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Rarefaction Shock Wave Cutter for Offshore Oil-Gas Platform Removal Final Report CRADA No. TC02009.0

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September 7, 2017

Disclaimer

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Rarefaction Shock Wave Cutter for Offshore Oil-Gas Platform Removal

Final Report
CRADA No. TC02009.0
Date Technical Work Ended: August 21, 2009

Date: October 5, 2009 Revision: 2

A. Parties

This project was a relationship between Lawrence Livermore National Laboratory (LLNL) and Jet Research Center, a wholly owned division of Halliburton Energy Services, Inc.

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B. Project Scope

This was a collaborative effort between Lawrence Livermore National Security, LLC/Lawrence Livermore National Laboratory (LLNL) (formerly the University of California) and Jet Research Center, a wholly owned division of Halliburton Energy Services, Inc. to design and prototype an improved explosive cutter for cutting the support legs of offshore oil and gas platforms.

This project was part of a three-phase program by Jet Research Center and the All-Russian Scientific Institute of Experimental Physics (VNIIEF), the participating NIS Institute, to develop an improved cutting technique for removing old offshore installations used to support undersea oil and gas production operations.

Phase 1 of the project involved work between Jet Research Center and VNIIEF to conduct a proof-of-principle live firing demonstration to establish that pipe used in offshore platform

supports could be cut with significantly reduced amounts of explosives. That demonstration was successfully conducted in Sarov in April 1998 and was a precursor to the present CRADA.

This project was conducted as Phase 2, and involved the design, construction, and test of a prototype RSW cutter and conveyance mechanism *for cutting pipe from the inside*, and a study to evaluate the effect of various operating parameters.

Under this project, VNIIEF designed a working prototype of an actual RSW internal cutter and conveyance mechanism that was subjected to a series of additional qualification tests by Jet Research Center. VNIIEF, in cooperation with LLNL, also conducted a parameter study to evaluate the sensitivity of the technique to gaps and pipe imperfections.

This CRADA project was originally designated as a 12 month project, and initially consisted of five major tasks. The CRADA was reconfigured to include an addition to Phase 2 which resulted in the fabrication and prototype testing of an RSW device *for cutting pipe from the outside*. There were four no-cost time extension requests executed between February 2001 and September 2003, essentially extending the Phase 2 project for a total of 42 months, due to various delays encountered during the project, thereby requiring more time to complete the project work.

After successfully concluding the demonstration of an internal RSW cutter in December 2003, which consisted of the design, production of a prototype, and full-scale live firing of an internal Rarefaction Shock Wave (RSW) cutter, a fifth no-cost time extension request was executed in October 2004. The extension was needed to allow enough time to receive funding from DOE to continue the CRADA project and for DOE's acceptance of a supplementary proposal to extend the project work by demonstrating that an *external* RSW cutter could provide significant advantages in certain circumstances.

Amendment One was executed in August 2005. This Amendment added tasks, deliverables, and funding, and extended the project for an additional 18 months. The purpose of the amendment was to conduct the design, testing, and full-scale live firing activities that would lead to the prototype qualification of an *external* RSW cutter.

Four more no-cost time extension requests were executed, extending the project for another 30 months. These extensions were needed due to delays in the Russian subcontractors receiving DOE funding, and to allow enough time to complete the tasks and deliverables, to receive the final technical report from the Russian subcontractor, to consider possible follow-on work, to discuss intellectual property and commercialization, and to prepare the CRADA final report. Phase 2 for the external cutter started May 2006 and lasted thru May 2009, (which included a one-year extension due to export control issues related to the receipt of Russian Equipment to the US). The export Control License was approved allowing the equipment to be sent to Texas. Finally, in February 2009 the full-scale live firing demonstration testing of the prototype external RSW cutter took place at the JRC Facility in Alvarado, Texas.

