**CONFIDENTIAL PROPRIETARY INFORMATION**

January 6, 2016
RP-364

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**Subject: Rough Order of Magnitude (ROM) Price for Design, Construction and Testing of a Liquid Hydrogen Target for Studying the Proton Radius Puzzle**

Dear Bill:

Pursuant to our discussions over the last two weeks, this letter responds to your request for a preliminary fixed price for the design, construction, and initial testing of a liquid hydrogen target to be used in a beam line at the Paul Scherrer Institute (PSI) in Switzerland. This letter constitutes a rough order of magnitude (ROM) price for the work briefly outlined below. It is our understanding that a more detailed and definitive firm fixed price will be needed if we are selected for a proposal award, and Creare is prepared to provide the necessary information when needed.

Creare makes commercially reasonable efforts to estimate ROM price and schedules for budgetary estimates by our customers. Please understand that such estimates are only approximate in nature and are supplied quickly for planning purposes. In contrast, Creare's formal proposals are examined thoroughly and subjected to more exacting internal evaluation criteria. ROMs are supplied on a best-estimate basis using the information available at the time. If the information relied on during preparation of the ROM changes, our estimates will likely require revision also.

## 1 OVERVIEW OF OBJECTIVES AND REQUIREMENTS

The George Washington University (GWU) is leading a multinational team of engineers and scientists developing a MUon Scattering Experiment (MUSE) to be conducted at PSI. A key element to these experiments is a liquid hydrogen target that will enable simultaneous μP and eP scattering measurements. A novel feature of the "target" in this experimental facility compared with previous testing of this type is that it will actually consist of four targets: (1) the aforementioned hydrogen target, (2) a carbon target, (3) a dummy target, and (4) a blank (i.e., empty) target. This arrangement will allow for very precise measurements of the background scattering caused by the walls of the test facility. To enable the use of these

four targets, there must be a translation system that can accurately move each of the targets into the beam line in a repeatable way. We are assuming, based on our understanding of the problem and our discussions with you, that position repeatability of the four targets is more important than absolute position accuracy. Repeatability should be easier to achieve than absolute position accuracy since much of the facility will be cryogenic and subject to significant thermal contraction. However, once at steady state thermal conditions, we expect that returning to the same position very accurately will be possible.

We understand that a key aspect of making this experiment a success is the assumption that the background, once measured with the blank target, will not change from one target to the next. Making this assumption as valid as possible will be critical to the target system design effort. We also understand that the minimizing of the background signal itself will be important, as it will minimize the amount of material in the primary beam and the scattering paths. This implies minimizing the thickness of the vacuum vessel and the cryogenic hydrogen test walls. The current baseline plan involves the use of thin Kapton™ material as the preferred material of construction. It will also be important to design the system so that the supporting structure for the targets and chamber structure is not in the path of the primary beam or the path of the scattered particles to the greatest extent possible.

## 2 SCOPE OF EFFORT AND PROGRAM PLAN

We have reviewed the two conceptual designs that have been developed to date for the target. We understand the general scope of the problem and what needs to be accomplished to achieve success. However, there are clearly many engineering details that need to be resolved. The engineering effort will be constrained by the physical and operating constraints of the facility and optimizing the design of the target system for the measurements at hand. Many of these requirements are not fully known at this point.

We envision a multiphase program with the elements described below. The first five elements would be sequential, and the final element (Documentation) would occur over the entire program period. Creare's scope of effort under each of these phases is briefly described below.

