Preliminary Designs for Criticality Safety Benchmarks—Iron/Steel/Chromium Series

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INTRODUCTION

The nuclear criticality safety community uses critical benchmarks extensively when analyzing nuclear systems. Having benchmarks sensitive to important materials of interest helps to ensure safety and constrain results. Critical benchmarks are also invaluable to the nuclear data community, which uses these benchmarks as a check and measure of quality of nuclear data libraries. Additionally, integral benchmarks are often used to validate the performance of computational tools for simulating nuclear systems. Many integral benchmarks have been documented in the International Criticality Safety Benchmark Evaluation Project (ICSBEP) handbook, the International Reactor Physics Experiment Evaluation Project (IRPhEP) handbook, and the Shielding Integral Benchmark Archive Database (SINBAD).

The National Criticality Experiments Research Center (NCERC), operated by Los Alamos National Laboratory, is the only general purpose critical experiments facility in the United States of America. NCERC regularly designs and executes critical experiments and other measurements useful to a wide variety of fields including nuclear criticality safety, commercial nuclear energy, nonproliferation, and nuclear data.

NCERC has recently developed tools to visualize gaps and deficiencies in existing criticality benchmarks – this work is still ongoing. Through this work and other reviews, some high priority deficiencies have been identified. This paper aims to highlight three areas where additional critical benchmarks would be useful to the nuclear criticality safety community and various other groups. Additionally, NCERC is seeking feedback in regards to these proposed measurements to make sure they are as useful to as many communities as possible.

Iron/Steel/Chromium

Steel, especially various forms of stainless steel, are used in almost every nuclear application. The nuclide with the largest mass fraction of all steel variants (^{56}Fe) was singled out as being so important that it was selected, along with ^{1}H, ^{16}O, ^{235}U, ^{238}U, and ^{239}Pu, to be studied by the Collaborative International Evaluated Library Organization (CIELO) collaboration. However, there are still some issues with the ^{56}Fe evaluation, and new integral experiments may help to solve some of these problems. In particular, in the region from 10 – 100 keV, ^{56}Fe capture cross sections have been tuned to match one single integral benchmark (HMI001, ZPR-34/9)[1-2]. Note, HMI001 and HMF072 referenced later are the names of benchmarks in the ICSBEP handbook. Adding additional integral benchmarks in this region can help to reduce the reliance on that single benchmark.

NCERC is proposing a series of benchmarks focused on steel, iron, and chromium. Iron is the base metal of all steels, and there are many benchmarks that are sensitive to iron cross sections. That said, there are very few benchmarks that are sensitive to iron in the intermediate energy region. Additionally, chromium is a major component of stainless steel; many varieties of stainless steel contain 18 % or more chromium. Like iron, there are many benchmarks sensitive to chromium in the thermal energy region, but almost none sensitive to chromium in the intermediate energy region. During recent meetings on critical benchmark needs, steel, iron, and chromium have been listed as priorities.

A series of measurements in the intermediate energy region starting with iron and moving to different forms of steel with varying chromium concentrations would help to pinpoint energy regions in the iron and chromium cross sections which are problematic, and would help nuclear data evaluators develop more accurate evaluations. They would also be very useful to the nuclear criticality safety community (and other communities) as these materials are used extensively.

Figure 1 shows the preliminary experiment design of a series of critical assemblies sensitive to iron and chromium in the intermediate energy region. This measurement would use the COMET assembly – a large vertical lift assembly. The Jemima HEU plates would be used with large layers of iron or steel and thin layers of moderators are used to moderate neutrons into the intermediate energy region. Surrounding the core are large copper reflectors to reflect neutrons back into the core (iron reflectors are also being investigated). A series of three experiments would be completed with iron and steels with different compositions. Since the fuel and reflectors are already available at NCERC, only the moderating material and iron/steels would need to be manufactured for these experiments.

