STATEMENT OF WORK

Numerical Modeling of the Response of High Explosives within Insensitive Munitions to Thermal (Fast and Slow Heating) and Mechanical Effects (from Fragments, Bullets, Shaped-Charge Jets)

1 GENERAL PROVISIONS

The objective of the work is to develop mathematical kinetic models and computational programs to analyze the response of high explosives (HE) within insensitive munitions to thermal and mechanical effects with consideration of geometry, dimensions, boundary and initial conditions.

The response of HE to thermal effects shall be analyzed using a kinetic model of thermal decomposition, the construction and the values of kinetic parameters of which will be based on experimental data of small-scale experiments on specific gas and heat release during thermal decomposition of HE.

The model shall be implemented in the form of an original software product.

The response of HE to mechanical effects shall be analyzed using a kinetic model of initiation and development of explosive transformation, the construction and the values of kinetic parameters of which will be based on known or new experimental data as needed to provide a complete description of the processes.

The model shall be implemented in the form of an application for one of the available commercial hydrodynamic codes (like ANSYS Autodyn).

The models shall be developed and verified using the Contractor's experimental data obtained for one or more Russian explosives similar to those proposed by the Customer in composition and properties.

The Contractor shall perform test computations of the response of HE loads within the Customer's full-size prototypes, for which the Customer shall provide all the necessary initial data. The Contractor shall provide training of the Customer's personnel in using the models and programs at the Customer's premises.

2 SCOPE OF WORK AND MILESTONES

2.1 Thermal Effects

The Contractor shall:

2.1.1 Specify a set of development and verification procedures for the kinetic models of thermal decomposition of condensed materials based on the data of specific gas and heat release during thermal decomposition of explosives.

2.1.2 Develop mathematical modeling software to study thermal decomposition of HE for insensitive explosives and their reaction safety.

2.1.3 Develop a model of thermal decomposition for one Russian explosive compound as agreed with the Customer and verify the model using Russian small-size prototypes.

2.1.4 Conduct test computations using available models and models developed under the project and initial data provided by the Customer to study reaction safety properties of the Customer's explosive compounds within full-size prototypes.

The Customer shall:

2.1.5 Specify the charge geometry, boundary and initial conditions, and effects on the Customer's full-size prototypes, for which the test computations shall be conducted.

2.1.6 Provide to the Contractor all the necessary data on the HE and liner properties as appropriate for the test computations.

The Contractor in cooperation with the Customer shall:

2.1.7 Agree on the Russian test explosive compound to be used for the verification of the model on small-size prototypes.

2.1.8 Organize and conduct training of the Customer's personnel in using the developed models and programs at the Customer's premises.

2.2 Mechanical Effects

The Contractor shall:

2.2.1 Make prototypes of Russian components to be filled with the explosive agreed upon by the Customer;

2.2.2 Conduct experimental studies using the prototypes to measure their parameters necessary for the numerical modeling, including:

- shock and isentropic compressibility of cold HE;
- flow properties of cold HE;
- expansion isentropes of explosion products;
- HE acceleration power;
- HE detonation properties;
- initiation of detonation by shock waves;

2.2.3 Experimentally establish initiation conditions for different regimes of explosive transformation in shielded HE samples (detonation / explosive transformation with incomplete energy release / no reaction) depending on fragment / bullet / shaped-charge jet parameters and strength of the HE shielding;

2.2.4 Select the kinetic explosive transformation model for the test compound and perform its verification (fit physical model constants) based on the experimental data;

2.2.5 Develop software in the form of an application for one of available commercial hydrodynamic codes for mathematical modeling of the response of explosive compounds to thermal effects and reaction safety analysis of the prototypes.

2.2.6 Conduct computational reaction safety analysis of the Customer's explosive compounds within full-size prototypes using the selected explosive transformation model and initial data provided by the Customer.

The Customer shall:

2.2.7 Specify the charge geometry, boundary and initial conditions and mechanical effects on the Customer's full-size prototypes, for which the test computations shall be performed.

2.2.8 Provide to the Contractor all data the Customer has on the properties of the explosive (manufacturing details, detonation properties, equation of state, shock sensitivity and test setup, critical diameter) and liners used in the prototypes as necessary for the computations.

