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Visualizing the Connections in the EXFOR Database

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The EXFOR database contains many datasets (over 6160) in which the measured values are reaction combinations, which means that they are not an absolute measurement of an experimental quantity. Rather, they are ratios of quantities, sums of quantities, or some other mathematical relation of experimental quantities. These reaction combinations couple large numbers of data sets together in non-trivial ways. Here a visualization is presented of the coupled data used to derive cross material covariances for the COMMARA-3 library. Links are provided to other larger visualizations on the NNDC website.

I. INTRODUCTION

EXFOR contains the most extensive compilation of experimental nuclear reaction data available [1, 2]. Neutron reactions have been compiled in EXFOR systematically from the discovery of the neutron, while charged particle and photon reactions have been covered less extensively. EXFOR contains nearly all neutron reaction data and all international evaluated nuclear reaction libraries evaluate data extracted from EXFOR in some fashion. EXFOR is the natural place too look for correlations between experimental measurements.

We have begun exploring correlations between a small subset of measurements in the EXFOR database and have developed diagrammatic representations of how they connect to one another. The resulting visualization is given in Fig. 1. This figure is more than just "eye candy", we can look for connections in the data that had previously been overlooked, and exploit connections that are underexploited.

II. HOW DO WE USE EXFOR?

Data is EXFOR is arranged into ENTRY(s) each corresponding to one piece of experimental work. Each work may consist of many separate experiments and hence data sets. The keyword-tagged fields in the BIB section of an EXFOR ENTRY describe in great detail the tabulated data sets. For our purposes, the most important fields for understanding what was measured are the REACTION fields and the MONITOR fields. The REACTION field describes what nuclear reactions and quantities were measured while the MONITOR field denotes what reactions and quantities were used to normalize the data denoted by the REACTION field. Both the MONITOR and REACTION fields are coded in the same way. Here is an example of a MONITOR field:

```
MONITOR    (1-H-1(N,EL)1-H-1,,DA)
```

In this case, the monitor was a measurement of $d\sigma/d\Omega$ for ^{1}H(n,el).

The EXFOR library contains over 51,341 data sets in which the measured values are made relative to a monitor, along with many reaction combinations which are not an absolute measurement of an experimental quantity. Rather, they are ratios of quantities, sums of quantities, or some other mathematical relation of experimental quantities that are not coded in the MONITOR fields. There are 6,129 sets containing reaction combinations in EXFOR of which this is an example:

```
REACTION   ((94-PU-239(N,F),,NU,,MXW)/
           (92-U-235(N,F),,NU,,MXW))
```

In this case, the measurement was the ratio of Maxwellian averaged $\overline{\nu}_p$ from ^{239}Pu(n,f) and ^{235}U(n,f).

III. VISUALIZATION

Given the large number of data sets, monitors, isotopes, *etc.* in the EXFOR library, consideration of all possible connections would result in a diagram too large to display in a poster format. Indeed, initial tests resulted in diagrams that would need paper the size of 1.5 football fields in area so that the node labels could be read. We were able to generate a smaller visualization which includes only the coupled data in EXFOR. This required a Google Maps-like interface handle the display which could only be displayed on-line [3]. To generate a

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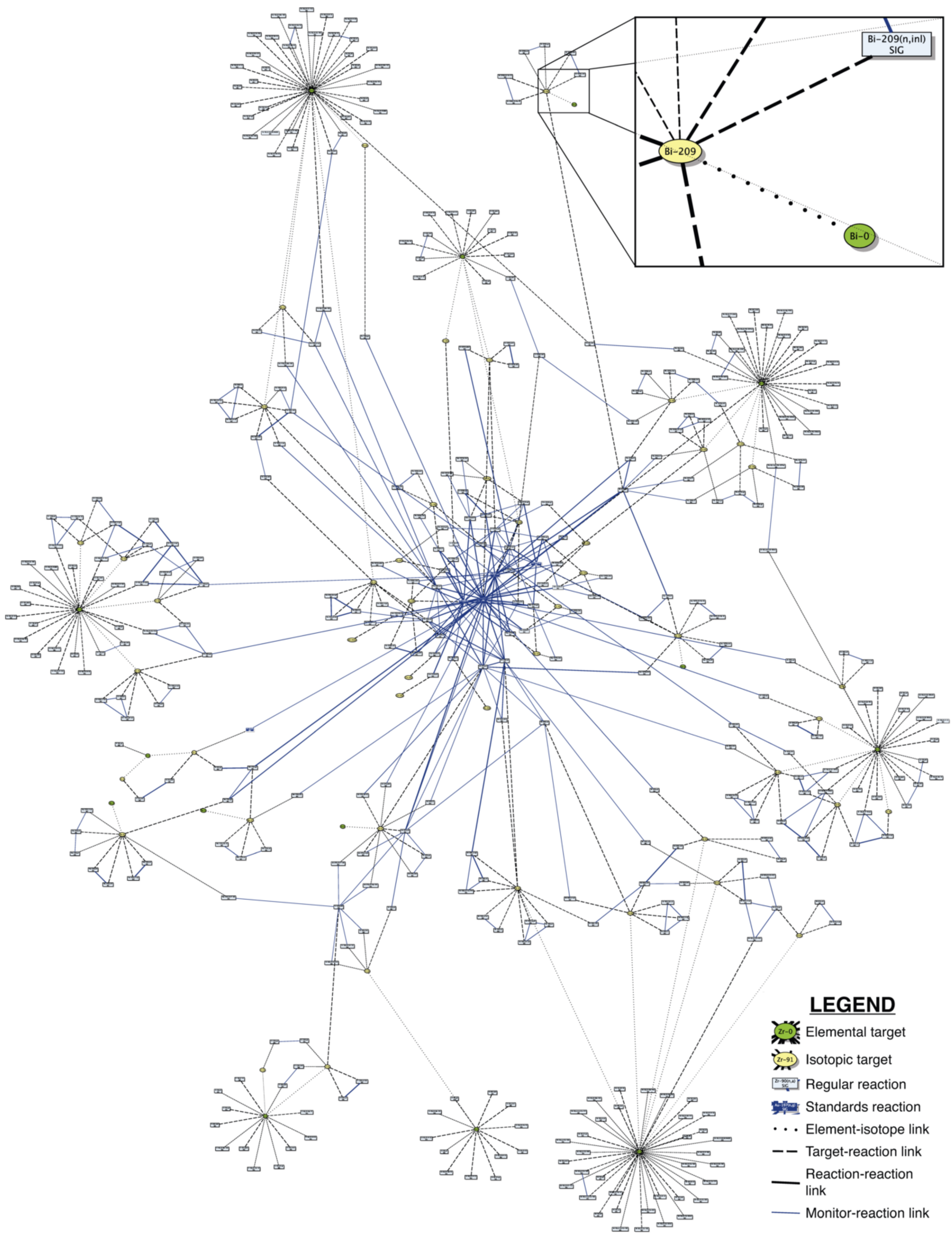

