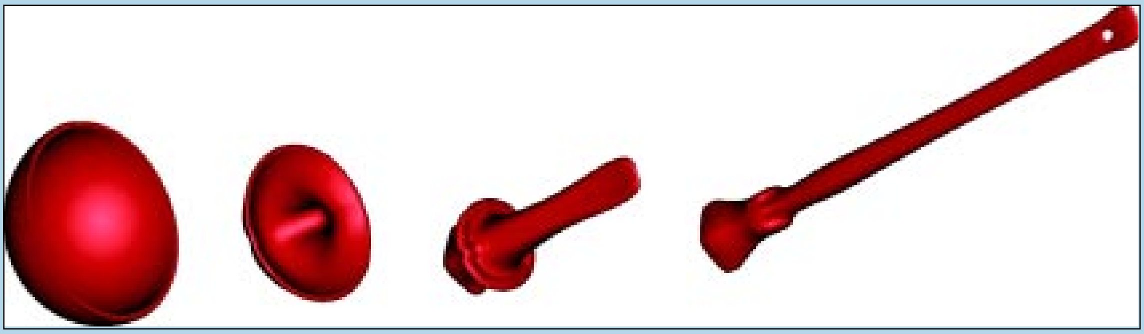
SWEDISH DEFENCE
RESEARCH AGENCY

FOI-R--0395--SE
April 2002
ISSN 1650-1942

Progress Report

Kristina Wahlgren (Editor)

WEAPONS AND PROTECTION DIVISION
Annual Report
2001



WEAPONS AND PROTECTION DIVISION
SE-147 25 TUMBA, SWEDEN

Brief history

FOI Weapons and Protection is located at the Grindsjön Research Centre, about 40 km south of Stockholm in the forests of the Södertörn peninsula, comprising an area of about 7.5 square km. The site was founded in 1941, during WW 2, as the Institute of Military Physics. In those days several noted Swedish Physicists, such as Nobel Prize Winner Professor Hannes Alfvén, worked here. In 1945 it merged with other defence research activities, mainly the Defence Chemical Institute, and the National Inventions Board, which among other things worked with radar, to become FOA.

The initial research areas at Grindsjön in 1941 were shaped charges and rockets. After 60 years we still do research on shaped charges and rockets. From time to time, authorities have thought that now was the time to end this research and do other important things, and there have indeed been shorter periods of lower activity of that. So far, these opinions have always been proven wrong. Anti-tank warfare has been a core activity at Grindsjön, and increased protection levels of armour and reactive armours, and requirements of increased performance of anti-tank munitions have again become a strong driving force for Sweden and FOI. FOI Weapons and Protection is still among the world leaders in high-precision shaped charges, as well as in high-velocity rockets, but now also in other areas such as energetic materials and computational physics.

In the 1950's nuclear weapons research, mainly detonics, became an increasing and important activity at Grindsjön. New land and the bulk of todays facilities were added to enable research, experiments, development, and finally preparations for production of "the bomb". Grindsjön became the "Los Alamos" of Sweden. The site was highly secret until a large forest fire in 1954, which required the assistance of all fire brigades of the Stockholm area, and of many hundred military personnel, made its existence known to the public. Vegetation on the long rock ridge on the western shore of the Grindsjön, which was completely obliterated in the fire, has only started to grow back in the last 20 years.

In 1958 development of the nuclear weapons was curbed by the Parliament of Sweden, and in 1968 came the final decision that Sweden would abandon all further work and procurement of nuclear arms. After this, conventional weapons and protection against weapons effects have been at the focus of Grindsjön.

The new Weapons and Protection Division was established in 1994

Going down from the early 70's maximum of about 140 to a minimum of about 85 in 1994, in December 2001 about 140 persons, including service personnel, work at Grindsjön.

In 2000 the Protection and Materials Department finally moved to Grindsjön from a test station, located at Botele udd, Märsta, close to Arlanda Airport, about 40 km north of Stockholm. One medium-sized blast tunnel will be kept by FOI at Botele Udd, and can be used for campaign testing. Also the activities of a research group on materials, especially their dynamic properties, moved from Ursvik to Grindsjön. 1 January 2001 all personnel of the division was, for the first time, located at Grindsjön.

The potential for further developments in conventional weapons effects, earlier judged as very limited, now seems to be quite high, based on the possibility to create new materials with much higher (3-10 times, or more) energetic content than the present most potent explosives, such as HMX. Combinations with sensors and computers in smart and brilliant weapons also serve to greatly increase performance potential. Fortunately enough there seem to be similar possibilities to increase protection, e g using ceramics, gradient composite materials and active armours with sophisticated sensors and warning devices. Relieved security political stresses may, contrary to common beliefs, mean an increased risk of more long-term development efforts and introduction of entirely new weapons principles.

On 1 January 2001 there was a merger between the Aeronautical Research Institute (FFA) and the Defence Research Establishment (FOA). The new research organisation is the Swedish Defence Research Agency, FOI, comprising an intact and developing Weapons and Protection Division.

In May 2001 the Division and its facilities at the Grindsjön Research Centre celebrated their 60th Anniversary during an entire week, which included an International Workshop on Demining Technologies, International Seminars on Demining and on the Future of Energetic materials in Europe, "Open house" at Grindsjön for our customers and personnel from other FOI Divisions, and one "Family day" for ourselves, relatives, friends and local residents around Grindsjön.

SWEDISH DEFENCE RESEARCH AGENCY

FOI-R--0395--SE
April 2002
ISSN 1650-1942

Kristina Wahlgren (Editor)

FOI WEAPONS AND PROTECTION DIVISION

Annual Report
2001

The cover picture illustrates the collapse and jet formation of a hemispherical liner in a twopoint initiated shaped charge warhead. The simulation was performed using the FEM-code LS-DYNA.

Contents

FOI's Weapons and Protection Division

Director:
Dr Bo Janzon, M.Sc. (Eng.Phys.), Ph.D. (Med. Sci.)

Deputy Director:
Mrs Carin Lamnevik, M.Sc. (Eng.Phys.)

FOI Weapons and Protection, Area of Activity:

- Energetic Materials
- Rapid mechanical and energetic processes
- Dynamic properties of materials

especially applied to

- Weapons, munitions and warheads
- Their effects and protection against effects

including, also for the needs of 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 advice
- Future and Threat prognoses
- Technical and Systems solutions and base data
- 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)

Lightweight armour materials produced by Spark Plasma Sintering – A strategic competence development project

By Dr. Pernilla Pettersson and Dr. Magnus Oskarsson

Introduction

The increased level of threats against lighter armoured vehicles, especially the increased use of armour piercing projectiles, requires that better lightweight armours are developed. To utilise the properties of the protection materials at a maximum, different materials must be combined in the nano- or the micro scale to produce the required ballistic properties. By combining different materials in an optimal way new products can be produced with considerably better properties, i.e. stronger, more ductile and optimised to fit the application. Functionally Graded Materials (FGM) has the potential to be very efficient armour materials. With the new sintering method Spark Plasma Sintering (SPS) completely new opportunities are available to effectively produce FGM materials. The SPS technique uses partly other mechanisms than traditional sintering techniques, resulting in very short compaction times, thereby strongly suppressing grain growth while still obtaining fully dense materials. Generation of the so-called spark plasma phenomenon make it possible to produce compounds that normally are incompatible or difficult to consolidate.

Two applications of the SPS technique have been studied in this project: sintering of submicron-crystalline alumina (Al_2O_3) and the possibility to produce Functionally Graded Materials (FGM) from the system titanium and titanium diboride ($Ti\text{-}TiB_2$). The importance of preserving the nano-size of the alumina particles after consolidation is due to the fact that a fine microstructure leads to higher fracture toughness, which gives better protection capabilities of the material. FGM offer major advantages to armour design: since significant structural loads can be supported from the ceramic/metal composite. From a ballistic standpoint it is also advantageous with no discrete material interfaces between the metal and the ceramic, shear coupling between the ceramic and the metal and mechanical attachment of the metal side [1].

In this report the SPS technique and the equipment used by FOI, is described. Some results on producing sub-micron Al_2O_3 and $Ti\text{-}TiB_2$ are also presented.

Spark Plasma Sintering (SPS)

All compacts were prepared with the spark plasma sintering technique (SPS). Figure 1 shows the laboratory scale SPS apparatus used in this project (located at Stockholm University, Dept. of Inorganic Chemistry).

Figure 1. The SPS apparatus with sintering press unit and DC pulse generator. The small picture shows the specimen chamber during heating.

To prepare fully dense compacts from ceramic powder precursors, earlier techniques such as hot pressing and hot isostatic pressing, in many cases did not give sufficiently good results. In these techniques the heat is generated by the power supply and the sample is heated by an external heating source, and the compaction is a diffusion-controlled process with the reduction of surface energy as driving force. In the modern Spark Plasma Sintering technique (SPS) the sample is directly heated with an ON-OFF pulsed direct current (DC, 1000-20 000 ampere and 3-4 volt) applied to the pressure die (see Figure 2). During sintering an external uniaxial pressure is applied (up to ~200 MPa). In addition to heat and pressure, this process utilises a self-heating action caused by the activation of the particle surface by a spark discharge between particles in the initial stage of the DC pulse and very locally the temperature reaches up to ten thousands degrees Celsius. Generation of so-called spark impact plasma also leads to cleaning of the particle surface, e.g. the removal of impurities and oxide skin on metals. The direct heating and the activation of the particle surface results in fast heating, sintering and cooling times, which makes it possible to prepare a fully dense sample within minutes and gives the possibility to fully control the sintering parameters. The discharge between the particles is visualised in Figure 3. The particles begin to melt together (necking) and the current generates heat. When the particles have melted together the remaining sintering process is also enhanced by high current, due to that the electrical field increases the diffusion controlled material transport. The extremely short sintering times and the possibility to control the sintering parameters makes the SPS technique unsurpassed when it comes to preparation of more complex and fine-grained materials.

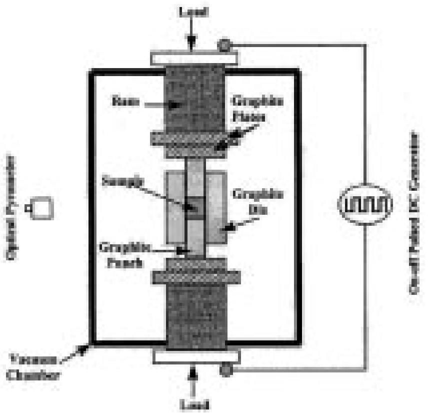


Figure 2. *A schematic drawing illustrating the features of the synthesis chamber of the SPS equipment. The graphite die has two functions, both as a sintering mould and a heating element, and the pressure is applied to the graphite punches. The size of the samples produced with the SPS at Stockholm University is a diameter between 12-40 mm and a thickness of 2-30 mm, after Gao et al. [2].*

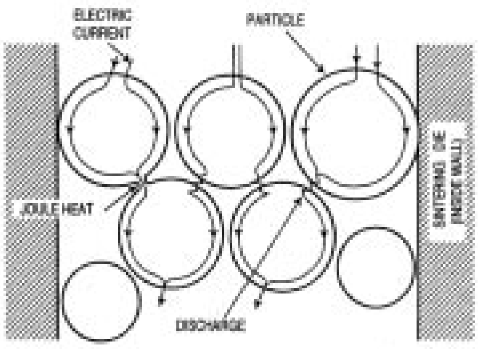


Figure 3. *The pulsed current flow through particles during SPS sintering, after Tokita [3].*

Experimental

Alumina (Al_2O_3)

The purpose of this study was to produce fully dense Al_2O_3 samples with submicron-sized grains from submicron-crystalline powder, i.e. limited grain growth during consolidation. The starting material was a commercially available powder with a mean grain size of 400 nm. The powder and the sintering parameters chosen gave fully dense (>99%) cylindrical samples, with good mechanical properties. The material hardness was 21-23 GPa (Vickers) with a fracture toughness of 3.5± 0.5 $MPam^{1/2}$ and the 4-point bending test gave a bending strength of 460 MPa. The SEM investigation showed that the grain size was of the order of 500-1000 nm, see Figure 4. The resistance to penetration will be tested in the near future.

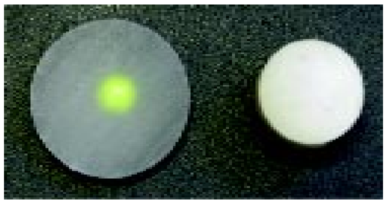


Figure 4. *Al_2O_3 samples. The left sample shows an example of an opaque Al_2O_3 produced by SPS (the grain size is in the same order as the wavelength of light, 400-700 nm), with a green light diode behind, and the right sample a traditionally sintered Al_2O_3.*

Titanium (Ti) – Titanium diboride (TiB_2)

Functionally Graded Materials (FGM) are interesting because materials with different advantages can be combined to produce materials with unique properties. Due to differences in thermal expansion it is not possible to join metals and ceramics, without a zone with graded composition of the constituents between these materials. The study has initially been focused on finding out the sintering parameters for the individual layers found in the graded composition zone.