1. Conceptual Design and Down Select. The GWU team has largely completed the conceptual design effort and identified two potential conceptual approaches: (1) one in which the entire vacuum system with the cryocooler and turbo pump is translated to expose each of the four targets through four separate windows, and (2) a second approach that involves a stationary vacuum chamber in which the targets are translated past a single window. We see advantages and disadvantages to each approach, and we will work with the GWU team during this initial phase of the effort to review these two general approaches and down select to one general concept that we will move forward to Preliminary Design.
2. Preliminary Design. We will move one design forward to the Preliminary Design phase, which will involve analysis and design work at a sufficiently detailed level to ensure that all the risks have been identified and that at least one practical solution exists to address each technical issue. For example, we will conduct analyses using both hand calculations and finite element analysis (ANSYS™) as needed to estimate

the cryogenic thermal loads on the target system (e.g., radiation and conduction through the mechanical supporting structure). This information will inform the overall design effort and is necessary to select a cryogenic refrigerator with an appropriate cooling capacity. We expect that we will work with the GWU team during this phase to conduct a preliminary safety review. Creare expects that someone from the GWU team, probably at PSI, will lead the overall safety review effort. We anticipate that we will support that effort, and that our continued design effort will be guided by the results of this preliminary safety review. At the completion of this phase, we will meet with the GWU team for a Preliminary Design Review (PDR) to discuss the design status and any remaining known concerns. We will then proceed to the Critical Design phase if authorized.

3. Critical Design. In this phase, we will advance the design to the point where fabrication can commence. All design concerns will be addressed and solutions will be backed up by appropriate analysis and/or laboratory testing. At the conclusion of this phase, all the design drawings will be complete and all commercial items will be identified. A complete Bill of Materials (BOM) will be developed. We expect that there will be a detailed safety review under this task that Creare will participate in and take design guidance from. At the conclusion of this phase, we will meet with the GWU team for a Critical Design Review (CDR). We will then proceed to the Fabrication phase once authorized to do so.

4. Fabrication. In this phase, we will fabricate the custom components and purchase any commercial items, some of which will likely require modification. We will assemble the target system and correct any readily identifiable issues. We will integrate the cryocooler cold head with the hydrogen condenser and the other components of the target system. We will also apply multilayer insulation as dictated by the design.

5. Functional Testing. Some minimal testing will be conducted to validate the key non-cryogenic functional aspects of the target, specifically the motion control and hermeticity of the vacuum system. We also envision a proof-pressure test of the hydrogen target. We could also discuss the potential for a cryogenic test, potentially with liquid nitrogen or liquid neon if that were desired. The target motion system will be tested at prototypical conditions. If the design of the key motion components is at cryogenic temperatures, then the system will be tested at (or suitably near) those temperatures. However it is not anticipated that the motion control system will be at cryogenic temperatures at this point. In our current estimate, we have not allotted for this type of testing since it is probably most cost-effective to conduct this testing at PSI, where the facility will be completely integrated.

6. Documentation. We are assuming minimal documentation requirements. Our assumption is that slide packages from the PDR and CDR described above will sufficiently document our work along with the CAD models and drawings used to fabricate the target. We will provide any manuals that we receive for any purchased components. We will provide a brief Operator's Manual with the deliverable target system describing the user input requirements for position control and the outputs from the various temperature and position sensors that we expect will be included. We will provide brief monthly progress reports via email to document our current and

projected activities. These progress reports will form the basis for our progress payments along with the CDR and PDR materials and the hardware deliverable item. Additional documentation and QA processes can be applied if desired, as Creare has extensive space qualification experience; however, this level of control and oversight is not included in this ROM.

## 3 EXCLUSIONS

In developing our ROM price, we have assumed that the following items would NOT be in Creare's scope:

