

Chapter 4

SAMPLE COLLECTION AND DOCUMENTATION

**Harry M. Cullings, Shoichiro Fujita, Tadaaki Watanabe,
Tomoaki Yamashita, Kenichi Tanaka, Satoru Endo, Kiyoshi Shizuma,
Masaharu Hoshi, Hiromi Hasai**

Introduction

Beginning within a few weeks after the bombings and periodically during the intervening decades, investigators in Hiroshima and Nagasaki have collected samples of materials that were in the cities at the time of the bombings. Although some early efforts were not driven by specific measurement objectives, many others were. Even some of the very earliest samples collected in 1945 were based on carefully conceived research plans and detailed specifications for samples appropriate to particular retrospective measurements, i.e., of particular residual quantities remaining from exposure to the neutrons and gamma rays from the bombs. This chapter focuses mainly on the work of groups at two institutions that have actively collaborated since the 1980s in major collection efforts and have shared samples among themselves and with other investigators: the Radiation Effects Research Foundation (RERF) and its predecessor the Atomic Bomb Casualty Commission (ABCC), and Hiroshima University. In addition, a number of others are listed, who also contributed to the literature by their collection of samples.

In the following sections we provide an historical account of collection efforts and their relationship to technologies of measurement and a summary of what is presently known about the locations where various groups of samples were collected in various time periods. The information on the exact *in situ* locations of newer samples (i.e., those from the DS86 period and later) is typically much better than that for earlier samples. We also attempt here to provide a complete listing and documentation of all of the sites from which samples have been measured. We include a cross-referencing, where possible, to the excellent collections of detailed materials about buildings and other sites that are published in books by the Hiroshima Peace Memorial Museum and the city of Nagasaki (Museum 1996; Nagasaki 1996), and we provide images showing important sample site locations on pre-bombing aerial photographs (Figures 1-5).



Figure 1. Pre-bombing aerial photograph of area near the hypocenter in Hiroshima: 1 = Shima Hospital; 2 = Hiroshima Central Post Office; 3 = Saikou Temple; 4 = Motoyasu Bridge; 8 = A-bomb Dome; 9 = Fuel Authority Building (now Rest House at Peace Park).

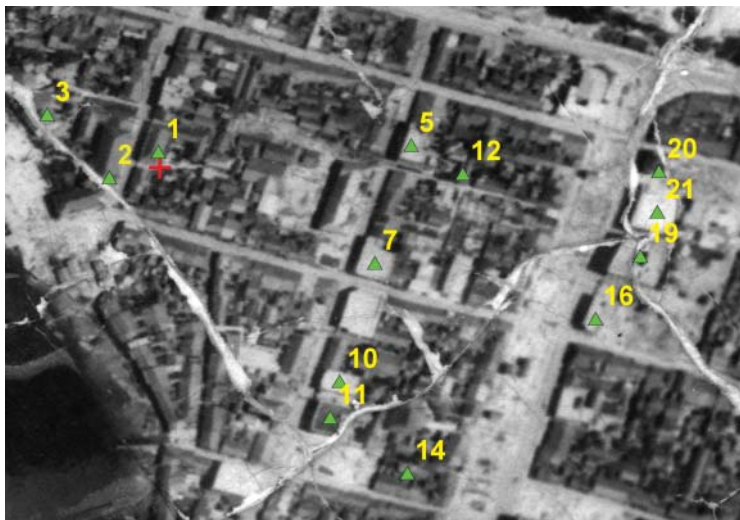


Figure 2. Pre-bombing aerial photograph of proximal area to the east of the hypocenter in Hiroshima: 1 = Shima Hospital; 2 = Hiroshima Central Post Office; 3 = Saikou Temple; 5 = Chiyoda Life Insurance Company; 7 = Daiichi Bank; 10 = Nihon Life Insurance Company; 11; Bankers Association; 12 = Shoujun Temple; 14 = Sensho Temple; 16 = Yasuda Life Insurance Company; 19 = Sumitomo Bank; 20 = Daido Life Insurance Company; 21 = Hiroshima (Geibi) Bank.



Figure 3. Pre-bombing aerial photograph of proximal area to the north of the hypocenter in Hiroshima: 6 = Torii (gate) at entrance to Gokoku Shrine Road; 8 = A-bomb Dome; 13 = Chamber of Commerce & Industry; 15 = Monument of Victory; 23 = Gokoku Shrine; 24 = Torii (gate) at north entrance to Gokoku Shrine; 27 = Motomachi Stone Wall.

