPE, France; DSTL, UK. FOI representative was Dr. Henric Östmark
- EUROLAB (Organisation for testing in Europe), represented by Dr. Magnus Oskarsson
- European Electromagnetic launch Society (EEMLS), represented by Sten E Nyholm
- Swedish Process Safety Promotion Association (IPS). Representative was Joakim Hägvall
- The European Working Group on Non-Lethal Weapons (EWG-NLW), represented by Ulf Sundberg
- Nato Working groups (LG/3 ToE and HFM-073/TG-012), represented by Ulf Sundberg
- The KLOTZ-group, key delegate, Dr. Michael Jacob
- NATO AC/258 RAWG, represented by Carl Elfving
- EWS, European Workshop on Survivability, represented by Ralf T Holmlin
- KCEM, represented by Helena Bergman and Dr. Henric Östmark
- Steering committee FEX, represented by Dr. Henric Östmark

and other national and international organisations.

Economy



Note 1) Supreme Commander's general task assignment to FOI.

The annual turnover of the division for 2002 was ab. 150 MSEK

Quality

The introduction of the quality management system SS-EN ISO 9001:2000 is an overall Swedish Defence Research Agency project, and the project leader is Leif Månsson from Linköping. For professional guidance the consulting agency Propia AB is at our service, they have extensive experience in helping other public authorities to introduce ISO 9001.

In keeping abreast with the development of the research community an introduction of a quality management system is mandatory. ISO 9001 will enhance our possibilities in marketing ourselves as an attractive research partner. The decision by the director-general Bengt Anderberg signed in November 2001 explains that the Swedish Defence Research Agency will establish and apply a quality management system which is in accordance with the demands of SS-EN ISO 9001:2000. Another contributory cause for the introduction of ISO 9001 is that one of our biggest costumers, Swedish Defence Materiel Administration, FMV, wants us to be quality assured.

In the beginning of 2002 an analysis of our present status was performed by Propia AB, to clarify what needs to be done in our organisation to fulfil the requirements of ISO 9001. The analysis gave rise to a number of discussion groups where participants from the divisions concerned could discuss the solution to different issues. There are three project groups, eight process groups and four method groups. Our division's annular work with our plan for performance excellence was ranked as a big step in the right direction.

At the turn of the year more than 10% of the employees at the division has been or is engaged in different discussion groups or has just started the work with the quality assurance of the laboratory facilities.

The quality assurance of some of the laboratory facilities will be performed before June 30 2003, the priority is on activities which delivers data from measurements. The next group is experimental work, which develops new techniques, and finally the research laboratories will be quality assured. The main part of the work performed at the Division of Weapons and Protection is research and consequently only a small number of the experimental facilities/laboratories will be quality assured initially.

The introduction of the quality management system SS-EN ISO 9001:2000 should be realized by June 30, 2003.

Environment

The Division participates in FOI´s common Strategic Environmental Program. The Division is organising a recycling system of all scrap, paper and garbage, and we have followed our detailed environment plan during year 2002. The plan included energy saving and education of all employees. The energy consuming has decreased about 4%/employed and year. The main reason to this success is a new controlling system. The progress to install heat pumps which take the energy from the ground is in the charges of the National Fortifications Administration.

The use of mercury in equipment has decreased radically during 2002. Now we only have mercury in some thermostats and thermometers.

We have engaged about 20 sheep from a nearby farmer, to get open landscape around the centre. We have a new environment plan for year 2003.

Measures to improve the work environment 2002

- Seminars have been held during the spring where the department's plan for performance excellence was presented to all personnel. A plan of action to improve the work environment is a part of this.

- Safety regulations have been established for current routines and security regulations at the department. The coordinator is responsible to see that visitors and contractors are served the folder.

- Hazard assessment of all activities has commenced, this extensive task will continue next year

- A plan of action for the departments handling of drug and alcohol related issues has been established.

- All personnel have been informed of current routines, laws and regulations regarding the hazards of handling explosives.

- Machine tools have been equipped with devices for emergency stop and under-voltage release for safety reasons.

- Work to insure that the department fulfills the demands that the rescue service laws put on the organization and structure of the internal fire-protection has been initiated.

- The occupational health service has been engaged to regularly provide health controls as well as counseling and treatment for work related musculo-skeletal disorders at Grindsjön.

- A more extensive, voluntary health control, with an interval of 2-4 years, has been offered the personnel through the occupational health service as of this year.

- A survey of buildings wich are suspected to have mildew problems has been performed and appropriate measures have been taken.

As a part of the department's effort to ensure that measures to improve work environment are an integral part of the day-to-day activities meetings at the place of work, staff conversations and rounds of precautions are held regularly.

Acknowledgement

Many persons have contributed to this report, including Mrs. Helena Bergman, Mrs. Carin Lamnevik and Mr. Ralf T Holmlin, all Department Heads and many Project managers.

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Annual Report 2002

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This is the annual report for FOI Weapons and Protection Division for the Fiscal year 2002. The activities of the Division's research departments are summarised. The report gives an overall description of the Division, its goals, activities, organisation and economy. It also provides information on facilities, scientific and technical competences and equipment. The Division's scientific publications and the customer reports are listed.

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Rapporten ger även en allmän beskrivning av avdelningens mål, verksamhet, organisation och ekonomi.

Information ges om våra anläggningar, vetenskapliga och tekniska kompetenser och utrustningar. Avdelningens vetenskapliga publikationer samt rapporter till uppdragsgivare är förtecknade.

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