NICER CALIBRATION:
Response Version History

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Version 1.0 2018-12-13 Initial Version
Version 2.0 2020-07-17 Updates for calibration release xti20200722
Version 2.1 2021-07-07 Update for CALDB release xti20210707 (off-axis ARF & RMF calculators)
Version 2.2 2022-10-01 Addition of "diagonal" response for non-X-ray background

Introduction

NICER response files provide the information required for spectral fitting of NICER X-ray data. The files are composed of the Ancillary Response File (ARF), which contains effective area information, and the Response Matrix File (RMF), which contains the redistribution properties of NICER focal plane module detectors. This document describes the versions released or considered in depth by the NICER calibration team.

ARF (Ancillary Response File) - contains the effective area and throughput terms associated with the X-ray Concentrator (XRC) modules. Specifically, it captures the energy-dependent effective collecting area of the concentrator reflectors, in addition to absorption in their thermal protection films. The detector quantum efficiency and window transmission are also included in the ARF.

The calibration team has used two different methods for ARF calculation:

- CONSIM, a full physics-based ray trace simulation of the NICER optics performance
- A semi-analytical calculation with some physics, which has produced reasonable results below 6 keV.

The ARF is characterized in terms of parameters that control the reflectivity and image quality of the XRCs. These are typically labeled as gold density ρ in g/cm^3, and surface roughness σ expressed in Angstroms.

RMF (Response Matrix File) - contains the photon-energy-to-channel redistribution terms associated with detector physics, based on the model of Scholze & Procop (2009; *X-Ray Spectrometry* **38**, 312) for silicon drift detectors. The RMF contains the electronics trigger

threshold efficiency function, which is pulse-height dependent. Because of this threshold effect, the rows of the RMF may not sum to unity.

IMPORTANT NOTES: Both the ARF and RMF files stored in NICER CALDB are the "on-axis array-average" files. On-axis means that the ARF is not appropriate for off-axis observations of targets. Array average means the files reflect the performance of 52 detectors as a whole. Please contact the Guest Observer Facility if you have an off-axis observation or fewer than 52 operating detectors in your observation.

Ancillary Response File (ARF) History

Public Release	NICER CALDB Ver	Internal Name	CALDB Date String	Comments
N/A		1.00		ARF derived from CONSIM ray-trace, not distributed to NICER team or to the public.
N/A		1.01		Semi-analytical ARF calculator; gold surface parameters ρ=18.95, σ=4.92A
2018-04-19	xti20180419	1.02	20170601v002	Gold surface parameters ρ=19.30, σ=3.50A. Note that version 20170601v001 in CALDB is not a valid ARF, but is numerically equivalent to this version.
N/A		1.03		Private internal version, not distributed to NICER team or to the public. No numerical change from 1.02
N/A		1.04		Private internal version, not distributed to NICER team or to the public. No numerical change from 1.02
2020-02-02	xti20200202	CONSIM135o	20170601v003 *nicer-arf-consim135o-teamonly-array52.arf*	Major shift to CONSIM (v1.35) method of ARF calculation. Per-shell optimization *("August 2019 Cal Summit")*

2020-07-22	xti20200722	CONSIM135p	20170601v004 *nicer-consim135p-teamonly-array52.arf*	CONSIM method of ARF calculation. New photon energy bin scale. Matches RMF version 6s *("March 17 2020 Release")*
2021-07-07	xti20210707	N/A	*Derived*	New ARF calculator 'nicerarf' uses observational conditions to create ARF for each spectrum individually (see last section of this document)

Table Notes: All files appear in NICER Calibration Database as `nicer/xti/cpf/arf/nixtiavonaxis`*SSSSSSSS*`.fits,` where *SSSSSSSS* is the CALDB Date String. Items listed in italics in the table are pre-release names used for internal testing purposes.