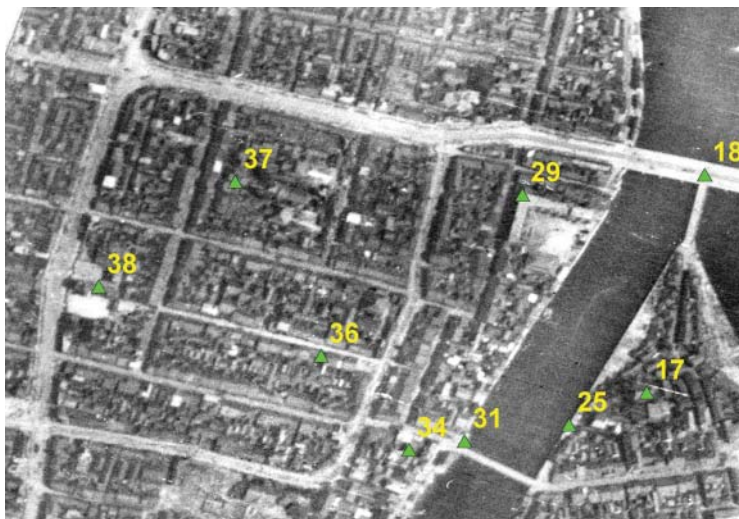


Figure 4. Pre-bombing aerial photograph of proximal area to the west of the hypocenter in Hiroshima: 17 = Jisen Temple; 18 = Aoi Bridge; 25 = Honkawa Stone Wall; 29 = Honkawa Primary School; 31 = Honkawa Bridge Stone Wall; 34 = Geibi Bank, Tsukamoto Branch; 36 = Kyouden Temple; 37 = Myouchou Temple; 38 = Koudou Primary School.

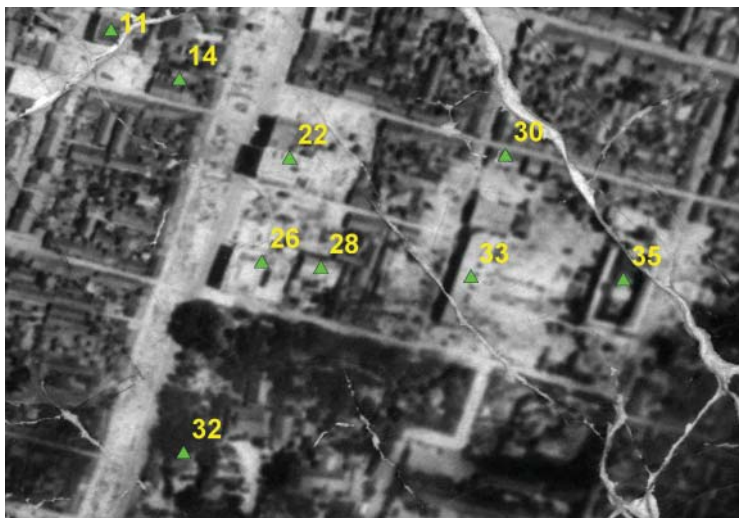


Figure 5. Pre-bombing aerial photograph of proximal area to the south and southeast of the hypocenter in Hiroshima: 11 = Bankers Association; 14 = Sensho Temple; 22 = Fukoku Life Insurance Company; 26 = Bank of Japan; 28 = Sanyo Memorial Hall; 30 = Fukuomachi East Orthopedic Surgical Hospital; 32 = Shirakami Shrine; 33 = Fukuomachi Primary School; 35 = Hiroshima Central Telephone Office.

Historical Chronology and Technical Basis for Sample Requirements

The history of sample collection can be divided chronologically into three main phases:

- 1) a period of several months immediately after the bombing,
- 2) a period of several years at the beginning of the 1960s, and
- 3) an extended period of ongoing activity from the beginning of the 1980s until the present day.

The first of these periods relates primarily to the initial efforts of Japanese scientists to investigate the physical nature of the bombings, The last two phases coincide with larger efforts at a quantitative system of dosimetry, which resulted in the T65D system in the first case, and the DS86 and DS02 systems in the second, and have increasingly reflected international participation and collaboration.

The types of samples taken have been related to the measurement technologies that have been developed. In the case of thermoluminescence, the requirement is for materials of a ceramic nature that were raised to high temperatures by firing during their manufacture at some reasonably well estimated time before the bombing (Maruyama et al. 1987). Because materials that are part of permanent structures are most desirable, because of being able to ascertain their *in situ* locations at the time of the bombings, the materials of choice have been tiles and bricks, and because investigators have not changed the signal they seek to measure except in certain details, the nature of the samples likewise has not changed.