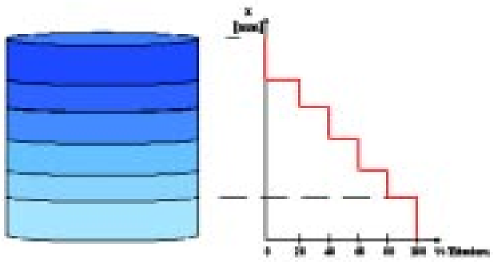


Figure 5. *Schematic drawing illustrating the principle of FGM.*

It is important to ensure that a good TiB_2 compact is produced, since most of the ballistic properties is limited by the outer layer of the FGM. Single phase TiB_2 was difficult to sinter to full density, a small amount of titanium was added (5%) to give a fully dense material. This material has a hardness of 23 GPa (Vickers) with a fracture toughness of 4.5 $MPam^{1/2}$ and the 4-point bending test gave a bending strength of 640 MPa.
Initial experiments to merge the different layers to create a graded material have been performed. The research will continue with ballistic testing of the materials, both the final FGM and the layer materials individually.

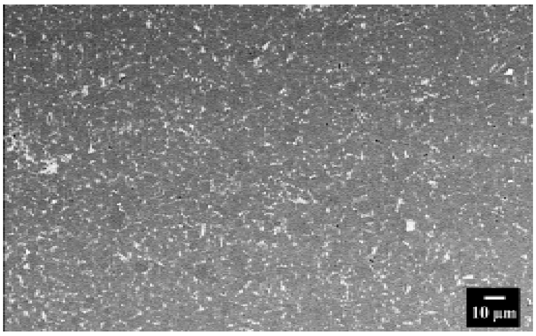


Figure 6. Micrograph of the $(TiB_2)_{0.95}(Ti)_{0.05}$ sample (white small areas pure Titanium).

References

1. W. A. Gooch et al, 17th Int. Symp. On Ballistics, South Africa, 1998, 3-41-48
2. Gao et al, J. Euro. Ceram. Soc., 1999, 19, 609-613
3. M. Tokita, "Mechanism of Spark Plasma Sintering"

Interface defeat: a promising armour concept for future combat vehicles

By Patrik Lundberg

In order to meet the contradicting demands of lower vehicle weight and highly improved armour protection in all directions, future generations of fighting vehicles will need new types of armour.

These will probably consist of a combination of an active system which attacks the threat warheads at a distance from the vehicle and a passive base armour, well integrated into the vehicle structure.

A promising passive armour concept, which is studied at FOI, is designed to cause partial or total interface defeat of the projectile. Interface defeat signifies that the projectile material is forced to flow radially outwards on the surface of the target material without penetrating, a similar process to what happens when water is flushed against a wall. Figure 1 shows how the projectile interacts with the target surface during interface defeat.

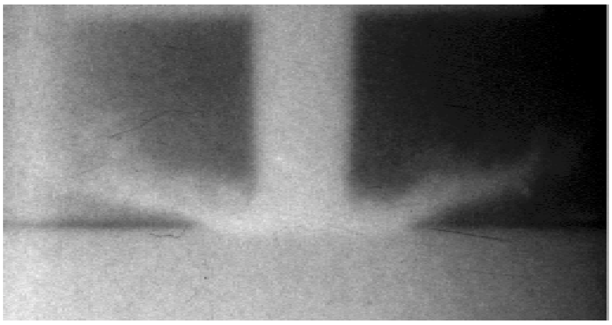
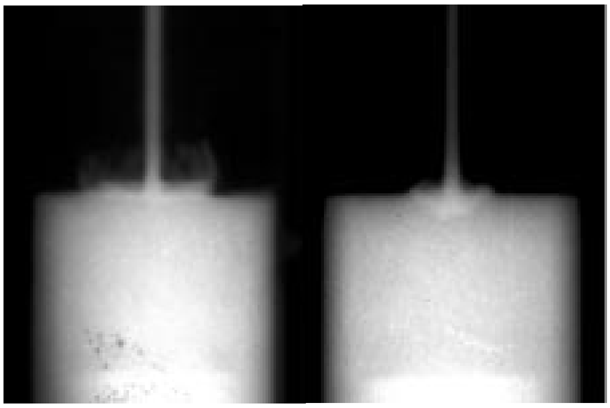


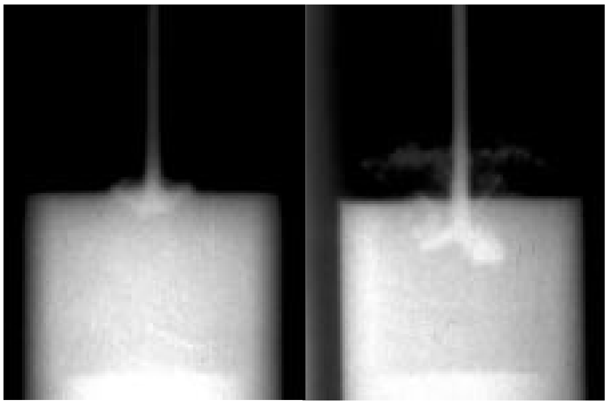
Figure 1: *Interface defeat*

Interface defeat against high density long-rod projectiles (depleted uranium or tungsten) at ordnance velocities (> 1000 m/s) has been demonstrated using different types of ceramic materials, e.g. alumina, boron carbide, silicon carbide and titanium diboride. To make the concept work with these brittle materials, it is necessary to use special devises to eliminate the impact shock and suppress macroscopic crack growth. Using today's ceramics and armour technique, interface defeat of tungsten projectiles has been observed at velocities close to 2000 m/s.

Figure 2 demonstrates the importance of using some type of shock attenuator in front of the target material. The two flash X-ray picture sequences show what happens inside the target material at two different times after impact. In the first sequence, 2(a), a special cover was used in front of the ceramic target and interface defeat was obtained. In the second sequence, 2(b), the projectile impacts the target surface directly and penetration takes place.



(a)



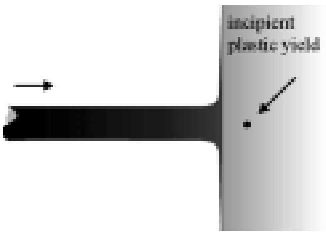
(b)

Figure 2: *Impact at 1500 m/s with (a) and without (b) a shock attenuator in front of the ceramic.*

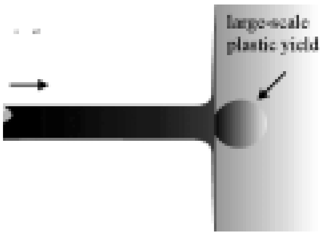
In order to estimate the maximum impact velocity for which interface defeat can be sustained, that is the protection potential of a given material, it is necessary to know the contact pressure generated by the projectile, the corresponding stress state in the target and the way the target material responds to this stress state.

The way the target material responds decides which contact pressure it can withstand. Two different response modes are illustrated in figure 3. A brittle behaviour will result in target failure as soon as an inelastic state is reached (this corresponds to incipient yield in a metallic material). This starts at a point below the surface of the target, see figure 3(a).

A material that can withstand inelastic deformations (this corresponds to large-scale plastic yield in a metallic material) will fail when the inelastic zone reaches the target surface, see figure 3(b). This takes place at double the contact pressure needed for a brittle material.



(a)



(b)

Figure 3: *Different types of target material response. Brittle behaviour (a) and "plastic" behaviour (b), respectively.*

These two different material responses give a lower and a higher contact pressure limit corresponding to a lower and higher impact velocity that a target material with a given strength can withstand. These limits are illustrated by the curves in figure 4 for the case of a tungsten long-rod projectile (projectile density 17600 kg/m^3). In figure 4 experimental data are also presented for some target materials available today.

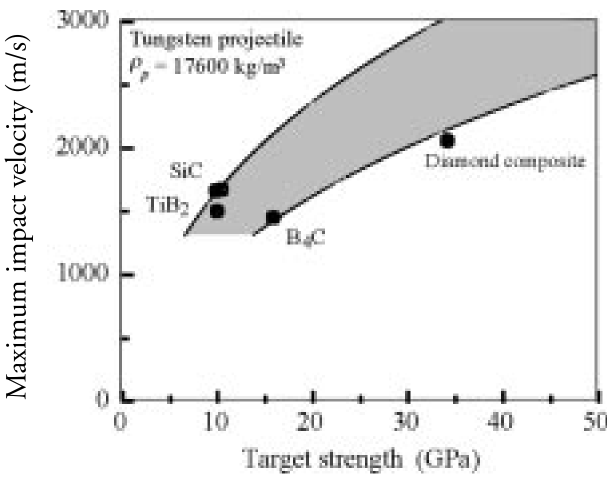


Figure 4: *Maximum impact velocity versus target strength for elastic (lower curve) and plastic target material response (upper curve). Filled circles correspond to experimental data.*

In order to convert these basic results into real interface defeat armour designs, new more damage resistant high strength materials are needed. These materials must also be incorporated into the vehicle design in such a way that maximum performance of the materials is achieved.

The rapid development of new and better materials make interface defeat one of the most promising armour concepts to cope with the rapidly increasing KE-threats encountered in future military conflicts.

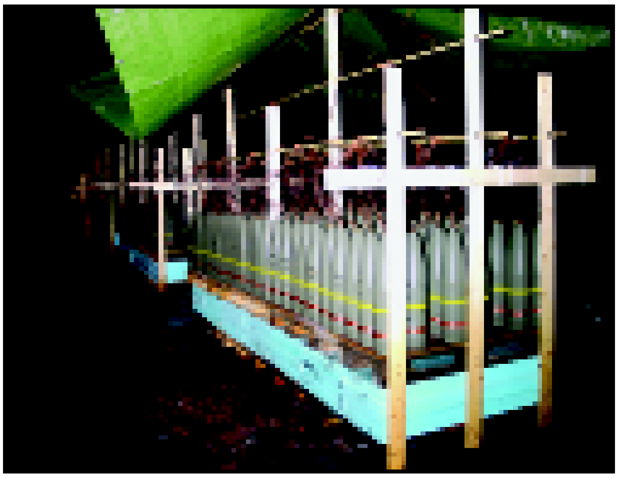
Large scale testing at the shooting-range of Älvdalen

By Dr. Roger Berglund

FOI has for several years continuously performed large or full scale testing at the artillery shooting range in Älvdalen. This has led to establishment of a number of more or less permanent test sites and furthermore a very close co-operation has been established with personnel at the shooting range and at ArtSS. Due to the large size of the shooting range (800 km^2) there are small or no problems with shooting permits or restrictions concerning weights of charges, types of high explosive and warheads due to interference with "ordinary" activities.

In the end of year 2000 and during 2001 a series of tests were performed for the **D**efence **S**cience and **T**echnology **A**gency (DSTA) in Singapore. A scaled underground ammunition storage was built during the year 2000. The facility is a large tunnel system with a total length of 250 m, ending in a 1000 m^3 large chamber in which, at most, so far, 10 tons of TNT has been detonated. The objectives for the test series were to give experimental results to validate the underground facility design and to determine the hazardous areas around ammunition storages in rock. The measurements were focused on, air blast, door pressure, ground shock, temperature, response of tunnels, response of adjacent chamber and debris distribution.

The first test was 10 kg TNT placed in a borehole in the explosion chamber, with the purpose to check the ground shock gauges. The second test consisted of ten TNT charges placed on "styrofoam" to decouple the charge from the concrete floor. The weight of each charge was 50 kg. The same charge placement was used for the third test in December, except that the charges for this test weighted 1 000 kg each. This gives a total charge weight of 10 000 kg TNT. Two new tests were performed in May-July, 2001. The first was a calibration test for several new gauges. The charge here was similar to test 3 but with total charge weight of 2 500 kg. The main test was conducted with 15.5 cm artillery shells placed on 10 tables with 145 shells on each, given a total explosive mass of 10 000 kg TNT. After the test all the steel fragments from the shells were collected. More than 99% of the 50 tons were found in the chamber or in the inner parts of the tunnel system, which was a very positive result. All the tests so far have been successful. In 2002-2003 further test are planned. First one with mixed explosives (shells and propellant) and after that a water mitigation test. Besides FOI, researchers from Norway and the USA participated with measuring equipment, and in total 160 channels were recorded in the tests.



To the left: Some of the 1450 artillery shell before detonation. To the right: Outside the tunnel system 9 seconds after detonation. To get a picture of the size note the 20 feet container in font of the smoke cloud.

Energetic Materials Department

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

Introduction

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 aim for the department is to be one of the world's leading research organizations in the field of energetic materials and energetic processes.

During 2001 the department purchased and got on line a LC/MS system and a 400 MHz NMR. The new equipment is a valuable asset to the research program on the department.