Comparison of NICER ARF to Other Observatories

Figure 1 shows a comparison of the NICER effective area as a function of energy to other recent flagship X-ray observatories that operate in a comparable bandpass.
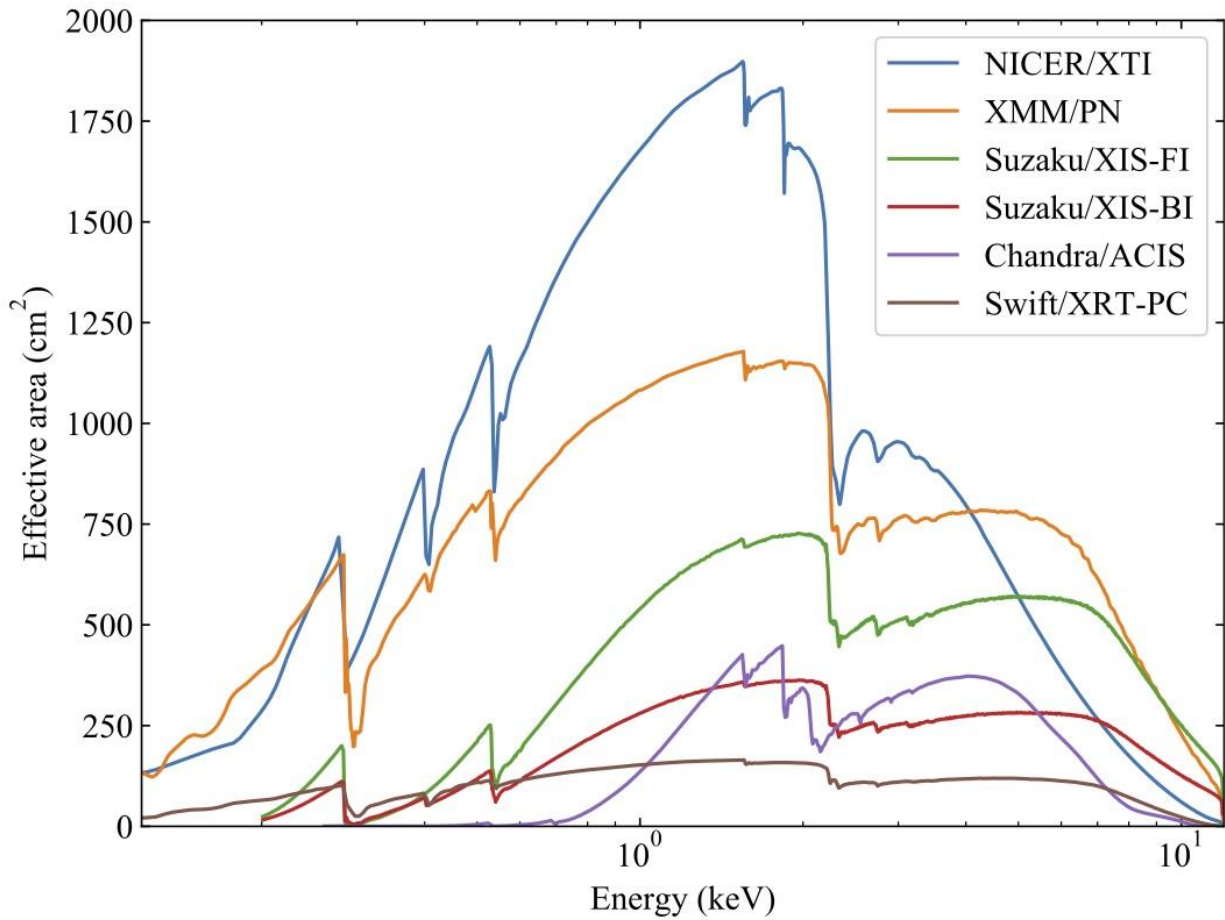
Figure 1. Effective area comparison of NICER (v1.02) and other active X-ray