FIG. 1. The visualization as described in the main text; inset in the upper right shows the region around ^{209}Bi and illustrates how the figure appears at higher resolution.

visualization of the EXFOR library that is both meaningful and practical, we limit our consideration to the following:

- Cross-section measurements,
- Neutrons as projectiles, and
- Forty-two highest priority materials in the COMMARA-2.0 library [4]: $^{1-3}$H, ^{nat}C, ^{16}O, ^{23}Na, ^{27}Al, ^{50,52,53}Cr, ^{54,56,57}Fe, ^{58,60}Ni, ^{55}Mn, $^{90-92,94}$Zr, ^{197}Au, $^{204,206-208}$Pb, ^{209}Bi, ^{234,235,238}U, ^{237}Np, $^{238,239-242}$Pu, ^{241,242m,243}Am, and $^{242-245}$Cm.

We used x4i to parse the EXFOR REACTION and MONITOR fields [5]. X4i enters this information in a searchable database and logs whether data are coupled or whether there was a reaction monitor. We distilled this database into undirected graphs and outputted them in GraphML format [6]. These graphs consist of a list of nodes (representing reactions and targets) and the links that connect them. The graph was then rendered by minimizing link distance and node overlap using yEd [7], resulting in the clustering seen in Fig. 1.

The central cluster consists of Neutron Standards [8] cross section nodes and actinide reaction/isotope nodes. These correspond to data commonly used as reaction monitors or normalization so are highly connected nodes. The Neutron Standards were chosen specifically so that experimenters can use them as monitors or for normalization and are very precisely known; arguably all cross section measurements should couple to these standards.

Surrounding the central cluster is an inner halo of nodes corresponding to reactions and isotopes connected to the central cluster nodes. The reactions in this area are directly or indirectly coupled to the Neutron Standards.

The outer "star bursts" are not very well (if at all) connected to the Neutron Standards. Counter-clockwise starting at the inset, the clusters correspond to Bi, Fe, Cr, Na, C, O, N, Zr and Pb. In each cluster, the central node is an element node and all the reactions surrounding it couple only to this element node. These reaction nodes do not use reaction monitors or other normalization and are absolute cross section measurements. This means key reaction data for carbon and sodium are not pinned to a Neutron Standard.

IV. CONCLUSIONS

Although this work is preliminary, the ongoing exercise raises several issues regarding the Neutron Standards and the Collaborative International Evaluated Library Organization (CIELO) projects [9] that can be addressed in a follow-on study. The neutron cross section standards [8] were developed so that one can measure cross sections relative to a standard rather than develop a direct measurement of a cross section. The CIELO project has been initiated to evaluate all reactions on several key target materials [9]. One expects that standards reactions are the most coupled reactions and the CIELO materials are the most coupled targets. Both raise questions that can be answered by means of an extension to this project:

- What are the most connected targets? What are the most connected reactions/quantities?
- Are there reactions/quantities that are so connected that they should be a standard?
- What is the connection number distribution for targets and reactions? What is the link number distribution between any two targets?
- Can we use this information to inform new measurements that decrease the distance between important targets and standards?
- Are there "bottlenecks" along the pathways from a given reaction to reaction standards that are not well measured?
- What elements and isotopes of reactions are not linked? Are any of them important for specific applications?

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