The department staff consists of 30 persons, 24 of whom hold academic degrees (12 Ph D, 11 M Sc). A positive sign is that 40% of the staff are women.

We also have an extensive co-operation with the Royal Institute of Technology and the Stockholm University: 5 graduate students. During the year we have had a visiting scientist from [dstl] in UK working on the N_4 project, and a post doc from Finland working on melt casing ADN and on activated aluminum. After finishing the post doctorate in the end of 2001, Dr. Hahma joined the department as a full time scientist. Members of the department have during the year taken part in advisory boards concerning explosives, ignition trains and safety. We have also participated in NATO workgroups like AC310 SG 1 and in NIMIC. The Energetic Materials Department has a number of international co-operation projects, e.g. 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-SW-D-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"). During 2001 a project proposal was sent to DSTA and the workplan will be implemented in April 2002.

New Energetic Materials

In the short range, research and development is focused on 4th generation energetic materials (e.g. CL-20, ADN, FOX-7, TNAZ) with application in shaped charge warhead, high performance warhead, higher performance rocket and gun propellants and better underwater explosives. A large effort has been put into characterising the chemical reactivity of FOX-7. We have found out that FOX-7 can be demiled by treatment with a strong base, which will lead to the formation of dinitromethane. An idea about how to make the synthesis of FOX-7 cheaper has been sketched and our hope is to try it during 2002. Two new synthetic routes for nitroform with high yields have been developed. Nitroform can be used in our search for new rocket fuels and as building block. A new energetic thermoplasic elastomer, aimed at ADN gun propellants, has been developed. Preliminary investigations show good compatibility and promising mechanical properties. Part of this work has been done in co-operation with KTH (diploma work). A FOX-7/polyGlyN-based formulation has been prepared. It has potential as a Comp B replacement due to the insensitiveness of FOX-7. Calculations indicate even higher performance than for Comp B. The new substances, mentioned above, have a potential use both as propellants and as explosives, with a performance 20 to 30 % higher than those in use today. Another important issue is the development of rocket propellants and explosives, based on the new substances, with better safety than that available today with equivalent or better performance. There is a trend towards greater variation in the choice of explosive/propellant depending on the application, and on safety and performance requirements. Further tests of the new type of aluminum, activated aluminum, have been tested. This test showed that this activated aluminum is more reactive than nano-sized aluminum (ALEX) in spite of the fact than it is more than 100 times larger. It is also much cheaper to produce. Another trend in the explosives community is the movement towards more environmentally friendly explosives (both from the point of view of manufacturing and of use).

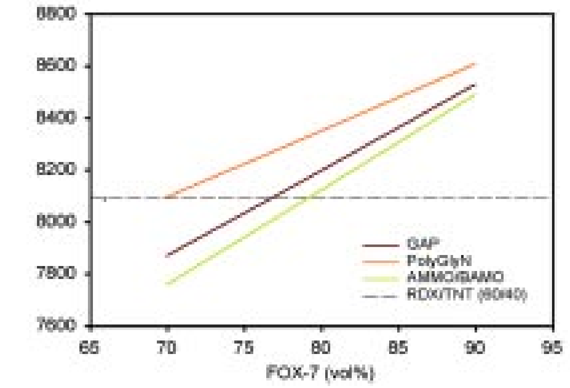


Figure 1. Detonation velocity as a function of volume % FOX-7. RDX/TNT is shown as a reference

The long-range research perspective focuses 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. In the search for new explosives, nitrogen clusters have surfaced as a potential candidate and the focus of the department is the synthesis of $N_4(T_d)$. Quantum mechanical calculations show that the rectangular N_2(D2h) molecule is stable and a LIF detection scheme has been proposed. This increases the probability of detecting the substance since LIF is more a more sensitive method than Raman spectroscopy. Synthetic efforts have been made during the year and bands from unidentified nitrogen containing species have been observed. Isotope experiments confirm the nitrogen contents of these species but no identification has been made. A new set-up for experiments with controlled temperature and deposition of species has been constructed. A more "chemical" approach using pentazole and tetrazole precursors has started and will continue.

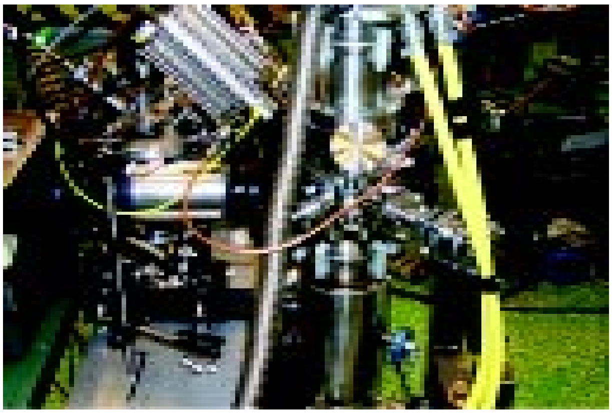


Figure 2. Synthesis equipment for N_4

New underwater explosives

Ammoniumdinitramide, ADN, is a high explosive that contains an excess of oxygen. By mixing ADN with aluminium, the aluminium is combusted with help from this excess oxygen. Since ADN melts at 93°C, the composition is castable. During 2001 experimental efforts were made to retrieve data for a reaction-rate model according to Lee.Tarver. This model can be used for studying the sensitivity for mechanical impacts and designing booster charges.

Figure 3. Test of the new underwater explosive ADN/Al

Mine detection

In the area of mine detection the focus is both at detecting a single mine as well as a minefields. When we try to detect a single mine, the aim is to detect the explosive. This can be done since vapour leaks out from buried mines and/or unexploded ammunition. Methods for workup of soil and air samples are under development and methods for analysis on gas chromatography and liquid chromatography combined with mass spectroscopy. The aim is to reach low detection limits and the GC-MS method today has a limit of 10^{-15} g for TNT. New techniques for extraction of TNT and related substances from soil samples have been developed.

A new filter and sampling system has been developed for air sampling. The aim of this part of the project is to optimise the vapour sampling and analysis system for mine detection. Due to this, development and evaluation of vapour phase sampling for TNT and DNT has been performed.

A study concerning the migration of explosives in soil and air around a buried mine concentrating on the parameters that affects the migration and what decomposition products that are formed in different environments and climates. The result from this study is very important to the development of training methods for dogs, biosensors and chemical methods.

In co-operation with Stockholm University, Institution for biochemistry, a project where bacteria will be used to detect explosives. This study will be ongoing during 2002.

Demilitarization and risk analyzes

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. At FOI an alternative approach, based on fluidised bed incineration, has been suggested. During 2001, a large-scale incinerator test on explosive binders, nitromethane and a selected choice of typical industrial waste has been carried out with excellent results.

Accidental explosions are 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 2001, several companies as well as government agencies have consulted the risk analysis team.

Propellant surveillance

The purpose of this project is to prevent accidental ignition of ammunition and stop a unnecessary demilitarisation of ammunition based on nitro-cellulose. During 2001 2039 tests of the stabiliser content in ammunition have been analysed. The power evolved from samples held at 65° C during 13 days has been measured for 303 samples. An investigation concerning the temperature dependence at microcalorimetry measurements of nitro-cellulose based powders has been carried. The project is an important part of the Swedish ammunition safety program.

Lectures and courses

The Department has been responsible for a number of courses and lectures on explosives chemistry and explosives safety, e.g. a high explosives course (3 parts of 3 days each with about 35 participants from the defense industry, FOI, Police, and other Government authorities), and one 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 from both Sweden and the rest of the world have taken place.

Warhead and Propulsion Department

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

The main goal for the department's activities is to offer scientific competence in application areas of essential importance for the Swedish defence, based on a solid foundation of basic physics, such as combustion physics, detonics, electrophysics, fluid mechanics and continuum mechanics. Our research areas are launch techniques for guns, propulsion, conventional warheads and detonics, underwater warheads, RF-warheads (microwave weapons) and computational continuum dynamics. The department has 30 full time employees, besides these there are other researchers connected to the department, mainly PhD students at different Swedish universities. During the past year our main efforts in an ongoing development of our activities have been development of our experimental techniques and extension of our computational physics resources.

1. Research on launch techniques

The current activities are mainly focused on electrothermal-chemical (ETC) launch techniques where electric energy is used to improve the performance of propellant guns. The purpose of supplying electric energy is to enhance and control the combustion of the propellant to improve the gun performance in terms of muzzle velocity and energy with a decreased variation in muzzle velocity. Using electrically controlled combustion can also enable an increase of the loading density well beyond what is possible with conventional charges. Thus, impact velocity, range and hit probability may be increased and a heavier projectile may carry a greater payload. Another advantage with ETC is that it may be used for retrofitting existing guns. The objective of the research on ETC at FOI is to investigate to what extent it is possible to control and augment the combustion of a propellant by conducting an electric current through the reaction zone. Electric energy is then supplied to the flame via resistive heating. Part of this thermal energy will be transferred to the unburnt propellant and added to the energy released by chemical reactions in the flame. The evaporation and thereby also the burning of the propellant can in this way be increased.
To be able to better understand how the combustion is affected by the supplement of electric energy, experiments are performed in a closed vessel where the volume is constant during the combustion of the propellant. The pressure in the bomb depends mainly on the amount of propellant burnt and electric energy added which means that the burn rate is closely related to the pressure versus time recordings. The electric energy is supplied from a 300 kJ pulsed power supply consisting of four modules with capacitors that can be charged to individual voltages, separate serial inductances and can be switched with different time delays. This gives a large flexibility in shaping the current pulse.
To increase the electrical conductivity in the flame, the propellants tested were prepared with additives of either 1% or 5% of potassium nitrate. In figure 1 pressure versus time recordings are shown from experiments with a 4-module and a 1-module discharge. The 4-module discharge is more extended in time, which results in a shorter burn time and increased gas generation rate compared to when the 1-module discharge is used. This strongly indicates that it is possible to control the propellant combustion by conducting a current through the reaction zone. Important factors to consider while working with this ETC-concept, are the degree of uniformity in mixing and the amount of alkali compound added, the amplitude and shape of the supplied electric current pulse and propellant composition.

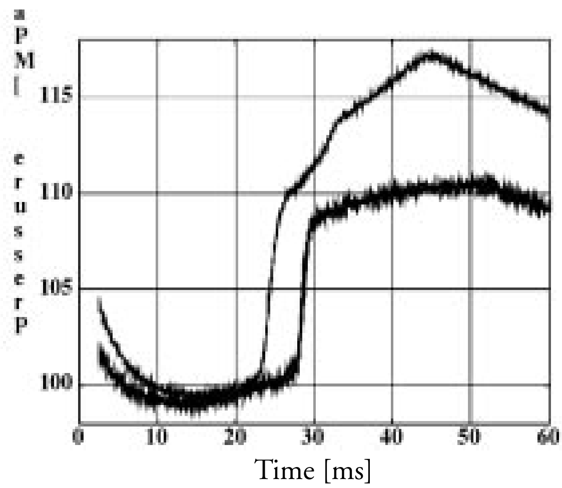


Figure 1: *Pressure versus time recordings from closed vessel experiments with 4-module (thin line) and 1-module (thick line) discharge. A double-base propellant has been used in the experiments.*

2. Research on Warhead technology Development of experimental techniques

Fiber optic probes for detonics

When studying detonation processes it is desirable to follow the detonation front in the explosive. One often-used method is to use optical fibers with micro-balloons assembled at the fiber tip with the fibers directed orthogonal to the detonation front. As an alternative to this procedure, another setup was tested where the fiber was aligned tangential to the detonation front. A laser beam was guided into one end of the fiber and a light detector was placed at the other end of the fiber. It was assumed that the shock wave from the detonation would quench the laser beam. Instead of a reduction in light intensity, an amplification of the light was detected. We intend to use this light generation effect in detonation and other studies during 2002.

Evaluation of cylinder tests

In order to test the performance of different types of explosives, cylinder tests have been performed. A rotating mirror camera was used in streak mode (streak writing rate 4 mm/µs), to measure the radial displacement and, indirectly, the radial velocity of the detonating cylinder, see figure 2a. In order to make the result available for computer aided evaluation, the streak image was scanned in an optical flatbed scanner in transmission mode. Since the instantaneous velocity should be evaluated, numerical smoothing and derivation had to be performed. The evaluation was done in two steps:

- The edge between the expanding cylinder and air was extracted by image processing
- The radial displacement velocity was calculated with digital Savitzky-Golay filters.

HI-Dyna2d was used for numerical simulations of the experiments and a specially written subroutine for this purpose in HI-Dyna2D dynacyl was used to monitor the appropriate node at a height of 70 mm. The extracted data used was the radial displacement ($r-r_0$) and radial velocity versus time. This data is directly comparable to the experimental data derived from streak-camera records, as shown in figure 2b. The results showed good agreement (as regards amplitude and periodicity) with the experiments, as is e.g. evident from figure 2b, where a comparison is made for the FOX-7 explosive.