observatories. For other observatories, the public "proposal" responses are used (except for XMM/PN, date 2015-09-19).
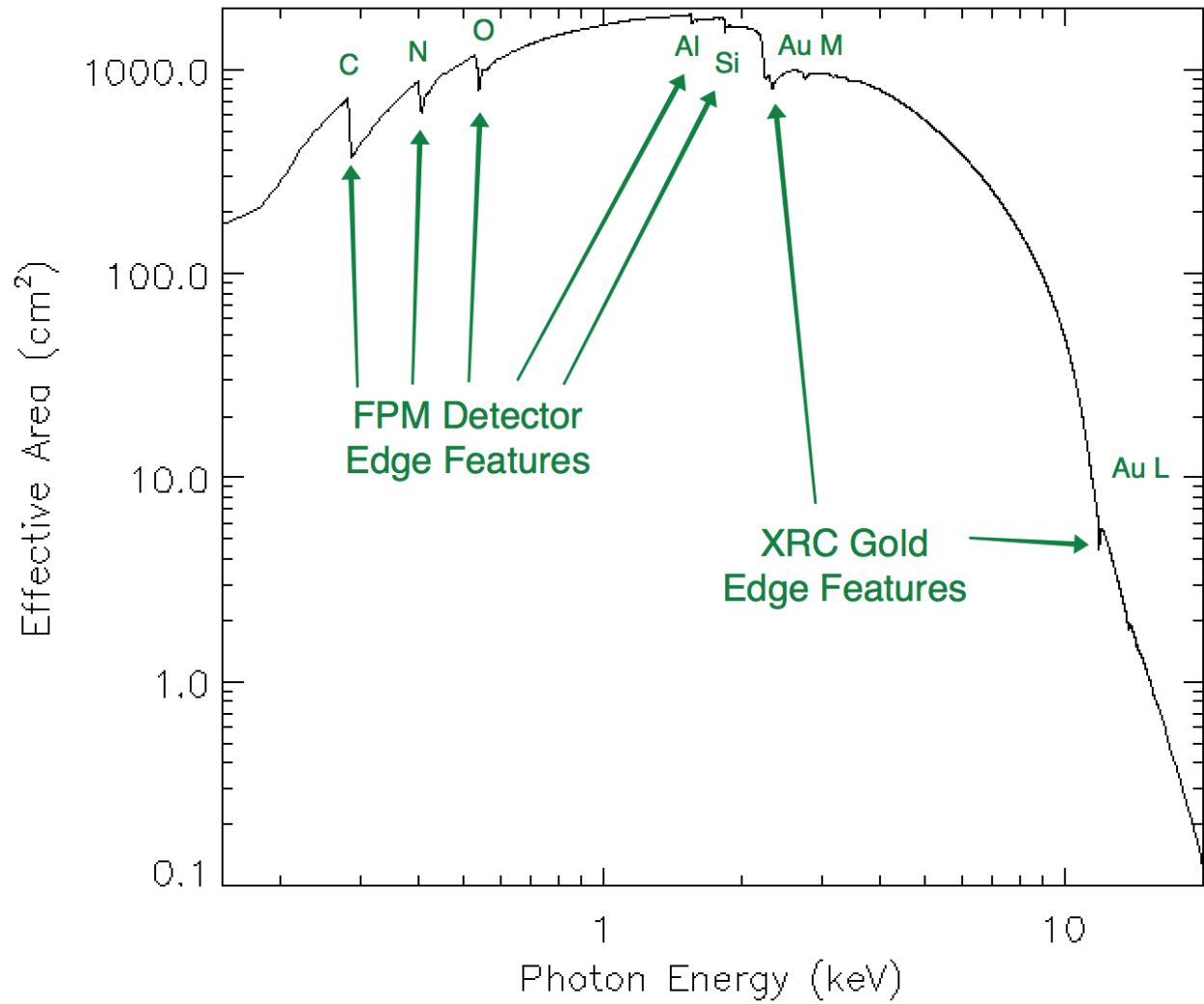
Figure 2. NICER full-array effective area for release xti20200722 (sum of 52 post-launch active detectors). Key spectral features relating to detector and optical physics are indicated.