This project consisted of the following major deliverables:

Internal Cutter

1. VNIIEF: Design drawings and specs of a working prototype of an RSW device with conveyance mechanism. Report on prototype design: Month 3

2. VNIIEF: Report on test/evaluation of prototype and conveyance mechanism: Month 6

3. VNIIEF: RSW prototype and segment. Jet Research Center witness full-scale demonstration in Sarov using Russian explosive components: Month 9

4. LLNL, VNIIEF & Jet Research Center: Conduct final full-scale demonstration in Alvarado, TX using US explosive components. Final report that includes the results of the parameter study and qualification tests: Month 12

Deliverables added under Amendment One:

External Cutter

5. Work out specifications for cutting segment and initiation system. Create design. Fabricate cutting segments. (LLNL, VNIIEF) Duration: 3 Months

6. Work out design of conveyance hardware and blast containment system. Fabricate prototypes. Conduct preliminary tests of initial design. (LLNL, JRC, VNIIEF) Duration: 3 Months

7. Refine design of complete cutting system: cutting segments, initiation scheme, conveyance hardware, and blast containment. Fabricate final prototype. Hold design review at Sarov; Jet Research Center witness full-scale demonstration in Sarov using Russian explosive components. (VNIIEF) Duration: 3 Months

8. VNIIEF build of a second system, using U. S. explosive components, and ship to the U.S. for final full-scale demonstration testing at the JRC test site in Alvarado, Texas. (VNIIEF, LLNL, JRC) Duration: 3 Months

9. LLNL, VNIIEF and JRC provide a final report. (LLNL, VNIIEF, JRC) Duration: 3 Months

All tasks and deliverables for this project were successfully completed.

After the successful completion of this project, Jet Research Center and VNIIEF intend to proceed with Phase 3 of this program, which will involve fabrication and field testing of RSW cutters based on the VNIIEF design.

C. Technical Accomplishments

The first stage of the IPP project was a resounding success. A prototype device using the RSW technique was developed for *internal* cutting applications. In that design the pipe is cut from the inside out by lowering the device through the pipe to the appropriate location and then activating the (explosive) cutting mechanism. The RSW technique takes advantage of the high-pressure phase change in iron to produce rarefaction shock waves. Such a cutting method can allow thick-walled steel pipes of various diameters to be cut with smaller quantities of explosive than other existing methods. The success of the ***internal*** cutting device generated enthusiasm for the design of an ***external*** cutting device, which was the subject of Amendment One to the CRADA.

The second and final stage of the IPP Project was the development of the external cutter. This prototype device was developed to enable the cutting of a hollow pipe from the outside.

The following milestones were successfully completed for the second stage of the IPP Project:

1. Patent research to explore existing explosive technologies that are relevant to the subject matter of the Project. It was determined that there were no ready engineering solutions at the time to meet the specified requirements, so that a new technology needed to be developed for cutting thick-wall pipe structures from outside.

2. Study and validation of possible design options. Designs were selected for a prototype outside cutter using the rarefaction shock wave technique.

3. Development of design drawings and specifications for prototype RSW cutters HKC2-00.000 for water environment and HKC2-00.500 for operation in the air. To limit debris scattering in pipe cutting operations in the air, the cutter design HKC2-00.500 was chosen because it contained fewer metal parts.

4. Laboratory test and evaluation of individual design components. Dimensions were determined for the main pipe cutting charge. They are: HE width of 70 mm, and thickness of 21 mm.

5. Mechanical parts of prototype RSW cutters were shipped to USA for tests conducted at the JRC test facility in Alvarado, TX.

6. Tests of the prototype RSW cutters were conducted at VNIIEF and Jet Research Center test facilities for cutting in a water environment (no water inside the pipe) and in the air.

7. Experiment to check the use of US-manufactured commercial explosive in operation of prototype RSW cutters.

8. Testing of the prototype RSW cutters in the two pipe conditions of (a) air outside/air inside and (b) water outside/air inside demonstrated that the pipes were separated into two pieces. The HE load used by the cutters was 6.0 kg.