2.2.9 Identify the range of parameters of mechanical effects (from fragments, bullets, shaped-charge jets) under consideration.

The Contractor in cooperation with the Customer shall:

2.2.10 Agree on the Russian explosive compound under consideration to be used for the construction of the model and its verification on the prototypes.

2.2.11 Organize and conduct training of the Customer's personnel in using the algorithm of problem solution by the proposed numerical code at the Customer's premises.

2.3 The work shall be carried out in three milestones.

2.3.1 Milestone 1 shall be completed based on the results of the work performed under items

2.1.1 and 2.2.1 - 2.2.2;

2.3.2 Milestone 2 shall be completed based on the results of the work performed under items 2.1.2 - 2.1.3 and 2.2.3 - 2.2.4;

2.3.3 Milestone 3 shall be completed based on the results of the work performed under items

2.1.4, 2.1.8, 2.2.5, 2.2.6, 2.2.11.

3 DELIVERABLES

Thermal effects

3.1 A procedure for comprehensive experimental and computational analysis of HE thermal decomposition kinetics to obtain initial data necessary for the construction of HE thermal decomposition models.

3.2 A procedure for the construction and verification of kinetic HE thermal decomposition models as applied to insensitive munitions. Within the given geometry specifications, boundary conditions and thermal effects, the models developed according to the procedure shall enable computations of:

- HE decomposition depth;

- induction time and temperature of self-sustained reaction (thermal explosion) in HE.

3.3 An installation kit of the software for mathematical modeling of thermal decomposition of explosive compounds for insensitive HE and computations of their reaction safety for Windows PC.

3.4 A report on the comprehensive analysis of thermal decomposition kinetics, construction and verification of thermal decomposition model for the Russian explosive compound as agreed upon under item 2.1.7.

3.5 A report on the results of the computational reaction safety analysis of the Customer-defined insensitive munition prototypes under specified conditions.

Mechanical Effects

3.6 A report on the results of the comprehensive experimental characterization of the Russian explosive compound.

3.7 A report on the results of experimental analysis of initiation conditions for different regimes of explosive transformation in HE samples (detonation, explosive transformation with

incomplete energy release, no reaction) depending on fragment (bullet, shaped-charge jet) parameters and strength of the HE shielding;

3.8 A report on the results of the development and verification of the kinetic HE detonation model for the Customer-specified HE.

3.9 An installation kit of the software for mathematical modeling of HE response to mechanical effects in the form of an application for an available commercial hydrodynamic code.

3.10 A report on the computational reaction safety analysis of the Customer-specified insensitive munition prototypes under specified conditions.

4. LIST OF DELIVERABLES

Description	Unit	Qty
Milestone 1 4.1 Reports 4.1.1 "Results of procedure development for comprehensive experimental and computational analysis of HE thermal decomposition kinetics, construction and verification of the thermal decomposition model"	Book, CD	2 + 2

4.1.2 “Results of experimental characterization of the Contractor’s HE to construct the model of its explosive transformation in response to mechanical effects”		
Milestone 2 4.2 Reports 4.2.1 “Results of experimental and computational analysis of HE thermal decomposition kinetics on the Contractor’s samples, construction and verification of the thermal decomposition model” 4.2.2 “Results of experimental analysis of initiation conditions for explosive transformation in response to mechanical effects on the Contractor’s samples, construction and verification of the explosive transformation model”	Book, CD	2 + 2
4.3 Software 4.3.1 Installation kit of the software for mathematical modeling of thermal decomposition of explosive compounds for insensitive HE and computations of their reaction safety. User Manual	CD, booklet	1 + 1
Milestone 3 4.4 Reports 4.4.1 “Computational reaction safety analysis of insensitive munition prototypes under specified conditions of thermal effects”	Book, CD	2 + 2

4.4.2 “Computational reaction safety analysis of insensitive munition prototypes under specified conditions of mechanical effects”		
4.5 Software 4.5.1 Installation kit of the software for mathematical modeling of HE response to mechanical effects (in the form of an application for an available commercial hydrodynamic code). User Manual	CD, booklet	1 + 1