Response Matrix File (RMF) History

Public Release	NICER CALDB Ver	Internal Name	CALDB Date String	Comments
N/A		Pre-1.00 versions		Not widely distributed outside of calibration team. Assumes trigger efficiency in ARF and not RMF
2018-04-04	xti20180404a	1.00	20170601v001	RMF contains trigger efficiency. Available publicly in NICER CALDB since version xti20180605
N/A		1.01		No change from 1.00; version number incremented to match ARF version 1.01
N/A		1.02		No change from 1.01; version number incremented to match ARF version 1.02
N/A		upd52	*nicer_upd_d52 .rmf*	Further refinements to model. Not recommended for general use *("August 2019 Cal Summit")*
2020-07-22	xti20200722	6s	20170601v002 *nicer-rmf6s-tea monly-array52. rmf*	Significant update: New photon energy binning to match ARF CONSIM135p Improvements to trigger efficiency Improvements to >9 keV response Improvements to <2 keV shelf *("March 17 2020 Release")*
2021-07-07	xti20210707		`nixtirmfbase 20170601v001` *Derived*	New RMF calculator 'nicerrmf' uses observational conditions to create RMF for each spectrum individually (see last section of this document)

Table Notes: All files appear in NICER Calibration Database as `nicer/xti/cpf/rmf/nixtiref`*SSSSSSSS*`.fits`, where *SSSSSSSS* is the CALDB Date String. Items listed in italics in the table are pre-release names used for internal testing purposes.

Figures 3 and 4 show example response matrix charts. Figure 3 is an example of one "slice" of the matrix, for an input photon energy of 3.75 keV. The main photo-peak is visible, with resolution-induced broadening. The photopeak's low energy tail and shelf features are consequences of partial charge collection. The rolloff at low energies is due to the trigger efficiency (i.e. gradual low energy threshold effect). This is a plot of probability per 10 eV PI bin; the sum of the values is nominally unity (1.0), with some reduction due to the loss of events below the low-energy threshold. Fluorescence and escape are also visible. Figure 4 shows the full response matrix as a logarithmic intensity diagram over the full 0-15 keV range of NICER.
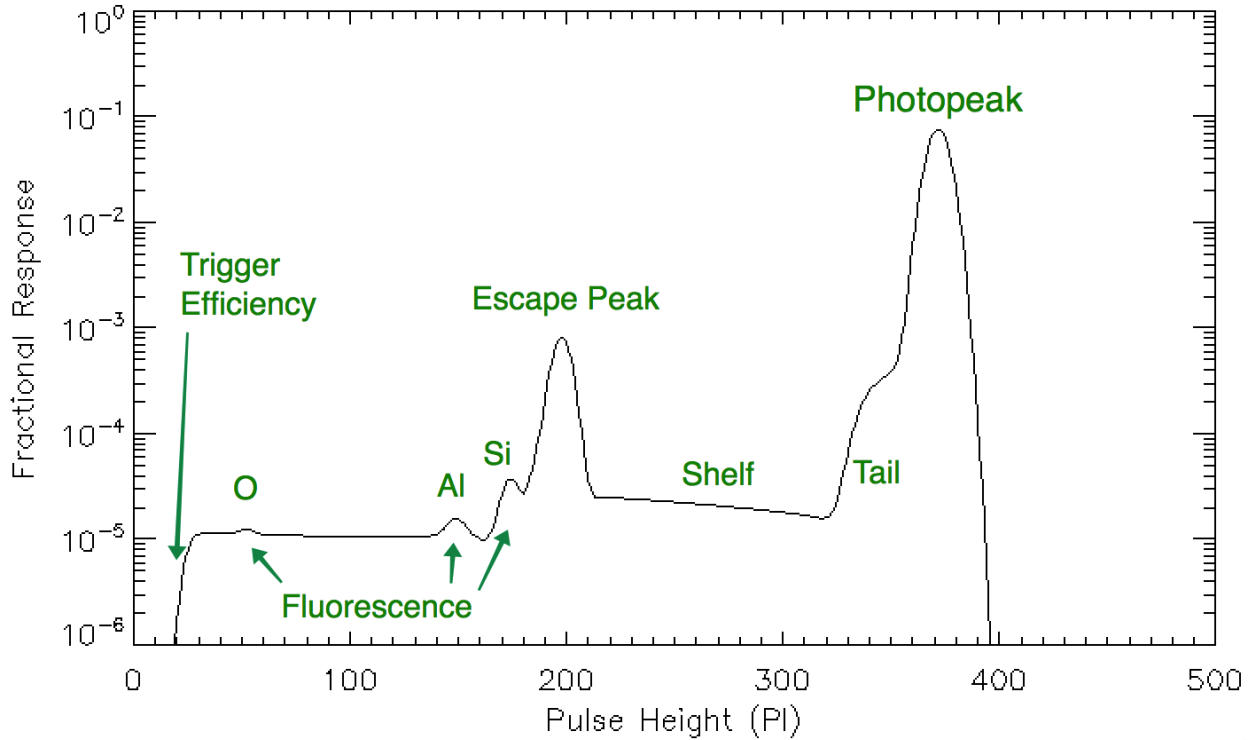