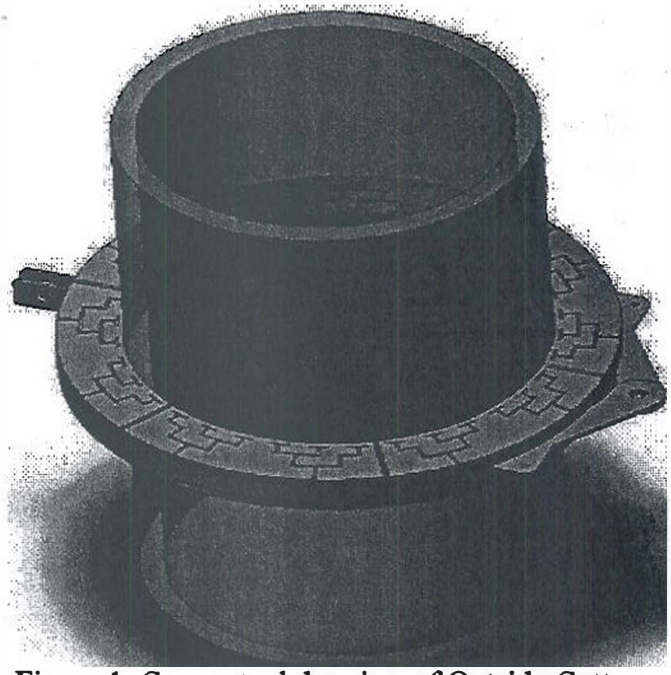

Figure 1. Conceptual drawing of Outside Cutter

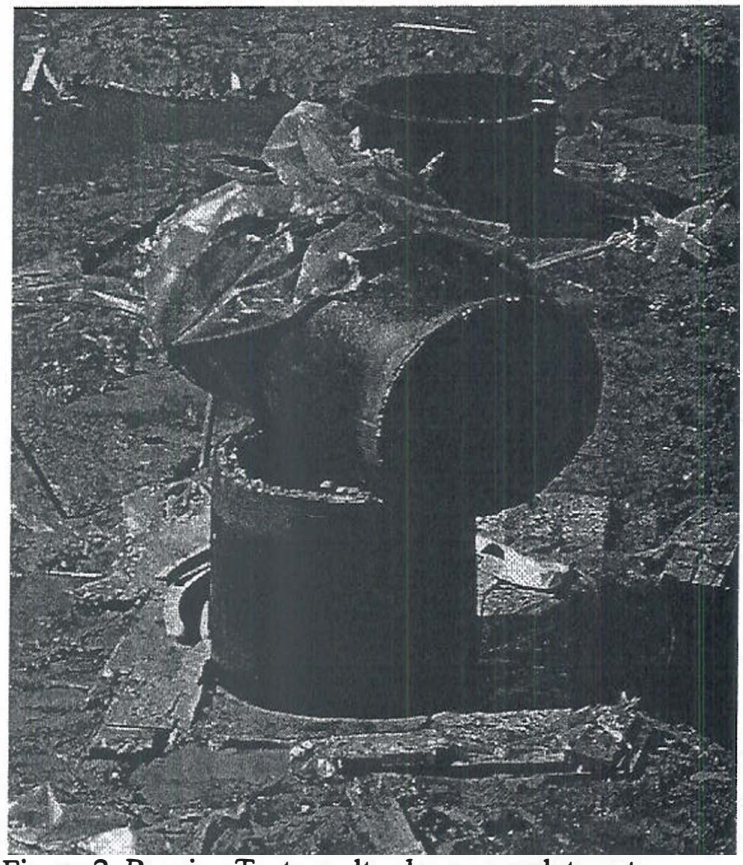

Figure 2. Russian Test results show complete cut.