5. MAJOR REPORTING REQUIREMENTS

5.1 Report 4.1.1 shall contain the following:

- Description of the algorithm of experimental and computational/experimental analysis of HE thermal decomposition kinetics with substantiated choice of the measurement range for the quantities under consideration, description of methods and hardware requirements;

- Description of methods to process the kinetic set of data (set of experimental responses) and character and structure of output parameters;

- List and specification of input parameters necessary for the construction of the kinetic thermal decomposition model and requirements for the methods of their specification;

- Description of construction methodology, character of output data and verification procedure for the kinetic HE thermal decomposition models.

5.2 Report 4.1.2 shall contain the following:

- Results of determination of shock and isentropic compressibility of the agreed cold HE (item 2.2.10), its flow properties, shock sensitivity, equation of state of explosion products, acceleration power, detonation properties and conditions of detonation initiation by shock waves;

5.3 Report 4.2.1 shall contain the following:

- Results of studies related to the construction and verification of the kinetic HE thermal decomposition model for the agreed HE (item 2.1.7) in accordance with the specified procedures (items 3.1 and 3.2);

- Description of the structure and values of kinetic parameters of the developed model;

- Calculated values of induction time and temperature for the self-sustained reaction (thermal explosion) in the agreed HE (item 2.1.7) under model experimental conditions and respective experimental data obtained during model verification;

5.4 Report 4.2.2 shall contain the following:

- Experimental data on the reaction violence (evolution of explosive reaction in time, level of structural damage) of the agreed HE (item 2.2.10) depending on the parameters of mechanical effects (including the absence of observable explosive reactions);

- Major assumptions and provisions of the model, its mathematical description and results of numerical verification against experimental data.

5.5 Report 4.3.1 shall contain the following:

- Calculated values of induction time and temperature for the self-sustained reaction (thermal explosion) in the HE for the Customer's full-size prototypes provided that the Customer submits all the necessary initial data (specifications of prototypes and thermal effects) (item 2.1.6).

- The calculated data shall be presented in the form of diagrams and tables.

5.6 Report 4.3.2 shall contain the following:

- Calculated data on the expected reaction violence (detonation / explosive transformation with incomplete energy release / no reaction) in the HE for the Customer’s full-size prototypes provided that the Customer submits all the necessary initial data (specifications of prototypes and thermal effects) (item 2.2.8).

- The calculated data shall be presented in the form of diagrams and tables.

5.7 To describe the experimental results (items 5.2, 5.3, 5.4), the reports shall contain illustrations in the form of experimental and calculated curves, tables with values of parameters, schematics of experimental setups, brand names and models of instruments and diagnostic equipment.

6. SCHEDULE OF WORK

Milestone No.	Description	Deadline	Price
1	1) Specification of a set of development and verification procedures for the kinetic models of thermal decomposition of condensed materials based on the data of specific gas and heat release during thermal decomposition of explosives. 2) Experimental characterization of the chosen HE necessary for the construction of the kinetic model and explosive transformation in response to mechanical effects. 3) Development and submission of Milestone 1 deliverables.	T_0+12 months*)	
2	1) Development of mathematical modeling software to study thermal decomposition of HE for insensitive explosives and their reaction safety analysis. 2) Construction and verification of the thermal decomposition model for the chosen explosive compound. 3) Experimental analysis of initiation conditions for different regimes of explosive transformation in the samples of the chosen HE under different mechanical effects (from fragments, bullets, shaped charge jets). 4) Construction and verification of the kinetic model of explosive transformation in response to mechanical effects. Software development. 5) Development and submission of Milestone 2 deliverables.	T_0+24 months	
3	1) Computational reaction safety analysis of the Customer's full-size prototypes under specified conditions of thermal effects. 2) Computational reaction safety analysis of the Customer's full-size prototypes under specified conditions of mechanical effects. 3) Training of the Customer's personnel in using the models and software. 4) Development and submission of Milestone 3	T_0+30 months	

	deliverables.		
Comment: *) - T_0 is the effective date of the contract			