Figure 2a: *Streak image of cylinder wall.*

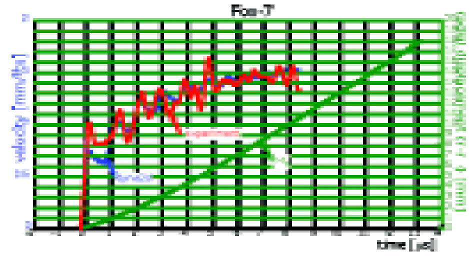


Figure 2b*: Extracted data compared with numerical simulation*

Improvements of flash radiography images.

Localization of edges and small details are important problems in many high-speed X-ray applications such as analysis of shaped charges and explosively formed projectiles. Photographic X-ray images are scanned in an optical flatbed scanner for further evaluation by computer software. However, the development, fixation and rinsing process of the photographs, as well as the scanning introduce noise and defects, which in turn diminish the available resolution. To solve these problems, directly scannable image plate systems have been tested and compared with conventional intensifying screen and film systems. An example of how the resolution can be improved is shown in figures

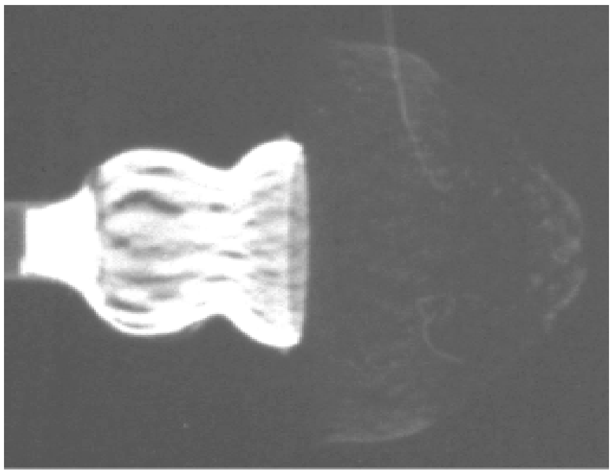


Figure 3a: *Intensifying screen and film system*

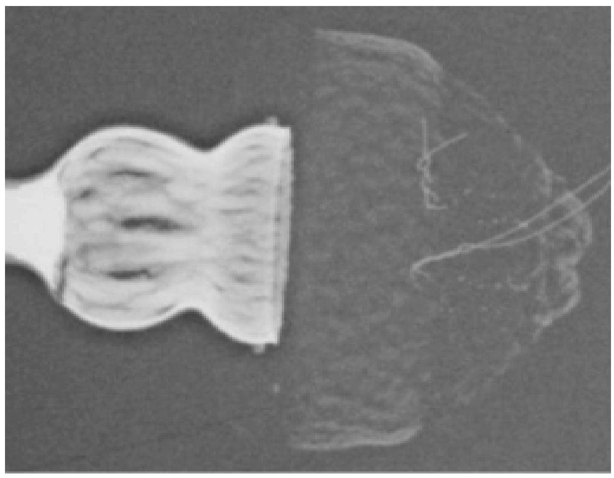


Figure 3b*: Image plate system*

3a and 3b, where a flash radiography of a blasting cap has been recorded with both techniques. The resolution increases from 200 μm^{-1} to 80 μm^{-1} when the image plate is used. The linear recording of the image plate makes it also easier to evaluate the image. Another advantage with the image plate system is the significant decrease of handle time from exposure to a digital image in the computer.

Detonations

Insensitive high explosives have become increasingly more important due to the stricter requirements for secure weapons. They are more or less non-ideal in the sense that the reaction zone is broad enough that initiation and size effects can not be neglected. To accurately simulate the propagation of a detonation in a non-ideal explosive, the physics in the reaction zone must be properly described. This can be accomplished by incorporating a reaction rate law, which describes the conversion of explosive to reaction products in the hydrodynamic equations. Thus, to predict performance and safety aspects for weapons containing insensitive explosives, a carefully calibrated reaction rate law is needed.

Direct measurements of reaction rates are very difficult to perform, which suggests that an indirect method should be used. A well-established method relays on the fact that the detonation velocity for a cylindrical charge depends on the charge diameter. For finite charges, radial flows will curve the detonation front, leading to incomplete reaction in the reaction zone. A lower reaction rate implies a larger curvature and a lower detonation velocity. By measuring the curvature and velocity of the detonation front for several different charge diameters, a reaction rate law can be constructed. In a direct method, the detonation process is simulated in a hydrodynamic computer code where the reaction rate law contains a number of parameters. The parameters are adjusted until agreement with measurements has been reached. Such method is very time consuming, considering the large amount of simulation that must be done and output files that must be analyzed to completely parameterize a reaction rate law. During 2001 a one-dimensional code was developed that calculates the flow in the reaction zone for a weakly curved self-sustained steady detonation. The code is based on the Detonation Shock Dynamics (DSD) theory, which is an extension of the ZND theory for plane detonations to weakly curved detonations. The advantage with this code is that a large number of simulations can be performed in a short time. A typical run for thousands of different parameter values and ten different charge diameters only takes a few minutes.

Shaped charges – high energy rate forming of liner-materials

Using equipment that can form liners at high strain-rates makes it possible to use certain refractory materials for liners in an economic way. One example is molybdenum, which is usually difficult to form due to its brittle behavior at room temperature. However, by elevating the temperature to about 200 C while keeping the strain rate above 400 s^{-1} it become possible to form conical liners of this material. The microphotographs in figure 4 shows the microstructure as received (36 µm) and heat-treated (26 µm). The plastic deformation was in the order of 60%. By using this technique when forming liners of copper, a large reduction of manufacturing time can be expected compared to cold pressing. Cold pressing manufacturing times is about one day for each workpiece while the manufacturing time with this technique is only a few seconds.

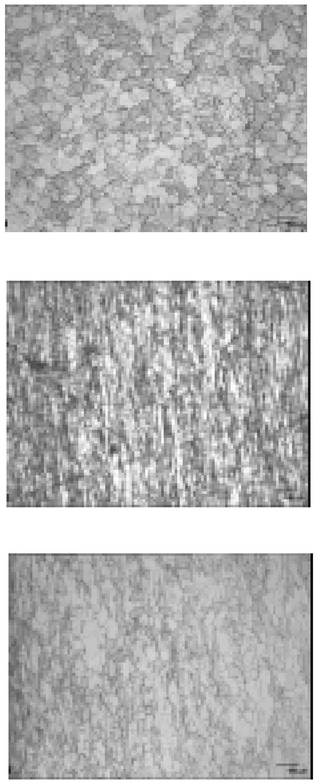


Figure 4: *Microphotographs of Molybdenum from top to bottom: as received, after forming and after heat treatment.*

3. Research on underwater explosives and warheads

The department includes a group that carries out theoretical and experimental research in the areas of underwater explosives and effects of underwater warheads as well as mine-surveillance (in collaboration with the Division of Systems Technology) and clearance. 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 Defense Materiel Administration, FMV.
The main goal of the work is to enhance the knowledge regarding surveillance, detection and clearance of mines, including buried mines. Another goal is to through development of computational tools and performance of experiments enhance the possibility to asses ship vulnerability regarding underwater detonations and signatures. A burn model for PBX has been further developed in the sense that improved experimental techniques have been developed for determining relevant parameters. Furthermore, a modified mine-clearance charge has been tested successfully. Regarding the vulnerability modeling the methods have been further developed and applied to a complete vessel with promising results. Finally, computer simulations of flow-induced noise around a rigid hull have increased our understanding of the physics of this phenomenon (see further under "Computational Physics").

4. Research on Propulsion

The propulsion project is divided into three areas: Pulse detonation engines (PDE), ramjets and high-speed combustion. During 2001, in the PDE area specific efforts were made to achieve efficient initiation and to solve the problems that appear at high frequencies. In the ramjet field the objective is to exemplify performance and the possibility of and conditions for regulation of mass-flow. Finally, regarding high-speed combustion, the goal is to achieve a higher level of understanding of the field enabling us to perform experiments and computations on complex propulsion systems.

Development of experimental techniques for combustion studies

In order to achieve more efficient numerical models and to gain a more fundamental understanding of combustion phenomena, there is a growing need to develop and apply experimental techniques for comparison and validation. Most desirable are measurement techniques, which give two- and three-dimensional information without disturbing the process under study. The most suitable techniques for these purposes are optical, non-intrusive methods.
The quantities that are considered to be of primarily interest to study are concentration fields, density variations, pressure variations, temperature distribution and velocity fields.
An experimental facility for studies of high-speed combustion using Schlieren 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. Initial experiments using Schlieren and shadow techniques has been performed where jet, originating from the combustion of a hydrogen/air mix in a cavity with a small "exhaust-hole", was studied, see figure 5. This case has also been studied numerically by the computational physics group. Regarding LIF, our effort has consisted of adapting the spectroscopic equipment for these kinds of measurements. Software for comparison between numerical computations and experimental results, using ray-tracing techniques, and for evaluation of Schlieren-experiments has also been developed.

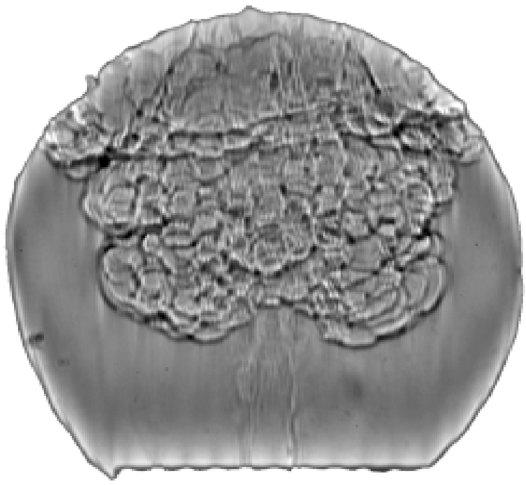


Figure 5: *Shadow image of an expanding hydrogen jet.*

The Pulse Detonation Engine

Due to the previous findings that PDEs operating in multi-cycle mode demonstrate considerably more reliable transitions as compared to single-cycle operation, the goal of the research at FOI has shifted from trying to optimize initiation of single cycle experiments to trying to explain – and take advantage of – the differences between single and multi-cycle operation. In order to better understand the effects of the chemical kinetics, and particularly its influence on the initiation, a 38 step hydrogen-oxygen reaction has been implemented in a computational code for constant volume explosions. This code has been used to simulate a constant volume reactor, and has been calibrated with a similar code developed at Lunds University. The main reason for undertaking this effort was to incorporate the detailed kinetics in a shock capturing, TVD (Total Variation Diminishing) Navier-Stokes code, something which has also been completed. The resulting code is suitable to model important aspects of transitions from deflagrations to detonations.
In the multi-cycle engine a large number of experiments have been performed, investigating the influence of for instance the point of ignition, equivalence ratio, fill fraction and frequency. Unfortunately, the performance of the engine has been unsatisfactory;

detonation has not been achieved throughout the entire engine but only locally. The main reason for this is believed to be the fact that this engine operates without any forced valves (only flapper valves were tried, but these did not improve the situation), i.e., both hydrogen and air are fed continuously into the engine. Therefore, an extensive effort has been undertaken to design a completely new engine, an effort which started in 2001, and will continue the following year. The ideas behind this new engine is based both on the result of the experiments with the present engine and on results from numerical calculations, and will hopefully result in an engine were reliable detonations are obtained in a major part of the engine.

Research on the ducted rocket test facility

Gas generators have been successfully test fired in the facility in order to provide input for the evaluation codes and to study IR- and UV-signatures with good results. Furthermore, a literature study on boron compositions for ramjet engines has been completed.

Additional activities

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

5. Research on Microwave weapons

The aim of the High Power Microwave (HPM) technology research is to evaluate the potential and feasibility of HPM weapons by studying selected subtechnologies for warheads designed to operate primarily with HPM.

Research on possible radiation sources suitable for explosives driven HPM began in 2001. Radiation has been produced and detected for the first time at the Grindsjön HPM laboratory. These studies were made using a non-vacuum low frequency (< 1 GHz) broadband radiation source powered by a 120 kV pulse from tabletop high voltage research equipment called TTHPM. This source is a laboratory tool for studying the fundamental physical processes in this kind of radiation source. Radiation sources and measurement probes are housed inside an anechoic chamber (see figure 6) to reduce radiation leakage to the surroundings and to achieve reflex-free measurements of the electromagnetic radiation. The anechoic chamber is covered with cones of an electromagnetically absorbing material. A specially designed feedthrough for the high voltage supply from the TTHPM system was constructed. There is also a feedthrough for the cables from the measurement probes, which are suspended inside the anechoic chamber.

Figure 6: *Anechoic chamber for electromagnetic field measurements.*

A measurement system for electric and magnetic fields has been assembled. Magnetic fields are measured with in-house built B-dot probes for all the three field components, while electric fields are measured with commercial D-dot probes. The signals are digitally registered for subsequent computer processing. Equipment with fiberoptic probes and optical transducers has been developed for registering light from electric flashovers at selected points in the system.