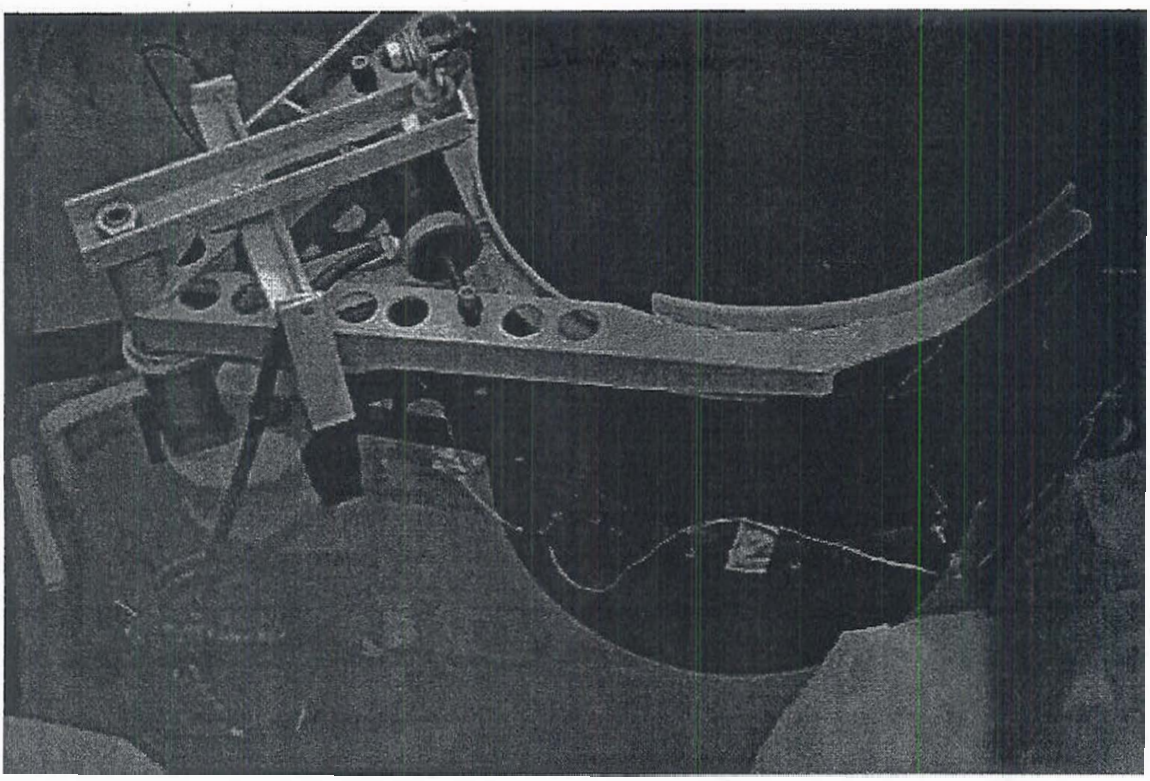

Figure 3. Test piece fully submerged at JRC Facility in Alvarado, Texas.