On the other hand, the types of materials used for measuring neutron activation have changed dramatically over the years, driven by the different types of activation products that have been measured. The choice of sulfur for measuring fast neutron activation promptly after the bombing was a remarkable insight, especially given the relatively simple geometry of insulators suspended on poles, the easily determined locations on major streets, and the virtual chemical purity of the sulfur paste (Hamada 1983). Unfortunately, the method could never be reproduced because of the short half-life of the activation product ^{32}P (half-life ~14 d).

Because no other fast neutron activation products were apparent possibilities for measurement, attention turned to attempts to measure thermal neutron activation products, when efforts resumed in the 1960s. Based on the insight that ^{60}Co would be produced by interactions of thermal and epithermal neutrons with natural Co that is typically contained as impurities of fairly substantial concentration in iron and steel, some early measurements were made circa 1960 on samples of fairly simple geometry (Saito 1987). However, as investigators began to appreciate that the relationship of fast and thermal neutron fluences was complicated in its dependence on local conditions and hard to calculate, the attention for the majority of the 1960s turned to samples embedded in concrete (reinforcement bars, or “rebars”). This was based on the premise that the moderation of faster incident neutrons by the overlying and surrounding concrete could be quantitatively estimated and would allow such samples to be used, in effect, as fast neutron dosimeters (Hashizume et al. 1967). Even at the time when measurements of ^{60}Co in “surface” samples of iron and steel, made in 1965, were first reported at a workshop in 1983, the difficulty of evaluating the relationships between fast and thermal neutrons was pointed out (Hashizume 1983). In the DS86 Final Report, although investigators had begun efforts to measure and understand ^{60}Co activation vs. depth in massive iron structures (Hoshi and Kato 1987), the predominant comparisons used were based on the concrete rebar samples (Loewe et al. 1987). Only in the period after DS86 did investigators begin to measure more “surface” samples of iron and steel and samples of more complicated geometry (Kerr et al. 1990; Kimura et al. 1990; Shizuma et al. 1992; Kimura and Hamada 1993; Shizuma et al. 1993; Shizuma et al. 1998), and this option rapidly diminished due to the relatively short half-life (~5 y) of ^{60}Co .

Because of the short half-life of ^{60}Co and the relative scarcity of surviving structures containing iron and steel, especially in Nagasaki, investigators began to seek an alternative, beginning in the early 1980s (Hashizume 1983; Okajima and Miyajima 1983; Sakanoue et al. 1987). Attention turned to the activation product ^{152}Eu , which has a longer half-life (~13 y) and is produced from natural Eu by interaction with thermal neutrons, natural Eu being ubiquitous in the lithosphere of the earth. A few measurements were also made on the similar activation product ^{154}Eu (Nakanishi et al. 1987; Rühm et al. 1990). Although Eu is typically found only in ppm concentrations in rocks such as granite, and is typically even more dilute in building materials such as concrete, it has an extraordinarily large nuclear cross section for interaction with thermal neutrons. Thus, it could be measured in rocks and in a variety of manmade building materials derived from minerals, particularly after techniques were developed for chemical enrichment of samples in Eu (Shizuma et al. 1993).

When the technique of accelerator mass spectroscopy (AMS) began to be developed for environmental measurements of neutron activation products, it allowed the detection of products with radioactive half-lives far too long to allow their detection by radiation counting methods at the concentrations of interest. This afforded an alternative to ^{152}Eu in the form of another thermal neutron activation product, ^{36}Cl (half-life ~300,000 y), which was first measured by German

investigators in collaboration with Japanese colleagues beginning in the early 1980s (Haberstock et al. 1986; Kato et al. 1990; Straume et al. 1992). ^{36}Cl could be measured in the same types of samples as ^{152}Eu , such as rocks, as well as in samples in which Eu is so dilute that effective measurement of ^{152}Eu at the desired levels requires chemical reduction of very large samples, such as some types of concrete. The complicated pros and cons of ^{152}Eu vs. ^{36}Cl , and the pros and cons of concrete vs. rock samples for measuring ^{36}Cl , are explained in Chapter 8. German and Japanese investigators also pioneered the measurement of another neutron activation product by AMS, ^{41}Ca , in the late 1980s (Rühm et al. 1990; Rühm et al. 1992).