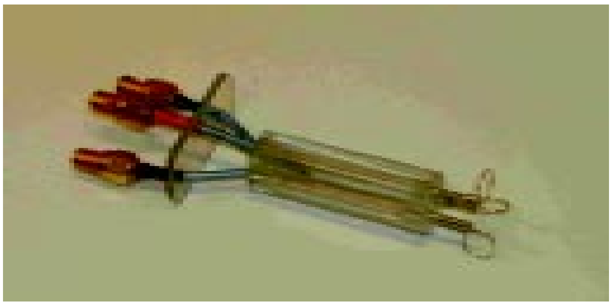


Figure 7: *Magnetic field probe for all three field components.*

The tabletop high voltage equipment TTHPM has also been used for research on high voltage generation. This is a continuation of the previous work conducted in this area. The experiences gained have led to improvements of the construction. A capacitive voltage probe has been constructed for contact free measurement of the generated voltage. The maximum voltage achieved is about 150 kV and is limited by electric flashovers in the system.

Along with experiments, simulation of electromagnetic key features has been initiated to support the fundamental understanding and improvement of the radiation sources and the high voltage generating equipment. For example, it is important to have a comprehensive knowledge of spark gap physics for controlling the rise time and amplification of the high

voltage pulse in the TTHPM system.
Besides the project work, a preliminary study on "HPM"-warhead was performed on which a RF demonstrator will be based.

6. Research on Computational Physics

Scientific computing is a powerful tool when designing or modifying military equipment, evaluating tactical situations, examining performance characteristics of military systems or platforms as well as for increasing the basic knowledge of related physical and chemical phenomena. The Computational Physics group at the Dept. Warheads and Propulsion is an inter-divisional group of researchers focusing on development of state-of-the-art computing methods and tools mainly for flow simulation and modeling.
Our internationally well-established research in LES modeling of turbulent flow has continued during 2001. In particular we have focussed on alternative methods for LES with the overall aim of addressing engineering problems with LES. Currently, we are pursuing two conceptually different approaches:
the use of Monotone Integrated LES (MILES) methods in collaboration with LCP & FD at NRL in Washington DC in USA, the use of homogenization-based methods to derive self-consistent and realizable LES models in collaboration with the Environment and Protection group at the Dept. of NBC Defence, and the Dept. of Mathematics at Chalmers University of Technology.
Within the area of reacting flows the research during the past year has focussed on further improving the flame-wrinkling model for premixed combustion, and extending the use of this model to partially premixed and non-premixed combustion systems. To illustrate the use of this model, figure 8 shows a snapshot of the flow and flame dynamics in a gas-turbine combustor.

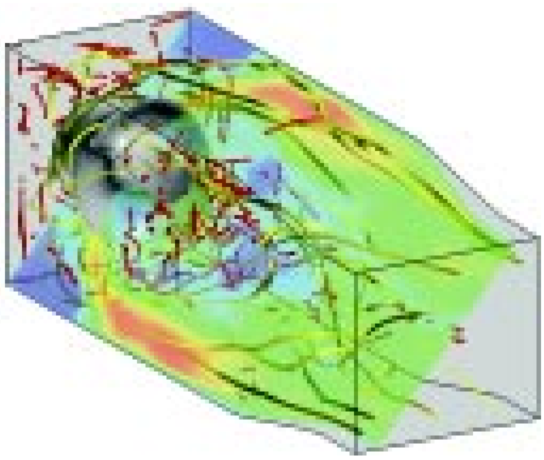


Figure 8: Perspective view from the rear end of the GELM6000 combustor showing streamlines released from the inlet (yellow), vortex cors (red), an iso-surface of the reaction coordinate representing the flame, and contour lines of the axial velocity on the inclined plane.

Comparisons between predictions and measurement data show good agreement, suggesting that the model developed can also successfully handle engineering problems.

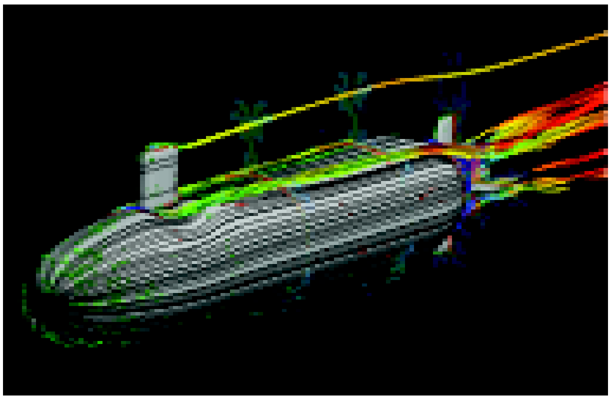


Figure 9: Flow around a modern attack submarine in terms of streamlines showing the horseshoe vortices from the sail and the rudders, contours of the vorticity magnitude at four cross-sections astern of the sail, and the surface flow pattern in terms of surface streamlines (black), separation lines (red) and reattachment lines (green).

Other research issues in the field of computational combustion that have been addressed during 2001 concern solid rocket motor combustion, and fire spread in buildings. Both these research projects are run as PhD projects together with Lund Institute of Technology.
Our internationally renowned work in the field of naval hydrodynamics has continued during 2001 with improved flow modelling and incorporation of additional physics in order to enhance our capabilities in predicting signatures.
A very important area of research is that of methods for moving boundaries and geometries. Our research in this area concerns development of 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. So far we have developed an ALE (Arbitrary Lagrangian Eulerian) method, and in collaboration with LTH a Volume Of Solid (VOS) method has been developed. These methods are presently undergoing validation tests, and we believe that during 2002 we can put them in production.

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 was formed in 1999 and has been located at Grindsjön Research Centre since 2000, partly through a relocation from the former Märsta and Ursvik sites. The personnel constitutes a fine mix between experienced and recently recruited persons, and the number of employees was 22 at the end of the year. Of these, 17 are researchers and 5 technical and administrative staff.

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 2001 a large number of projects have been carried out and presented as reports and publications, and at symposia and conferences around the world. Some of the project activities are described here below.

Fire

Main focus of the fire research activities during 2001 has been on further development and testing of a method for performing non-destructive smoke spread tests in new and existing buildings.

The method is based on a heat source generated by means of burning methanol in different size steel trays cooled by water. Several tray sizes are available to cover fire sources up to nearly 1 MW. The smoke is supplied by means of a suitable number of smoke generators that produce a smoke, which can be described as a non-toxic aerosol. The advantage of the method is that it provides a means for performing non-destructive tests in already existing buildings and other installations for the purpose of evaluating the functionality and design of the active fire protection measures such as smoke extraction systems etc.

There has also been a possibility to evaluate the method from a number of applied tests in for example large meeting places and sections of the Royal Castle. Figure 1 shows the development of the smoke layer during one test.

***Figure 1.** Development of smoke layer during smoke spread test in a large meeting place.*

Further, a number of less comprehensive investigations and experimental work has been performed throughout the year in order to evaluate certain risks associated with specific activities. For example various consequence analysis work has been done to evaluate fire and smoke spread on industrial premises.

Fortification

The large scale testing at the shooting range of Älvdalen have been continued during 2001, by direction of the Swedish Armed Forces Headquarter and the Singapore Defence Science and Technology Agency. This is further described in a separate section of this annual report.

During the year the department has continued the work initiated 2000 regarding the co-operation with Norway

(FFI and HFK-AMK), with the mutual purpose to further develop the risk analysis model AMRISK. AMRISK calculates individual and collective risk for the general public (third person) in the vicinity of an ammunition storage in the case of a detonation.

The department has developed a model for classification and assessment of exposed objects existing protection against burglary, sabotage and terrorism. The work was carried out under contract to the Swedish Agency for Civil Emergency Planning (ÖCB).

Under contract to the Headquarters of the Swedish Armed Forces the department has made tests where materials and combinations of materials, which are part of the covering of a fortification in ground, were exposed to shaped charges. 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.

Materials

Activities in the Materials group have been focussed on dynamical material properties and on synthesis of future materials for ballistic protection, together with a wide range of other issues surrounding characterisation and modification of materials and their properties, for various applications.
A Spark Plasma Sintering project was initiated during 2001 for the tailoring of novel materials, such as nanostructured and gradient, which is described in more detail in a separate section in this annual report.

The equipment in the field of dynamic material properties includes a commercial servohydraulic testing frame, together with apparatus for torsional and tensile Hopkinson experiments as well as an induction heater for mechanical testing at elevated temperatures. During 2001 the competence has been extended to initial studies of dynamic indentation characterisation of ceramics.

Simulation

Structural protection for stationary and mobile tactical behaviour

The activities for the project "Structural protection for stationary-mobile behaviour" focus on the use of advanced material models and numerical simulations to describe structural behaviour during dynamic events, penetration in concrete and penetration of steel armour. Modelling of materials subjected to weapons effects has been a major area of interest for a long time, and several material models to describe the material behaviour at high pressure and high strain rates are developed. However, it is not until recent years with the development of advanced material models that can be used together with the numerical ALE, Euler or SPH (Smooth Particle Hydrodynamics) formulations that it seems possible to model the behaviour of materials during penetration with an acceptable result. The objectives for the project are to develop methodology and tools to predict and determine weapon effects on protective structures.

Perforation of concrete was studied with the use of Autodyn version 4.2 with the RHT model from EMI implemented. This material model shows promising behaviour for penetration/perforation simulations. Numerical simulations with Lagrange, Euler and SPH formulations were compared with earlier performed benchmark tests of projectile perforation of concrete, and the strengths as well as weaknesses of the formulations were studied. The damaged areas for the different models are shown in figure 2 below.

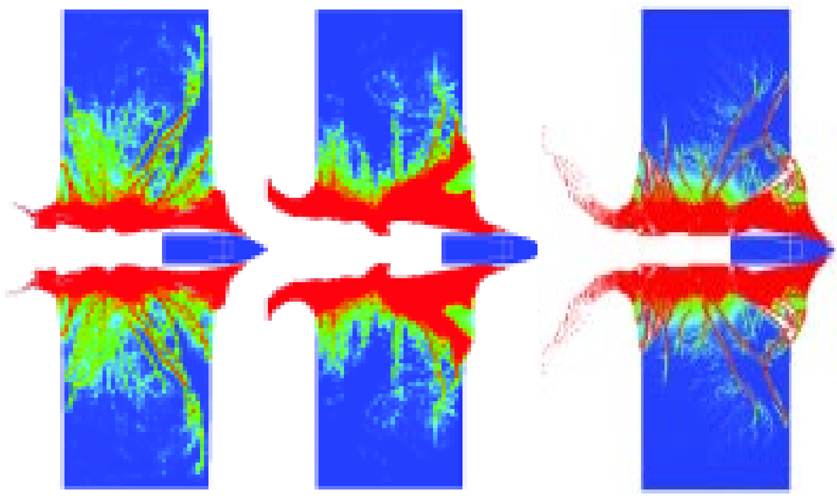


Figure 2. Calculated damage contours for Lagrange, Euler and SPH models.

A study of the possibilities to determine penetration depths and ballistic limits for steel armour with the use of numerical models was conducted. Autodyn versions 4.1 and 4.2 were used together with the Johnson & Cook (J&C) material model to study the possibilities to model perforation of steel armour numerically. Strength parameters for the J&C model were determined from mechanical tests performed at FOI on high nitrogen alloyed steel (HNS) material and used for the simulations. Earlier performed ballistic tests with armour piercing small arms ammunition against HNS were used for comparison with the perforation simulations. It was shown that the ballistic limit of the HNS material was described by the model with an acceptable degree. However, the perforation models are very sensitive for the value of the used erosion strain in the material model for the Lagrange formulation. A numerical formulation with a fixed mesh or a mesh-less formulation is necessary to avoid the problems caused by heavily distorted elements during penetration calculations. However, the meshless formulation SPH was also used and this method was considered to be inadequate to describe the large tensile strains in the model during perforation.

Structural response was studied with the explicit FEM code LS-Dyna and the K&C (Karagozian and Case) concrete model. This model was earlier used to study air blast induced structural response at FOA, and the material model was further developed during the last year. Earlier performed drop weight tests on reinforced concrete beams were used for comparison with the numerical simulations. However, the numerical model was not able to describe the local induced loading in the contact area of the concrete beam. The overall behaviour of the beam was on the other hand predicted to an acceptable degree.

Crystal plasticity

The development of a new simulation tool called KRYP was initiated during 2001. KRYP is a finite element program for meso-mechanical crystal plasticity simulations. The theory is based on a continuum mechanical approach, where dislocations are treated as field variables.

The objective of the ongoing development project is to reach a state where KRYP becomes a useful tool for predictions of grain interaction characteristics and texture formation properties in the process of developing new materials.