Figure 3. Example redistribution (RMF) for photon energy of 3.75 keV for release xti20200722. The X axis is pulse height in PI units (1 PI = 10 eV). The Y axis is probability per PI bin.
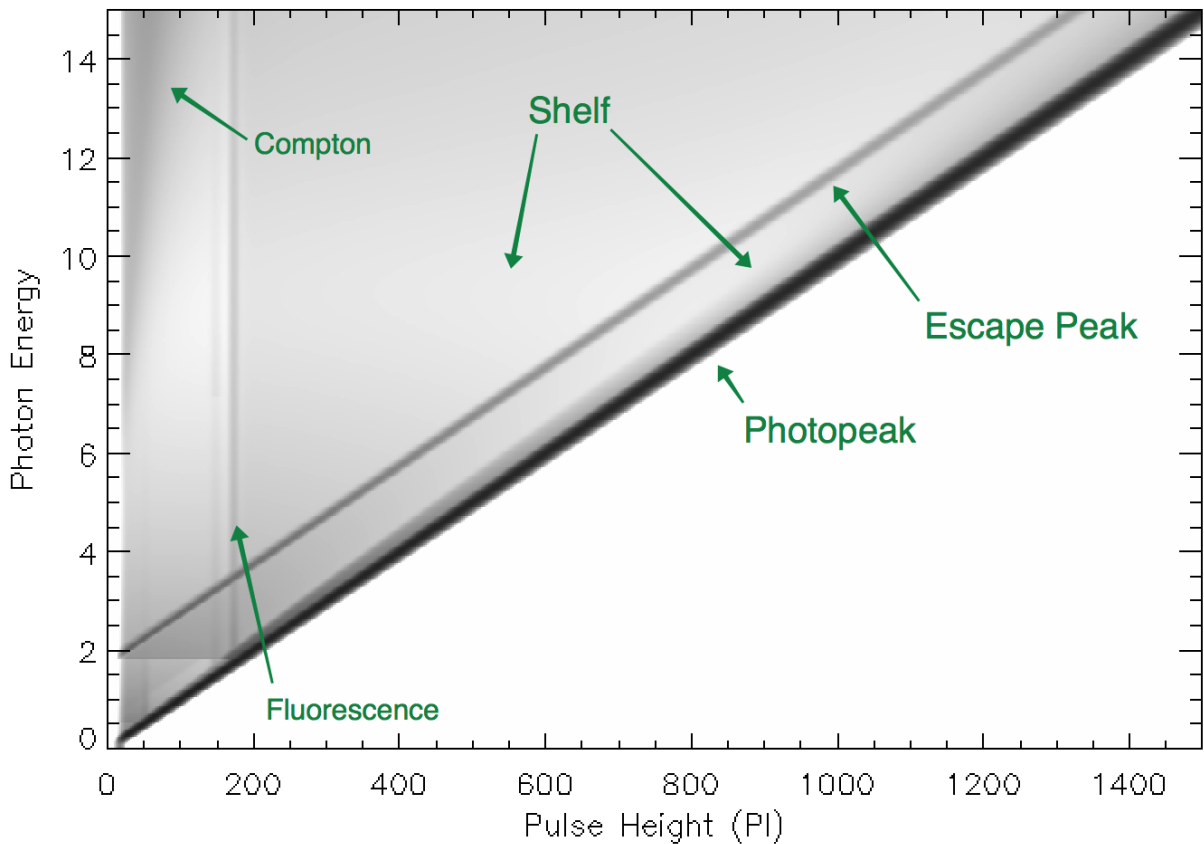
Figure 4. Full two dimensional NICER full-array average response matrix (calibration release xti20200722). The X axis is pulse height as PI (1 PI = 10 eV), and the Y axis is incident photon energy. The logarithmic intensity scale is probability per PI bin, ranging from 10-6 (white) to 1 (black). Key features are indicated.