The most recent development occurred beginning in the 1990s, when investigators realized that an isotope of nickel with a fairly long half-life (~ 100 y), ^{63}Ni , is produced by interactions of fast neutrons with copper (Shibata et al. 1994). Although tremendous sample enrichment chemistry is required to measure the concentrations of interest, ^{63}Ni can be measured via both radiation counting and AMS methods. And although samples of copper are very difficult to find, particularly samples of structural materials of adequate purity, the prospect of being able to measure fast neutron activation directly, rather than by proxy via thermal neutrons, has led to considerable effort, reflected in Chapter 9 of this work, which contains a much more extensive discussion of the conception and development of ^{63}Ni measurements by U.S., German, and Japanese investigators.

These developments are discussed in more detail, with respect to particular sample collection efforts, in the following sections.

1945

Sulfur Samples. Within a few weeks after the bombing, groups of Japanese investigators collected samples of sulfur paste that was used in porcelain insulators on poles carrying electrical power in Hiroshima, with the specific intent of measuring the radioisotope of phosphorous produced from sulfur by interactions of fast neutrons. The more useful of these for which records were available for analysis in later years were taken from locations documented on a map by F. Yamasaki, as reported by T. Hamada (Hamada 1983), and, as they were located on major streets and have fairly specific place names, could be estimated fairly accurately for this work. These samples and the related measurements are discussed in detail in Chapter 9.

Geological Survey. Between 27 October and 3 December, 1945, a team of Japanese investigators led by T. Watanabe collected a number of samples within about 1.5 km radius from the hypocenter in Hiroshima for an early geological survey related to bomb damage (Watanabe et al. 1954). A field notebook giving dates and locations was also kept by Hide, who collected the samples. These included samples of stone and roof tiles. They were found years later by investigators at Hiroshima University, as discussed further below.

Soil Samples. On August 9, 1945, soil samples were collected at 28 locations in Hiroshima by a team led by Nishina, which performed a very early survey of the bomb's effects. These samples, which were sequestered in storage in the following decades and therefore not exposed to atmospheric fallout from nuclear weapons testing, have been re-measured in recent years, most recently by a group led by K. Shizuma at Hiroshima University (Shizuma et al. 1996) for ^{137}Cs to determine fallout concentrations. Because they relate to fallout and not to direct dose received by

survivors, they were not used in the creation of DS02 and are not included in the detailed listings of this chapter.

1960s

Tokyo University (Institute of Physical and Chemical Research). In 1960, N. Saito made measurements of ^{60}Co in iron samples provided by M. Nakaidzumi, taken from the A-bomb Dome in Hiroshima (water troughs) and the Nagasaki University School of Medicine (iron rods from the roof) (Saito 1987). Although the sites are well known, detailed site information is not available; i.e., we do not know the *in situ* location of the sample materials relative to the rest of the building, oriented with respect to the direction to the hypocenter, in either case.

Kyoto University and Nara University of Education. In 1963, T. Higashimura, Y. Ichikawa, and T. Sidei at Kyoto University reported the first measurements of thermoluminescence in roof tiles from Hiroshima, using samples collected by S. Nagaoka, the former director of the Hiroshima Peace Memorial Museum (Higashimura et al. 1963). In 1966, a related group led by Y. Ichikawa, who had moved to Nara University of Education by the time the paper was published, reported a series of measurements of roof tiles from both Hiroshima and Nagasaki, using a refined method and again using samples collected by S. Nagaoka (Ichikawa et al. 1966). Unfortunately, the only surviving documentation about sample location is that given in the published paper of 1966, which gives compass direction to the nearest point of the compass at 22.5° intervals (e.g., NNE, etc.) and a distance from a contemporary estimate of the hypocenter location (which unfortunately is not explicitly identified) for the city in question, along with place names that vary from particular sites of small extent (certain temples) to particular sites of large extent (Hiroshima Castle) to designations of towns and city subdivisions called “cho” or “machi.” Thus, the locations of these samples are somewhat less precise than most of the other samples considered in DS02. Some of these samples were later measured for ^{152}Eu by groups led by M. Sakanoue and T. Nakanishi of Kanazawa University (Nakanishi et al. 1983; Sakanoue et al. 1987).

ABCC and JNIRS. In 1963, T. Hashizume and other investigators from the Japan National Institute of Radiological Sciences (JNIRS) submitted a protocol to ABCC for the measurement of a number of samples in two categories: 1) Tile samples to be measured for gamma dose by thermoluminescence (TL), and 2) Iron or steel samples to be measured by radiation counting of the neutron activation product ^{60}Co .