Even though there is a lot of work ahead, KRYP is actually already a fully functioning explicit finite element code (5000 lines of Fortran 90) with some unique capabilities:

- It contains an advanced FCC crystal plasticity model that is coupled to a set of equations controlling the flux of dislocations generated by plastic flow. This feature enables the analysis of grain size and grain geometry effects.

- KRYP works with a non-local grain orientation control, enforcing a uniform crystal orientation. Regular, spatially local, plastic flow laws can not correctly predict the activation of correct glide mechanisms.

- Integration points of severly deformed brick elements are moved towards the element centers in order to avoid material inversion. The technique allows the use of selectively reduced integrated elements at extremely large strains.

The current focus of the project is to benchmark the code against experimental data.

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, 24 persons, which is the same number as a year ago.

The “Armour” group of the department consists of fourteen persons, working on the projects “Armour and projectiles”, “Lightweight armour” and “Active armour”. 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 Dr. 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 seven persons, comprising the projects “Vulnerability and lethality assessment” and “Human vulnerability criteria”.

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

Armour and projectiles

The focus of the research on armour protection against heavy KE threats has been on passive and reactive armour components to defeat long rod projectiles at velocities up to 2 km/s. Especially ceramic and reactive armours have been considered.

The work on ceramic armour was concentrated on the interface defeat phenomenon, which is described in more detail in a separate section of this annual report. The experimental studies and the effort to model the pressure exerted by a long rod penetrator and the stress-strain state in the ceramic material has continued. Using a slightly modified experimental design, we showed that the ceramic material can sustain interface defeat for hundreds of microseconds.

The basic mechanisms of reactive armour have been investigated by studying a long rod projectile hitting a moving oblique plate. This is studied experimentally using the kinematically equivalent case of an oblique plate hitting a yawed penetrator (reverse impact experiments). Experiments to study the influence of the angle and velocity of the plate have been carried out. Numerical simulations of the interaction between the plate and a long rod penetrator have been compared to the experimental results. A major problem is to model the fracture of the projectile correctly and new numerical techniques (SPH) have been tried. Together with the experimental results, this should enable reliable predictions of the capability of many different types of reactive and active armours.

An experimental study of how a double plate electromagnetic armour interacts with long rod penetrators has been carried out (static model scale experiments) together with a theoretical study of how different response parameters scale with the size of the penetrator. The influence of projectile material, dimensions and geometry (smooth versus threaded projectile) has been evaluated for small scale, static experiments and predictions to dynamic full scale cases have been made.

Figure 1: *EM armour experimental set up. Note cables from the pulsed power supply in the lower left and voltage probe to the right*

Figure 2: *Cardboard with splash and burn marks of transversely accelerated rod in EM armour experiment. Note the trace of rod and current arc along the lower armour plate. Upper plate is removed.*

A review of the unclassified literature on the performance of telescopic penetrators in homogeneous targets has been made and continuum dynamic simulations of the interaction with stationary and moving oblique plates have been carried out.
A summary of the performance of various types of armour against heavy KE-threats has been made.

Lightweight armour

As armour-piercing projectiles from small calibre weapons are a growing threat, the efforts have concentrated on the possibilities to obtain protection against this kind of threat. There are different types of armour-piercing projectiles and their penetration capability differs a lot. AP-projectiles with tungsten-carbide cores are supposed to increase in numbers. The penetration capability of this kind of projectile is so good that it might constitute a very severe threat against most lightly armoured vehicles.

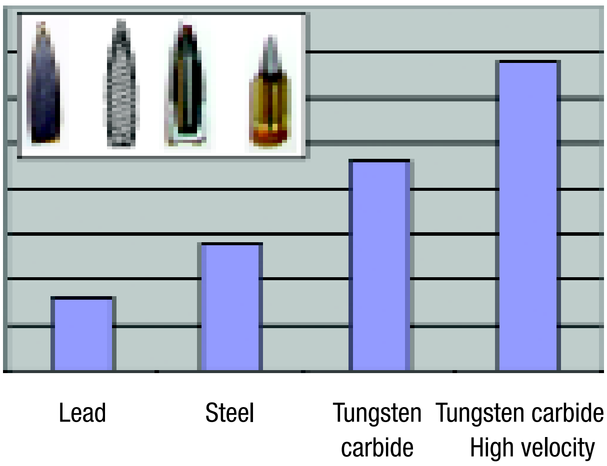


Figure 3: *Difference in penetration capability between different types of projectiles in the same calibre.*

The problem from a protection point of view is mainly that the strength of the projectile core is so high that it penetrates homogeneous armour materials without deforming at all, which is very good for the penetration capability. Additionally the projectile velocity for new kinds of small calibre tungsten-carbide projectiles increases to the same range as that of medium calibre projectiles.

To defeat these armour-piercing projectiles one has to use materials with extreme strength properties as well as solutions based on geometrical disturbances. To utilize the potential of these new materials in armour constructions, interaction with other materials is often needed. For instance one might use backing and confinement materials when using very hard and brittle armour materials and the choice of matrix material in composite materials can be of large importance.

It has been found out that the material group with the best potential to overcome the strength of tungsten-carbide penetrators is ceramics. Some high quality ceramic materials, combined with suitable backings and/or confinements are, in principle, capable of defeating these projectiles on the surface of the ceramic. The main task in this area is now to obtain a lightweight backing that is stiff enough to make the ceramics perform in that way. The first attempt to achieve that is to produce a combined ceramic/metallic tile of sintered materials were the frontal part of the tile consists of ceramic material and the rear part of metallic backing material.

Another way to break up the projectile is to transfer geometrical disturbance to the projectile. There are a lot of construction possibilities available to do this. We have tried to sort out which parameters are of importance in this case. We have studied the influence of material, thickness and obliquity of a thin plate in front of the basic armour and found that this kind of exterior armour can be made very weight effective.

To realize better lightweight armours we continuously improve the methods for dynamic material testing and registration of ballistic events. We measure the material properties for the materials involved in order to use these results in the constitutive modelling needed for the numerical simulations to be relevant. In the ballistic testing great efforts are taken to register the penetration processes so that relevant comparisons with the simulated results can be made.

Figure 4: *Test set-up for small calibre experiment. The projectile is fired into a tank equipped with different types of registration apparatus primarily for measuring velocity and to register the penetration event in the target and after penetrating the target.*

Active Protection

Active protection systems are a promising concept for countering various of threats against armoured vehicles such as KE projectiles, anti-armour missiles, handheld AT weapons, smart artillery munitions and anti armour bomblets.

In the Active Protection project, sensors and hard kill countermeasures are studied for the purpose of active defeat of incoming weapon threats. These protection systems are mainly studied as a component in the ballistic protection of armoured vehicles, but the concepts may also be of interest for protection of fixed military installations against hard target bombs.

The main focus during the last years has been on defeating long rod, kinetic energy penetrators, since these pose the greatest challenge to both sensor systems and defeat mechanisms.

During 2001, sensor studies have been performed within the areas of radar sensors, signal processing, algorithms for trajectory computations, measurement of dynamic radar signature (KE), IR-sensors and IR system aspects.

Within the area of countermeasures, a large number of numerical simulations have been carried out to investigate various launch techniques as well as the interaction between countermeasures and projectiles.

Vulnerability and lethality assessment

Assessments of platform vulnerability to weapons effects and weapons effects on platform systems are of essential value in materiel design, procurement and refurbishment processes as well as in war gaming prior to deployment of armed forces in outright war or participation in international joint Peace Support Operations.

To ensure qualitative assessments, there are needs of understanding of specific operational environments, threats related to the environments, design of specific weapons and platforms designs and fundamental physical understanding of relevant weapons effects. For the actual kind of assessments, all kinds of effects from conventional warheads (including underwater warheads) are of importance.

Extensive theoretical and experimental work has been carried out to develop physically based models for use in vulnerability assessment codes. Special attention has been paid to effects like Behind Armour Debris (BAD), blast effects in confined spaces and underwater shock.

A “fire and smoke spread” module in the Swedish vulnerability assessment code “AVAL” (formerly known as “LIBRA”) has been verified and validated. To some part, this work has been carried out in collaboration with Prins Maurits Laboratory / TNO in the Netherlands. The work on fire and smoke has been complemented by CFD-calculations by use of a LES-code.

For vulnerability and lethality assessments purposes, target and warhead descriptions compatible to “AVAL” has been produced.

Figure 5: *Experimental water tank set-up for BAD study.*

Weapons effects on humans

The subject “weapons effects on humans” is very broad. Only a few aspects of this subject are studied within the project. The focus is on physical instead of medical matters, since the latter are dealt with in the other projects in the "weapons trauma" research area. Physical models of weapons effects on biological material are required as an input to large computer programs for assessment of effects and vulnerability for complex targets, in which personnel are vital components. The general intention of the project is to develop new models and improve old models.

Experiments in gelatine have shown that projectiles with the same mass, diameter and velocity penetrate differently deep depending on the shape of the impact end. Sharp-nosed projectiles reach the greatest depths but do not go straight. Round-nosed projectiles reach greater depth than flat-nosed projectiles and both go straight. A simple mathematical model describes the penetration depth with reasonable accuracy. The density and a strength parameter characterize the target material. A drag coefficient characterizes the nose shape of the projectile. The mathematical model yields the transmission of kinetic energy to the target material along the penetration trajectory. Energy transmission is often assumed to be the most significant physical measure of damage to biological material.

When fragments are produced the plastic deformation heat in the material corresponds to temperatures that are many hundred degrees centigrade. The heat energy in the fragments is typically ten times greater than the kinetic energy. This effect has not yet been accounted for in human vulnerability assessment.

Two methods for human vulnerability assessment, namely the computer program ComputerMan and the witness plate pack NATO Unprotected Man, have been studied. In the former method there is a rule for how penetration depths for projectiles with non-standard shape shall be calculated. This rule gives very wrong results for projectile penetration in gelatine, which is generally assumed to be a good substitute for living biological material. In the second method the kill probability only depends on the penetration depth but not on the calibre of the projectile. It is concluded that neither method presently can be used to determine human vulnerability in the Swedish Armed Forces vulnerability program AVAL (previously Libra).

Impulse noise around a rifle (PSG 90) has been measured and compared with theoretically calculated values. At this stage agreement is far from good. It is believed that a much finer mesh, and consequently much longer calculation times, if numerical calculations shall become an alternative to experiments in this field.

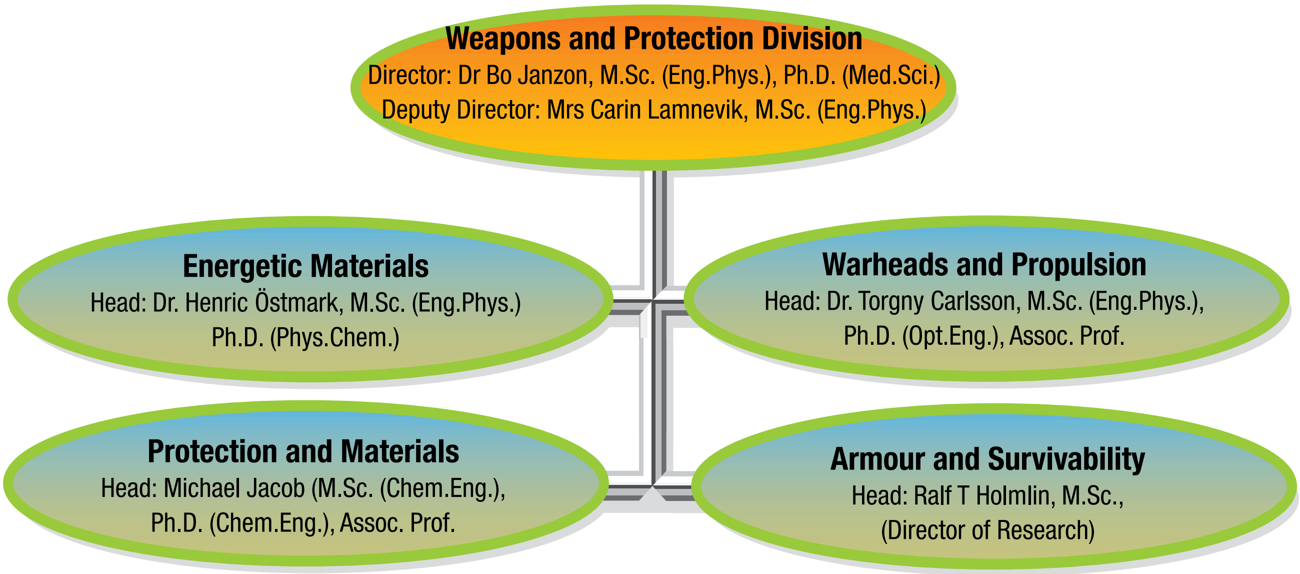
Adaptable effects

The Project has been concentrated to scan usable less-lethal technologies as a background to the Defence Forces studies in problems concerning activities and reliable rules of engagement in Peace Support Operations (PSO) as result of an analysis of estimated scenarios. Policies and decisions about when this type of effects will be permitted are very important for further work and definition of the problems.