ARF and RMF Calculators (HEASoft 6.29 and later)

Beginning with HEASoft 6.29 (NICERDAS version 8), the NICER software is capable of calculating a response which is based on the specific observing conditions encountered by NICER during the accumulation of a given spectrum. In addition, the ARF now includes the effects of off-axis throughput changes (i.e. vignetting) as well as detector on-off history.

Because of these significant changes, NICER's ARF and RMF calibration products are no longer stored as precomputed files. Rather, the CALDB stores "base" generic files which contain the basic information used to calculate a specific ARF or RMF.

The NICER ARF depends primarily upon the following variable quantities,

- Off-axis angle; used to compute vignetting factors

- Which detectors are enabled/disabled (or selected/deselected); used to calculate ARF contribution of active detectors

The NICER RMF depends primarily upon the following variable quantities,

- Optical loading (undershoot count rate); used to compute broadening of response as well as low energy trigger efficiency function

Information needed to retrieve these quantities are stored in the NICER filter file (niNNNNNNNNNN.mkf).

The following CALDB files are used to compute the ARF.

- nixtixrcalignparamYYYYMMDDvVVV.fits - boresight alignment and tip-tilt of each module
- nixtivignetteYYYYMMDDvVVV.fits - off-axis vignetting profiles for individual shells
- nixtioffareashellYYYYMMDDvVVV.fits - on-axis energy-dependent ARF
- nixtixrcshellparamYYYYMMDDvVVV.fits - per-shell throughput and roughness factors
- nixtidetqeYYYYMMDDvVVV.fits - detector quantum efficiency function
- nixtidettranYYYYMMDDvVVV.fits - detector entrance window transmission function
- nixtixrctranYYYYMMDDvVVV.fits - XRC thermal shield transmission function
- nixtixrccorrYYYYMMDDvVVV.fits - XRC spline correction function

These files are documented in the calibration documents "NICER-Det-Params-20210707" and "NICER-Window-Transmission-20210707."

The following CALDB files are used to compute the RMF.

- nixtirmfbaseYYYYMMDDvVVV.fits - "base" RMF with standard broadening and no trigger efficiency function applied
- nixtipidetparamYYYYMMDDvVVV.fits - detector parameters for slow channel ("PI") which have the resolution and trigger efficiency parameters of each module

These files are documented in the calibration documents "NICER-Det-Params-20210707."

Diagonal Response Matrix File (RMF) History

Public Release	NICER CALDB Ver	CALDB Date String	Comments
2022-10-20	xti20221001	20170601v001	Initial release

Table Notes: All files appear in NICER Calibration Database as `nicer/xti/cpf/rmf/nixtidiagresp`*SSSSSSSS*`.rmf`, where *SSSSSSSS* is the CALDB Date String.

Beginning in October 2022, NICER releases a "diagonal" response file. This response file should *not* be used for X-ray source modeling. Rather, it is used for background modeling.

The diagonal response contains a purely diagonal response matrix, with no resolution or other off-diagonal response terms that would be included for X-ray analysis. In addition, the trigger efficiency function is not modeled. This file is only suitable for modeling of non-X-ray backgrounds such as the noise peak or particle backgrounds that do not enter through the normal optical path. Since the matrix is diagonal the models to be used with it will be phenomenological in nature.

This file is index in CALDB with the following important boundary keywords

- CHANTYPE(PI) - slow channel only
- DETNAM(91) - diagonal only
- RMFTYPE(DIAG) - diagonal only

Users querying CALDB should not retrieve this file for normal analysis.