The tile samples collected by ABCC Field Investigations staff including Saito and S. Tanaka were measured at JNIRS and reported by Hashizume et al. (Hashizume et al. 1967a; Hashizume et al. 1967b). Sample locations were documented using coordinates of the U.S. Army maps (see the section below on determination of map coordinates and Chapter 7) and were converted to longitude and latitude for the paper in *Health Physics* (Hashizume et al. 1967). Among the iron and steel samples, measurements of reinforcement bars embedded in concrete were reported in the same documents as the TLD measurements (Hashizume et al. 1967a; Hashizume et al. 1967b), whereas measurements of “surface samples,” such as iron rings used to secure emergency ropes on the roofs of buildings, were reported much later at a workshop in 1983 (Hashizume 1983).

At the time of sample collection in the 1960s, locations were estimated on the U.S. Army maps and were only approximate, as it was not realized at the time that precision to a level of a few meters would be necessary, and the scale and limited detail of the available maps was such that most collection sites were not depicted explicitly (e.g., as individual buildings or properties, etc.) on the maps. In later years, RERF staff made several successive efforts to improve the map information on these samples, as documented in memoranda to Department Chief Kato from H. Yamada in 1981 (Yamada 1981) and from T. Watanabe in 1985 (Watanabe 1985). The locations of four important samples of concrete reinforcement bars measured for ^{60}Co were revised in the DS86 Final Report (Maruyama and Kawamura 1987), but other sample locations have not been re-evaluated in the published literature since 1967, until this work.

The TL measurements of samples from the 1960s continue to be important (Chapter 7), particularly because of the relative paucity of such measurements at short distances from the hypocenter. As technology improved in later years, allowing lower-level measurements, investigators became interested in successively more distant measurements. Similarly, the ^{60}Co measurements reported in 1967 and 1983 remain important (Chapter 8), particularly because the fairly rapid decay of that radioisotope (half-life 5.27 y) has made measurements much more difficult in recent years, even as technology has improved. In the preparation of DS02, the sample locations were re-evaluated with the GIS (Geographical Information System), using pre-bombing aerial photographs in combination with the revised coordinates and place names determined by H. Yamada and T. Watanabe (Yamada 1981; Watanabe 1985). In some cases of the iron samples, records were maintained by Oak Ridge National Laboratory, and materials including some site drawings and an early packing list were kindly made available by G. Kerr (personal communication, January 30, 2002). Thus in some cases sample locations can be estimated as precisely as more recent samples, whereas in other cases sample locations cannot be distinguished on aerial photographs (e.g., the “watering trough for horses” and the “sentry box” in Hiroshima among the iron samples) or the site lacks a drawing or is otherwise unclear from the recorded place names (e.g., the “powder magazine” in Hiroshima and both locations in Nagasaki among the iron samples, and several of the sites where tiles and bricks were collected for TLD).

1980s (through DS86)

Samples Collected by RERF. In the years leading up to the DS86 report and during the preparation of that report, RERF collected samples from a number of large, public buildings in Hiroshima, often collecting multiple samples from suitable buildings, particularly those that were scheduled for demolition. These efforts were mainly focused on brick and tile samples appropriate for thermoluminescence (TL) measurements, as this was the prominent interest among measurers in that period. Among many other activities, a complete set of drawings of sample locations in sampled buildings was prepared for a workshop on TL on November 7-8, 1985. On September 11, 1985, T. Watanabe of RERF prepared a complete compendium of information on samples collected in Hiroshima by RERF and Hiroshima University, which was revised on November 11, 1987. It included a list of 20 major collection sites consisting of public buildings, as shown in Table 1, and the details of samples collected, along with 36 other sites at private residences, temples and shrines, etc., which are not included in the table shown here.

Sample Collection and Documentation

Table 1. RERF list of Hiroshima public buildings where samples had been collected by RERF and Hiroshima University (as of September 11, 1985)