1. Cryocooler. Creare will work with GWU to select an appropriate cryocooler that provides the required cooling capacity based on our thermal load calculations, but we are assuming that others on the GWU team will purchase the cryocooler. We will request that the cold head is provided to Creare for integration into the target system. This is probably best accomplished at Creare given the thermal interfacing requirements with the hydrogen heat exchanger.
2. Turbomolecular Vacuum Pump and Vacuum Gate Valve. We will work with the GWU team to select the optimal vacuum pump and gate valve. Creare will need to understand the interfaces and operating constraints. We may request delivery of these items to Creare for integration with the target system for system-level testing, or we may ask that the GWU team perform the integration at PSI. This is a TBD item.
3. Instrumentation Electronics. Creare is assuming that Lakeshore PRT boxes, data acquisition electronics, etc. will be provided by others or that such required instrumentation exists at PSI. We assume that the target positioning sensors and associated electronics (any sensors and actuators within the target/chamber) would be Creare's responsibility. We will work with the GWU team to define the appropriate sensors and interfaces to existing equipment.
4. Travel. Travel expenses are not included in our ROM price. We are assuming that Creare personnel will not need to travel for this effort. We expect that all our meetings can be accomplished via web-enabled teleconferences. However, Creare is willing to host meetings as needed, and we will look for opportunities to meet at GWU when we are traveling near GWU, which happens frequently. Should travel to PSI be required, we will update our fixed price to accommodate the desired travel.
5. Safety Analysis and Documentation. We are assuming that others on the GWU team will conduct some type of Failure Modes and Effects and Criticality Analysis (FMECA) to evaluate the safety of the liquid hydrogen target. We assume that FMECA would be an important activity to conduct and would be planned by GWU but conducted by a member of the GWU team with more knowledge of and experience with the overall PSI test facility than Creare. Should GWU request that Creare participate in FMECA activities, we would be happy to provide a fixed price for Creare's involvement with specific FMECA activities.

   Creare will conduct safety analyses of all components within the chamber target system, including a rapid boil-off vent analysis. This analysis will not cover disposal of the $H_2$ gas external to the target vessel. The analysis will cover mechanical failure

prevention and effects of a failure internal to the vessel system; it will not cover effects external to the vessel.

a. Warranty. Given the experimental and developmental nature of this work, Creare cannot provide any sort of warranty.

b. Shipping. Creare is not assuming any significant shipping cost beyond shipping the target system to GWU in Washington, DC. Creare is familiar with international shipping and carnets and can facilitate this work if requested, but we are currently assuming that GWU will handle this and have not included international shipping and related expenses in this ROM price.

## 4 ROM PRICE

Our overall ROM price for the work described above is $250,055, which includes some contingency for the many unknowns and expected issues with an effort of this type. The effort breaks down in Table 1 below.

Table 1. ROM Fixed Price Breakdown by Key Target Component

| **Description** | **Design** | **Construction** | **Testing** |
|---|---|---|---|
| Target Cell (with sensors and connections | $25,850 | $23,000 | $ 1,500 |
| Heat Exchanger and Reservoir (and $H_2$ plumbing) | $12,000 | $14,000 | $ 6,000 |
| Scattering Chamber (with windows and frames) | $33,000 | $39,000 | $ 3,500 |
| Motion System (with controller and motor) | $ 6,000 | $16,000 | $ 1,500 |
| Emergency Dump System | $ 3,000 | $ 8,000 | |
| | | | |
| Total | $79,850 | $100,000 | $12,500 |
| Contingency | 1.3 | | |
| **Grand Total** | $250,055 | | |

## 5 SCHEDULE

We have not discussed schedule in any detail at this point. Creare is currently envisioning that this effort might begin on or about June 1, 2016. We believe that this effort can be comfortably completed within about 12 months, but a slightly more compressed schedule could be possible. Key parts of Creare's effort will be driven by interactions with other members of the GWU team, who will need to provide design specifications and customer-furnished equipment (e.g., the cryocooler cold head) in order for Creare to perform our proposed activities. It has been our experience that this type of collaborative effort involving the required interaction among several members of a project team can often pace activities.

## 6 TERMS AND CONDITIONS

Creare proposes to conduct the above work scope on a Firm Fixed Price Basis. We will develop a payment schedule based on key deliverables including the monthly progress reports, PDR and CDR slide packages, and the target system.

Please let me know if you have any questions or need further information.

Sincerely,

Patrick J. Magari

Patrick J. Magari, Ph.D.
Principal Engineer

4255/btt
cc: Contracts
Sheldon Stokes