Within the frames of the "FoRMA"-study it is possible that the subject will include a wider area of weapon effects. Effects witch is tailored to the target in terms of armour, weakness points, risk for collateral damage etc.
During FY 2001 FOI has made some experimental studies of some cal. 60 and cal. 12 rounds.

FOI participated in September in the "1st European Symposium on Non-Lethal Weapons" in Ettlingen, GE. The problem was seen from a holistic point of view, including besides legal, medical and psychological as well as technical aspects.

Organisation, management and personnel



The Division employs about 115 persons. It is served by a unit of FOI's Administrative Division, in total about 30 persons. This unit comprises mess and housekeeping, mechanical workshop, service units, field and construction service, transports and heavy machinery.

Location and facilities

The division is located at the Grindsjön Firing Range, about 40 km south of Stockholm.

Facilities at the Grindsjön Firing Range are:

- 7,5 km^2, 23000 m^2 buildings
- ab. 10 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

Cooperation

The division interacted and cooperated with numerous organisations, institutions and companies in Sweden, like:

- Universities and Institutes of Technology
- Military authorities and Schools
- FMV - Swedish Defence Materiel Administration
- ÖCB - the Swedish Agency for Civil Emergency Planning
- SRV - Swedish Rescue Services Agency
- Defence Industries

There were well established contacts and cooperations, formal and informal, with universities and research organisations in many countries, such as Australia, Canada, Finland, France, Germany, Netherlands, Norway, Russia, Singapore, Switzerland, UK and USA.

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. 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. Bo Janzon
- EUROLAB (Organisation for testing in Europe), represented by Dr. Magnus Oskarsson
- European Electromagnetic launch Society (EEMLS), represented by Sten E Nyholm
- OECD-IGUS International Group of Experts on Unstable Substances. National Representative was Stefan Lamnevik
- Swedish Process Safety Promotion Association (IPS). Representative was Stefan Lamnevik, who was also the Manager of IPS
- 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

and other national and international organisations.

Economy

Revenues/Customer	Revenue 2001
Defence Forces (1)	62 %
Defence Forces, other	4 %
FMV	9 %
ÖCB/SRV	3 %
Others	22 %
TOTAL	**100 %**

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

The annual turnover of the division for 2001 was ab. 145 MSEK

Quality

This year a major step was taken towards the idea of Total Quality Management. A plan for performance excellence was set up containing an overview of the division according to the Swedish Institute for Quality (SIQ) model for performance excellence. Goals for improvements, sorted into seven sub-areas were set up. The plan was presented to the division's entire staff at a series of seminars and work was executed during the year to fulfil the goals for improvements. A basis for next year's plan was collected through a series of seminars at all levels of the organization and through an analysis using the SIQ-model.
In November the Director-General decided that the Quality Management System SS-EN ISO 9001:2000 will be implemented at FOI. The deadline for the implementation is set to 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 2001. The plan included energy saving and education of all employees. The energy consuming has increased about 4%/employed and year. To strongly decrease our oil consumption we have done an investigation to use heat pumps which take the energy from the ground. The investigation shows that it is very economy to introduce heat pumps and it is in our plan for the next two years that to have a system running.

About 75% of the employees have got environment education. Half a working day, for all employees at Grindsjön was dedicated to clean up in old store rooms and the forest near the centre. We have engaged about 20 sheep from a nearby farmer, to get open landscape around the centre and the farmer also let three calves be around the bird pond, which also inhabit a few beavers. We have a new environment plan for year 2002.

Working environment

The division closely follows up the work environment to conform to all laws, ordinances and directives. The division also strives for a work environment free of accidents and health hazards.

In the beginning of the year all employees were informed about the work plan of the work environment committee, which is operated jointly with the FOI Administrative Division to cover all of Grindsjön, plus other sites where the Weapons and Protection Division has activities.

- Those in charge of working with development of the work environment (director, dep. director, department heads, project managers and safety representatives) have attended a three-day education held by TBV.

- Own personnel from the Division have, with the assistance of a fire consultant, held an exercise in fire protection and escape and firefighting training. As part of this education a presentation was made of documented faults in the fire security including proposed ways to amend these.

- The division's health care provider, Previa, has organised:
  - heart- lung resuscitation education and training
  - an orientation in the use of the exercise equipments in the Grindsjön Gym ("feel-good" room)
  - TBE and Influenza vaccinations

- In accordance with the enactments from the Work Environment Authority, routines and plans for action has been put to print for:
  - equal opportunities in the work place
  - demeaning special treatment
  - planning for and handling of crisis situations

- The health venture of last year has continued offering the employees a wide variety of activities.

- The work with the work environment is included as a natural part of all activities. As a part of this work, regular meetings at the place of work, staff conversations and rounds of precautions have been held.

Acknowledgement

Many persons have contributed to this report, including Dr. Bo Janzon, Mrs. Carin Lamnevik, all Department Heads and many Project managers.

Scientific Articles and Reports, Conference Papers

Appelgren P., Nyholm S. E., Skoglund M., Double plate electromagnetic armours KE-projectiles: static model scale experiments and consideration of scaling. Stockholm, FOI 2002. FOI-R—0202—SE. (Scientific report)

Bergman H., Eldsäter C., Goede P., Holmberg E., Wingborg N., Östmark H., Conference papers of the 32nd International annual conference of ICT. Karlsruhe, Germany 2001. Stockholm, FOI 2001, 41 p. FOI-S—0274—SE.

Bittererova M., Brinch T., Östmark H., Theoretical study of the singlet electronically excited states of N_4. Stockholm, FOI 2001, 7 p. FOI-S—0271—SE. (Chemical Physics Letters 340 (2001) pp. 597-603.)

Bittererova M., Östmark H., Brinck T., Ab inito study of the ground state and the first excited state of the rectangular (D2h) N_4 molecule.Stockholm, FOI 2001, 9 p. FOI-S—0272—SE. (Chemical Physics Letters 347 (2001) 220-228.)

Delin M., Walmerdahl P., Full scale fire tests with a double skin glass façade. Interflame 2001. Edinburgh, Skottland 2001. Stockholm, FOI 2001, 13 p. FOI-S—0195—SE.

Delin M., Walmerdahl P., Hot smoke test – ett sätt att utvärdera brandskyddet. Stockholm, FOI 2001, 4 s. FOI-S—0194—SE. (Publ. i Bygg och teknik, 6/01, 55-59.)

Goede P., Wingborg N., Bergman H., Latypov N. V., Syntheses and analyses of N,N'-Dinitrourea. Stockholm, FOI 2001, 4 p. FOI-S—0018—SE. (Propellants, Explosives, Pyrotechnics 26, 17-20 (2001)

Hansson H., Numerical simulation of air blast. In: Proceedings of the 10th international symposium on interaction of the effects of munitions with structures. May 2001. Stockholm, FOI 2001, 13 p. FOI-S—0207—SE.

Janzon B., Lamnevik C., Lamnevik S., Östmark H., Energetics research at FOI, Sweden. In: Intensive Munitions and Energetic Materials Symposium, arranged by EUROMURAT and NDIA. Bordeaux, France. 08-11 October 2001. Stockholm, FOI 2001, 13 p. FOI-S—0181—SE.

Latypov N., Goede P., Bemm U., Wingborg N., Langlet A., Conference papers of IMEMTS 2001. Bordeaux, France 2001. Stockholm, FOI 2001, 25 p. FOI-S—0275—SE.

Lundberg P., Renström R., Holmberg L., An experimental investigation of interface defeat at extended interaction time. Proc 19th Int. Symp. on Ballistics, Switzerland 2001.

Lundberg P., Renström R., Westerling L., Transition between interface defeat and penetration for a given combination of projectile- and ceramic material. PAC RIM 4 Int. Conf. on Advanced Ceramics and Glasses. Hawaii 2001.

Lundberg P., Renström R., Inverkan av projektilspetsen på möjligheten att erhålla "interface defeat" med kerampansar. Stockholm, FOI 2001, 15 s. FOI-R—0141—SE. (Scientific report in Swedish)

Magnusson J., Hallgren M., High strength concrete beams subjected to shock waves from air blast – experimental results. In: Proceedings of the 10th international symposium on interaction of the effects of munitions with structures. May 2001. Stockholm, FOI 2001, 9 p. FOI-S—0206—SE.

Pettersson A., Oskarsson M., Petersson J., Gradient- och matrismaterial – en litteraturstudie. Stockholm, FOI 2001, 30 p. FOI-R—0128—SE. (Scientific report)

Sandén R., Castable silicone based heat insulations for jet engines. Stockholm, FOI 2001, 4 p. FOI-S—0281—SE. (In: Polymer Testing 21 (2002) 61-64.)

Tegnér J., An introduction to the pulse detonation engine. In: Novel aero propulsion systems international symposium. London, September 4th 2000. Stockholm, FOI 2001, 12 p. FOI-S—0057—SE.

Tegnér J., Dynamic parameters in detonations. In: USAF Edwards AFB, December 6th 2000. Stockholm, FOI 2001, 35 p. FOI-S—0058—SE.

Tegnér J., Swedish PDE-program. In: Proceedings of the Fourteenth ONR propulsion meeting. Chicago, August 8-10 2001. Stockholm, FOI 2001, 9 p. FOI-S—0059—SE.

Unosson M., A review of methods of analysis for problems of penetration, field theory and constitutive equations. Stockholm, FOI 2001, 26 p. FOI-R—0126—SE. (Scientific report)

Unosson M., Numerical simulations of the response of reinforced concrete beams subjected to heavy drop tests. In: Fourth international symposium on impact engineering (ISIE/4). Stockholm, FOI 2001, 8 p. FOI-S—0090—SE.

Wallin Ss., Östmark H., Synthesis Efforts and Detection of N^4 in Nitrogen Matrices. Posterbidrag på ”Matrix 2001”. Szklarska Poreba, Polen, 7-13 july 2001. Stockholm, FOI 2001, 2 p. FOI-S—0273—SE.

Westering L., Lundberg P., Lundberg B., Tungsten long-rod penetration into confined cylinders of boron carbide at and above ordnance velocities. Stockholm, FOI 2001, 12 p. FOI-S—0113—SE. (In: International Journal of Impact Engineering 25(2001)703-714)

Wijk G., En enkel teoretisk modell för beräkning av deformationen av ett fordons bottenplåt vid en minexplosion. Stockholm, FOI 2001, 11 s. FOI-R—0087—SE. (Vetenskaplig rapport)

Wijk G., Collin Å., Rigid projectile perforation of target plates. Stockholm, FOI 2001, 37 p. FOI-R—0110—SE. (Scientific report)

Östmark H., Bemm U., Bergman H., Langlet A., N-guanylurea-dinitramide: a new energetic material with low sensitivity for propellants and explosives applications. Stockholm, FOI 2001, 7 p. FOI-S—0243—SE) (In: Thermochimica Acta 6866 (2001) 1-7.)

Östmark H., Launila O., Wallin S., Tryman R., On the possibility of detecting tetraazatetrahedrane (N^4) in liquid or solid nitrogen by Fourier transform Raman spectroscopy. Stockholm, FOI 2001, 5 p. FOI-S—0017—SE. (Journal of Raman spectroscopy, 2001;32:195-199)

Customer Reports

Unclassified

Andersson K., SOFRAM – Rapport av kompletterande skjutförsök år 2000, samt tillbakablickar och framåtblickar. Stockholm, FOI 2001, 40 s.
FOI-R—0241—SE. (Underlagsrapport)

Andreasson S., Bemm E., Nyholm S. E., Resultat och erfarenheter från forskning inom ETK-området. Stockholm, FOI 2002, 18 s. FOI-R—0299—SE. (Användarrapport)

Berglund M., On the development of a computational tool for interior ballistics simulations. Stockholm, FOI 2002, 15 p. FOI-R—0308—SE. (Base data report)

Bergman H., Eldsäter C., Östmark H., FOX-7 formulering: Del 1. Stockholm, FOI 2001, 9 s.
FOI-R—0195—SE. (Underlagsrapport)

Bergman H., Östmark H., Holmgren E., Wingborg N., FOX-7 stabilitet: Del 2. Stockholm, FOI 2001, 11 s. FOI-R—0067—SE. (Användarrapport)

Carlsson T., Dyhr K., Johansson M., Lamnevik S., Destruktion av rökgranater under vatten. Stockholm, FOI 2002, 20 s. FOI-R—0280—SE. (Användarrapport)

Elfving C., Carlberg A., Kristoffersson G., Bergman C-G., Svedbjörk G., Försök med luftstötvåg mot kylkrets till skyddad anläggning. Stockholm, FOI 2001, 42 s. FOI-R—0037—SE. (Teknisk rapport)

Elfving C., Carlberg A., Olsson L G., Försök med eldhandvapen mot lätt befästning. Stockholm, FOI 2001, 22 s. FOI-R—0036—SE. (Teknisk rapport)