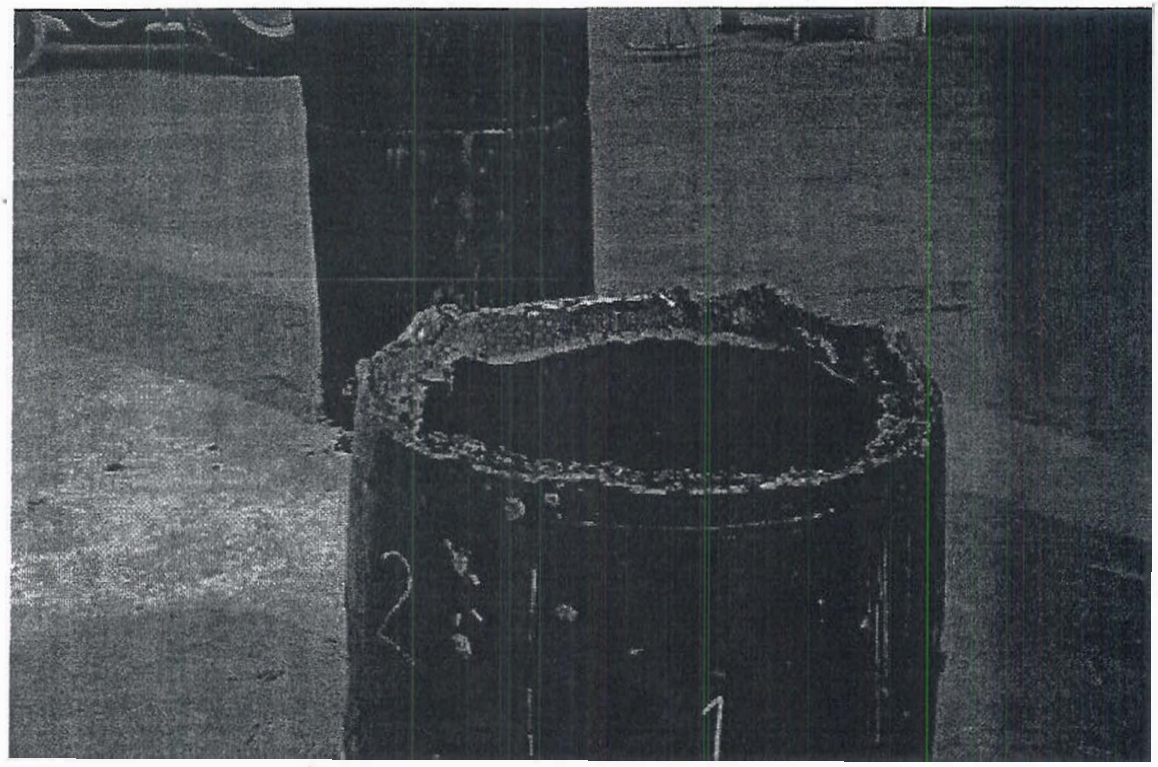

Figure 4. Final test cut from fully submerged pipe at JRC Facility, Alvarado Texas.

Final Testing at the JRC Facility included:
- Demonstration of the apparatus and prototype method of operation
- Verification of performance using US commercially available explosives
- Conduct test shot 1 in air environment
- Conduct test shot 2 with water environment around the outside of the pipe (with air inside)

The technical requirements specified for RSW cutters were satisfied as follows:

a) the pipe structures of platforms with 762 mm outside diameter and 51 mm wall thickness are cut from outside;
b) minimum of the RSW cutter opening when positioned onto pipe is 862 mm;
c) in deployed cutter position, the gap between its inside and the pipe outside keeps within 3.0 mm;
d) the RSW device functions well in a water environment when submerged to about 300 m depth; holding one HE-loaded charge segment and the initiation system (a string of six electric detonators) in a water-filled vessel under 3.0 MPa pressure for a one-hour period had no impact on the functioning,
e) for operation in the air, the cutter design contains no metal parts, so that it is no longer meaningful to have a debris protection system *per se*. With no metal debris in the pipe cutting operation, the air shock wave is the only destructive effect.
f) the total HE load of the RSW cutter is less than 6.0 kg.

D. Expected Economic Impact

The economic impact of the RSW cutters, both internal and external, is dependent on platform decommissioning activity. The cutters will be used in specialized situations where thick-wall pipe must be cut with minimal environmental impact. The level of cutting activity is expected to increase over the next several years as 30- to 40-year old facilities are decommissioned.

D.1 Specific Benefits

Benefits to DOE

The project benefits the Department of Energy's non-proliferation objectives by creating non weapons work to Russian Scientists at the nuclear weapons institute (VNIIEF) in Sarov. DOE benefits because it is furthering the goals of an important non proliferation program (Global Initiatives for Proliferation Prevention) for the NNSA. Additional benefits for the DOE include the cooperative engagement and collaboration of former soviet weapons scientists.

Benefits to Industry

The full-scale live firing demonstrations showed that the RSW technique is suitable for cutting large diameter thick-wall pipes either from the inside or outside.

E. Partner Contribution

For both the internal and external RSW portions of the project, Jet Research Center/Halliburton actively participated in all key activities including:

- Project scoping and review
- Proposal submissions
- Obtaining and renewing Technology Export Licenses
- Procuring and shipping large diameter thick-wall test pipes to Savov
- Attendance at multiple design reviews and live firings at Sarov
- Preparing the Jet Research Center test site with technician and heavy equipment support
- Hosting of VNIIEF delegation at Alvarado TX
- Overseeing and assisting with the loading of explosives into RSW cutters
- Conducting multiple full-scale live test firings at the Jet Research Center facility in Alvarado TX

JRC provided frequent progress reports to LLNL throughout the life of the project.