A number of steels and alloys are being examined as potential measurement candidates. In particular, stainless steel 304 is one of the most widely used steels and additional benchmarks could be very beneficial to many communities. Stainless steel 304 also has a relatively high chromium content (18 % to 20 %). Another candidate material is FeCrAl, also known as C26M and IronClad, which is being developed by Oak Ridge National

Laboratory and General Electric as an accident tolerant cladding material[3]. The elemental compositions of carbon steel, IronClad, and SS 304 have been listed in Table 1 below. Other iron/chromium alloys are also being investigated, including pure chromium (although early analysis suggests pure chromium would be cost prohibitive). Additionally, it may be useful to measure other minor steel elements such as manganese or nickel, this may be explored in a future proposed measurement series.

Table 1: Compositions of various metals being investigated, in percent.

	Carbon Steel AISI 1018	IronClad/C26M	SS 304
Fe	98.81-99.26	79.95	66.5-74.0
Cr	0	12	18.0-20.0
Ni	0	0	8.0-10.5
Mn	0.60-0.90	0	≤2.0
Al	0	6	0
Si	0	0	≤0.75
N	0	0	≤0.10
C	0.14-0.20	0	≤0.08
P	≤0.04	0	≤0.045
S	≤0.05	0	≤0.03
Mo	0	2	0
Y	0	0.05	0

There was one recent series of measurements similar to this performed at NCERC, the HMF072 series in the ICSBEP using carbon steel (~99% Fe), the Jemima HEU plates, and polyethylene plates as moderators[4]. However, these measurements were classified as "fast" (>50% of fissions occurring above 100 keV incident neutron energy). The goal of this new series of measurements would be to create intermediate energy systems, with a high sensitivity to intermediate cross sections.

By adjusting the thickness of the moderating material, the energy spectrum of each of these measurements can be tuned to be harder or softer. Work is also underway at LANL to develop optimization techniques for designing new critical experiments, and this methodology will be used to optimize the performance of the proposed systems.

SUMMARY

A new series of benchmark experiments has been proposed by NCERC to measure iron and various iron/chromium alloys, and input and feedback are requested from relevant stakeholders. In particular, NCERC is requesting information on how to design these measurements to be most useful to many different communities, including but not limited to nuclear criticality safety, nuclear data, and reactor design (including accident tolerant materials).

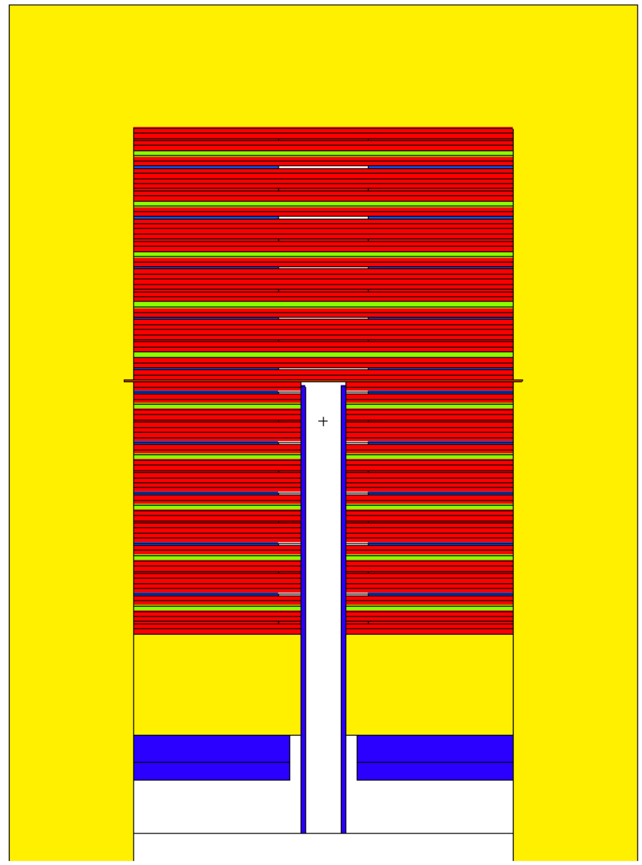

Fig. 1. Potential experiment geometry. Layers of red are iron, layers of blue are HEU, and layers of green are moderating material.

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