Elfving C., Magnusson J., Modell för klassificering och värdering av skyddsobjekt. Stockholm, FOI 2001, 19 s.
FOI-R—0079—SE. (Underlagsrapport)

Eriksson J., Nilsson M., Pettersson A., Skoglund P., Vrid-Hopkinson – en metod för snabba skjuvbelastningar. Stockholm, FOI 2001, 53 s.
FOA-R—00-01775-310—SE. (Metodrapport)

Fast L., Tryckverkan i slutna volymer. Stockholm, FOI 2001, 22 s. FOI-R—0145—SE. (Teknisk rapport)

Fureby C., Almström H., Hull induced noise. Part 1: Hydrodynamic noise produced by the turbulent flow around a rigid hull. Stockholm, FOI 2001, 23 p.
FOI-R—0130—SE. (Base data report)

Fureby C., Berglund M., Lillberg E., Wijk G., Towards the accurate simulation of shock-waves around weapon systems. Stockholm, FOI 2001, 20 P.
FOI-R—0129—SE. (Base data report)

Hansson H., Skoglund P., Numerical simulation with Euler and Lagrange formulations. Stockholm, FOI 2001, 66 p. FOI-R—0190—SE. (Technical report)

Hansson H., Modelling of steel behavior with application to armor penetation. Stockholm, FOI 2002, 30 P. FOI-R—0201—SE. (Technical report)

Hansson H., Skoglund P., Unosson M., Structural protection for stationary/mobile tactical behaviour 2001. Stockholm, FOI 2002, 71 p.
FOI-R—0281—SE. (User report)

Helte A., On calibrating reaction rate laws using detonation shock dynamics. Stockholm, FOI 2001, 14 p.
FOI-R—0151—SE. (Methodology report)

Helte A., Edvinsson H., Hahma A., Framtagning av brinnmodell för ammoniumdinitramid. Stockholm, FOI 2001, 14 s. FOI-R—0071—SE. (Underlagsrapport)

Helte A., Lillberg E., A comparison of potential and viscous flow models for pressure signature computations. Stockholm, FOI 2001, 10 p.
FOI-R—0140—SE. (Base data report)

Holmberg L., Teleskopprojektiler. Stockholm, FOI 2001, 25 s. FOI-R—0213—SE. (Användarrapport)

Holmberg L., Ballistiska skydd mot tunga KE-hot. Stockholm, FOI 2001, 14 s. FOI-R—0333—SE. (Användarrapport)

Janzon B., Wahlgren K., (Editors), Weapons and protection division. Annual report 2000. Stockholm, FOI 2001, 40 p. FOI-R—0065—SE. (Progress report)

Latypov N., Goede P., Chemical Building Blocks Part 2: Nitroform. Stockholm, FOI 2001, 9 p. FOI-R—0276—SE. (Base data report)

Launila O., Östmark H., Tryman R., Walllin S., The N_4 project. Report for the first quarter of 2001. Stockholm, FOI 2001, 39 p. FOI-R—0127—SE. (User report)

Launila O., Tryman R., Petri G., Östmark H., Wallin S., Pettersson A., The N_4 project. Activity report for the first half of the year 2001. Stockholm, FOI 2001, 59 p. FOI-R—0160—SE. (User report)

Lundberg P., Johansson B., Andersson O., Modellförsök med KE-projektiler: Inverkan av projektilgeometrin vid penetration av snedställd plåt. Stockholm, FOI 2001, 20 s. FOI-R—0274—SE. (Användarrapport)

Magnusson J., Unosson M., Carlberg A., High performance concrete "HPC"-field experiments and production. Stockholm, FOI 2001, 166 p. FOI-R—0256—SE. (Technical report)

Nilsson M., Westerling L., Skoglund P., Karaktärisering/simulering av hårdmetallprojektiler. Lägesrapport. Stockholm, FOI 2001, 17 s. FOI-R—0296—SE. (Användarrapport)

Oskarsson M., Lundberg P., Lägesrapport – Nya sammansatta keramer. Stockholm, FOI 2002, 13 s. FOI-R—0303—SE. (Lägesrapport)

Pettersson J., Mikrostrukturell undersökning av WniFe-stavar. Stockholm, FOI 2001, 11 s. FOI-R—0093—SE. (Metodrapport)

Pettersson A., Översikt över hur laser och NQR kan användas i minröjningssammanhang. Stockholm, FOI 2001, 16 s. FOI-R—0301—SE. (Teknisk rapport)

Pettersson A., 7nde ECERS-konferensen i Brugge. Stockholm, FOI 2001, 15 s. FOI-R—0193—SE. (Användarrapport)

Pettersson A., Besök vid Kennametal Hertel AG. Stockholm, FOI 2001, 14 s. FOI-R—0253—SE. (Användarrapport)

Sandén R., Aluminised gelled fuels for ramjets. Introductory experimental studies. Stockholm, FOI 2001, 17 p. FOI-R—0183—SE. (Base data report)

Sandén R., Borinnehållande drivämnen i rammotorer – ett högaktuellt område. Stockholm, FOI 2001, 24 s. FOI-R—0153—SE. (Underlagsrapport)

Sarholm L., En sammanfattning av US General Accounting Office utvärdering av USA:s forskning avseende detektion av landminor. Stockholm, FOI 2001, 13 s. FOI-R—0279—SE. (Underlagsrapport)

Skoglund P., Pettersson A., Studier av riktade volframrhenium-legeringar. Stockholm, FOI 2001, 19 s. FOI-R—0254—SE. (Användarrapport)

Tegner J., Experiment on predetonators for PDE's. Stockholm, FOI 2001, 15 p. FOI-R—0123—SE. (Technical report)

Tegner J., Olsson S., Multi cycle experiments on a pulse detonation engine. Stockholm, FOI 2001, 23 p. FOI-R—0135—SE. (Technical report)

Unosson M., Modelling of concrete material behaviour with application to reinforced concrete beams subjected to impact. Stockholm, FOI 2001, 34 p. FOI-R—0167—SE. (User report)

Walmerdahl P., Werling P., A method for smoke spread testing of large premises. Stockholm, FOI 2001, 25 p. FOI-R—0046—SE. (Technical report)

Wijk G., FHS-kurs i Vapeneffekter på människa. Stockholm, FOI 2001, 18 s. FOI-R—0020—SE. (Användarrapport)

Wijk G., FHS-kurs i Värdering av verkan och sårbarhet. Stockholm, FOI 2001, 24 s. FOI-R—0021—SE. (Användarrapport)

Wijk G., Workshop i Stockholm om hörselskador från impulsljud. Stockholm, FOI 2001, 19 s. FOI-R—0056—SE. (Användarrapport)

Östmark H., Bittererova M., Brinck T., Hore N., Clarige R., Tryman R., Wallin S., Pettersson A., Launila O., The N_4 project. Activity report for the third quarter of 2001. Stockholm, FOI 2001, 34 p. FOI-R—0223—SE. (User report)

Issuing organization	Report number, ISRN	Report type
FOI – Swedish Defence Research Agency Weapons and Protection Grindsjön Research Centre SE-147 25 Tumba Sweden	FOI-R—0395—SE	Progress report
	Research area code	
	Month year April 2002	**Project no.**
	Customers code	
	Sub area code	
Author/s (editor/s) Kristina Wahlgren (Ed.)	**Project manager** **Approved by**	
	Scientifically and technically responsible	

Report title (In translation)
Weapons and Protection Division
Annual Report 2001

Abstract (not more than 200 words)

This is the annual report for FOI Weapons and Protection Division for the Fiscal year 2001. 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.

Keywords
Weapons, missiles, munitions, warheads, projectiles, explosives, propellants, armour, protection, annual report

Further bibliographic information	**Language** English
ISSN 1650-1942	**Pages** 42
	Price acc. to pricelist
	Security classification

Utgivare FOI - Totalförsvarets Forskningsinstitut Vapen och skydd Grindsjöns Forskningscentrum SE-147 25 Tumba	**Rapportnummer, ISRN** FOI-R--0395--SE	**Klassificering** Verksamhetsrapport
	Forskningsområde	
	Månad, år April 2002	**Projektnummer**
	Verksamhetsgren	
	Delområde	
Författare/redaktör Kristina Wahlgren (Ed.)	**Projektledare**	
	Godkänd av	
	Tekniskt och/eller vetenskapligt ansvarig	

Rapportens titel
Avdelningen för Vapen och skydd, årsrapport 2001

Sammanfattning (högst 200 ord)
Årsrapport för FOI Avdelningen för Vapen och skydd. Verksamheten inom avdelningens institutioner beskrivs i sammandrag.

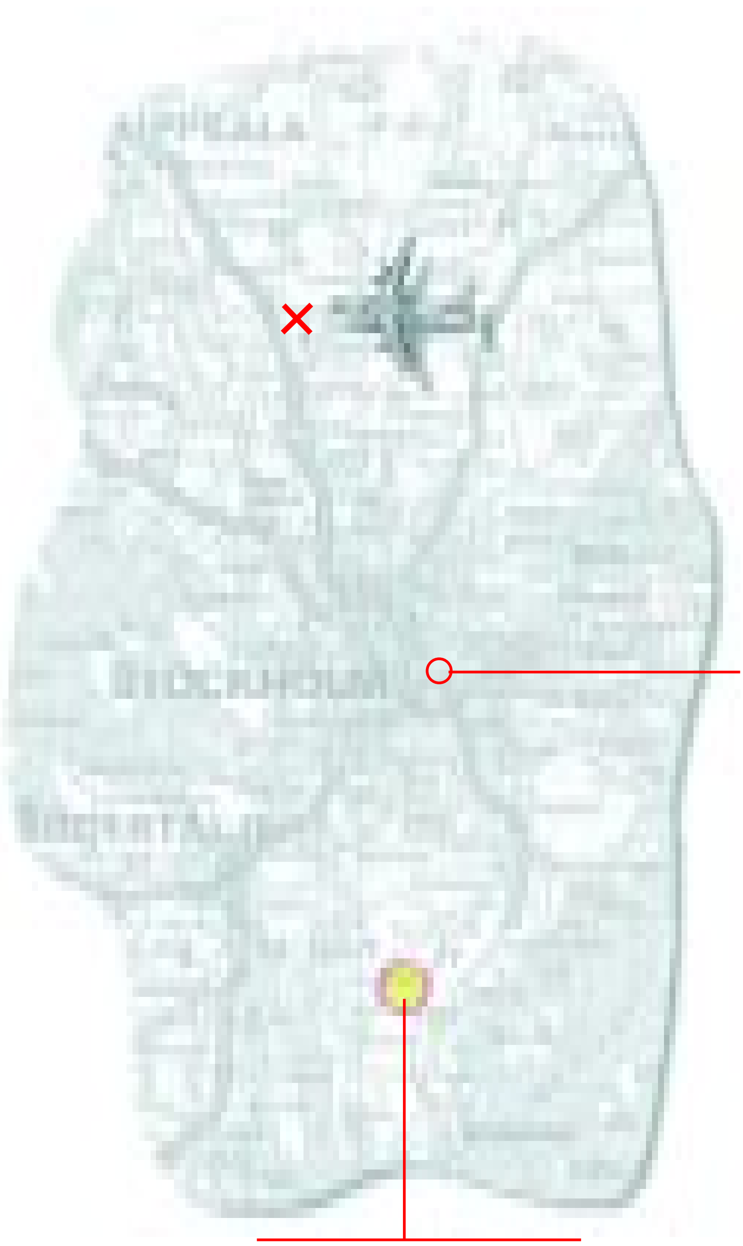
Rapporten ger även en allmän beskrivning av avdelningens mål, verksamhet, organisation och ekonomi.

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

Rapporten är skriven på engelska.

Nyckelord
Vapen, robotar, ammunition, stridsdelar, projektiler, explosivämnen, krut, pansar, skydd, årsrapport.

Övriga bibliografiska uppgifter	**Språk** Engelska
ISSN 1650-1942	**Antal sidor:** 42
Distribution enligt missiv	**Pris: Enligt prislista** **Sekretess**



Telephone numbers and e-mail:

Dr. Bo Janzon	+46 8 55 50 39 98 bo.janzon@foi.se	Dr. Torgny Carlsson	+46 8 55 50 39 31 torgny.carlsson@foi.se
Mrs. Carin Lamnevik	+46 8 55 50 39 54 carin.lamnevik@foi.se	Dr. Michael Jacob	+46 8 55 50 41 63 michael.jacob@foi.se
Dr. Henric Östmark	+46 8 55 50 35 17 henric.oestmark@foi.se	Mr. Ralf T Holmlin	+46 8 55 50 39 59 ralf.holmlin@foi.se

FOI, Weapons and Protection, Grindsjön Research Centre, SE-147 25 TUMBA, Sweden.
Telephone: +46 8 55 50 30 00, Fax: +46 8 55 50 41 43, Internet: www.foi.se