F. Documents/Reference List

Reports

Russian Project reports

1. Annual technical report "Rarefaction Shock wave Cutter for Cutting Offshore OilGas Platforms from Inside". Sinitsyna L.M., Batkov Yu.V., Lobanov V.N., Andreevskikh L.A., Kislinsky V.P. 2008. RFNC-VNIIEF IFV.
2. "Rarefaction Shock wave Cutter for Cutting Offshore Oil-Gas Platforms from Inside". ISTC Partner Project Agreement# 3362.
3. Design of outside RSW cutter and debris containment system. Sinitsyna L.M., Batkov Yu.V., Lobanov V.N., Andreevskikh L.A, Kislinsky V.P. Annual report (2007). RFNC-VNIIEF IFV.
4. Quarterly ISTC Reports for the duration of the project (kept on file with the GIPP Program Manager).

LLNL Published Documents

1. J.P. Morris, L.A. Glenn, T.H. Antoun, and I.N. Lomov. NUMERICAL INVESTIGATION INTO THE PERFORMANCE OF A RAREFACTION SHOCK WAVE CUTTER FOR OFFSHORE OIL-GASPLATFORM REMOVAL, UCRL JC-142023, *Lawrence Livermore National Laboratory, Livermore, CA 94550*

JRC Published Documents

1. J. Barker, A History of Collaboration Between VNIIEF and Jet Research Center to Develop and Commercialize a Novel Explosive Cutting Techniques for Offshore Platform Removal, International Scientific Journal for Alternative Energy and Ecology, ISJAEE no 6(26), 2005
2. T. Grattan, Technical Report, Rarefaction Shock Wave Cutter Task IV Prototype Demonstration, ENG-ALV-TFG-001/04, 13 May 2004

3. T. Grattan, Technical Report, Rarefaction Shock Wave Cutter External Prototype Demonstration, ENG-ALV-TFG-001/09, 04 May 2009

Copyright Activity

None

Subject Inventions

LLNL/LLNS: None

JRC: None

VNIIEF Invention:
Invention Certificate # 321/MKH 42, [(3/00-3/06. Zeldovich Ya.B., Ivanov A.G., Novikov S.A et al.

Background Intellectual Property

No Background Intellectual Property was disclosed by either Party for this project.

G. Acknowledgement

Industrial Participant's signature of the final report indicates the following:

1) The Participant has reviewed the final report and concurs with the statements made therein.
2) The Participant agrees that any modifications or changes from the initial proposal were discussed and agreed to during the term of the project.
3) The Participant certifies that all reports either completed or in process are listed and all subject inventions and the associated intellectual property protection measures generated by his/her respective company and attributable to the project have been disclosed and included in Section E or are included on a list attached to this report.
4) The Participant certifies that if tangible personal property was exchanged during the agreement, all has either been returned to the initial custodian or transferred permanently.
5) The Participant certifies that proprietary information has been returned or destroyed by LLNL.

11 NOV 2009

James Barker, Technology Manager
Jet Research Center
Date

12/4/09

Lewis A. Glenn, LLNL Principal Investigator
Lawrence Livermore National Laboratory
Date

12/8/09

Erik J. Stenehjem, Industrial Partnerships Director
Lawrence Livermore National Laboratory
Date

Attachment I – Final Abstract

Rarefaction Shock Wave Cutter for Offshore Oil-Gas Platform Removal

Final Abstract (Attachment I)
CRADA No. TC02009.0
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All tasks and deliverables for this project were successfully completed.

C. Benefit to Industry

The full-scale live firing demonstrations showed that the RSW technique is suitable for cutting large diameter thick-wall pipes either from the inside or outside.

D. Benefit to DOE/LLNL

The project benefits the Department of Energy's non-proliferation objectives by creating non weapons work to Russian Scientists at the nuclear weapons institute (VNIIEF) in Sarov. DOE benefits because it is furthering the goals of an important non proliferation program (Global Initiatives for Proliferation Prevention) for the NNSA. Additional benefits for the DOE include the cooperative engagement and collaboration of former soviet weapons scientists.

E. Project Dates

December 21, 1999 through August 21, 2009.