| Site No. | Building | Material | Number of samples collected | Sent to or collected in cooperation with ^a |
|----------|---|--|-----------------------------|---|
| 1 | Hiroshima Naka Telephone Office | tile, roof or floor of roof tile, wall concrete | 31 | NIR, GEN, NAR, USA |
| 2 | Chugoku Electric Co. | tile iron ring concrete | 18 | NIR, GEN, NAR, USA |
| 3 | Hiroshima University Faculty of Science | tile tile, roof or floor of roof tile, railing, roof | 35 | NIR, GEN NAR, USA |
| 4 | Former Elementary School Attached to Hiroshima University | tile tile, roof or floor of roof tile, railing, roof | 14 | NIR, GEN NAR |
| 5 | Hiroshima Red Cross Hospital | tile, wall tile, roof or floor of roof | 8 | NIR, GEN |
| 6 | Hiroshima Regional Postal Savings Bureau | tile, wall tile, roof or floor of roof | 21 | NIR, GEN, NAR, USA |
| 7 | Japan Electric Tool Testing Facility | tile, wall tile, roof or floor of roof | 4 | NIR, GEN, NAR |
| 8 | Hiroshima University Faculty of Technology (former Hiroshima Higher Industry School) | tile, wall granite rain gutter | 9 | GEN |
| 9 | Army Clothing Depot | iron ring | 10 | NIR, GEN |
| 10 | Army Arsenal Barracks | iron ring | 4 | NIR, GEN |
| 11 | Army Provisions Depot | iron ring tile, roof or floor of roof glass | 14 | NIR, GEN |
| 12 | San-in Joint Bank (former Hiroshima Commerce and Industry Central Credit Association) | tile, roof or floor of roof tile, wall | 4 | NIR, USA |
| 13 | Motoyasu Bridge | granite unknown | 4 | GEN |
| 14 | Aioi Bridge | concrete unknown | 10 | NIR, GEN |
| 15 | Fukoku Life Insurance Building | concrete iron ring tile rain gutter | 13 | NIR, GEN |
| 16 | Hiroshima Bank Main Office | concrete | 2 | NIR, GEN |
| 17 | River Abutment (Motomachi) | granite | 2 | GEN |
| 18 | Ono Petroleum Shop | granite concrete | 4 | GEN |
| 19 | Sumitomo Bank | iron | 1 | GEN |
| 20 | Yokogawa Bridge | iron | 1 | NIR, GEN, USA |

^aNIR = Japan National Institute of Radiological Sciences, Tokyo/Chiba; GEN = Hiroshima University Institute of Radiation Biology and Medicine (Geniken); NAR = Nara University of Education; USA = United States of America (University of Utah)

Sample Collection and Documentation

Y. Okamoto of the RERF Nagasaki laboratory compiled a similar list for Nagasaki at about the same time, which included 13 sites at public buildings (including shrines and temples in this case) and one other at a private residence (Table 2). The “Ieno wall” is included in this list because of its prominence as a site of multiple TLD measurements in DS86, and temples and shrines have been included because there are so few large buildings comparable to those in Table 1 for Hiroshima. Even when temples and shrines are included, the list in Table 2 is primarily confined to sites sampled in 1963 by ABCC as described above under “ABCC and JNIRS.” Although the list for Nagasaki does contain a few other, relatively distal sites at which samples for TLD measurements were collected in 1981 (e.g., the cemeteries in Zenza-cho and Chikugo machi and the warehouse in Inasa cho), the types of large buildings available for sampling in Hiroshima did not exist in Nagasaki.

Beginning in the 1980s, samples were typically collected with drawings to document the positions of samples in relation to the building or other structure from which they were taken, and later efforts increasingly included photographs of the sample sites. It was also at this time that workers documenting the map coordinates of samples began to use the newer Japanese city maps to provide alternative estimates of coordinates in addition to the U.S. Army maps. Typically, carefully annotated photocopies of maps with lines drawn to document the coordinate estimates were prepared. This type of work was originally done by H. Yamada in Hiroshima and Y. Okamoto in Nagasaki, and taken over later by T. Watanabe in Hiroshima and T. Yamashita in Nagasaki.

These efforts were a major source of information for the large Tables 1 and 2 in the chapter on TLD in the DS86 Final Report (Maruyama et al. 1987). A major development in this part of DS86 involved the sharing of samples from an important site in Hiroshima (the Hiroshima University Faculty of Science building) and one in Nagasaki (the brick wall at a private residence in Ieno cho) among various collaborating investigators in Japan (JNIRS, NUE-HU), England (Durham University and Oxford University), and the United States (University of Utah) for

Table 2. RERF list of Nagasaki public buildings where samples were collected by RERF and Hiroshima University (as of August 1, 1984)

| Site No. | Building | Material | Sent to ^a |
|----------|---|---------------|----------------------|
| 2 | Ieno machi (wall near house) ^b | brick (red) | NIR, USA |
| 3 | Inasa cho (warehouse) | brick (red) | NIR, NU, USA |
| 4 | Urakami Church | brick (red) | NIR |
| 5 | Sakamoto cho Foreigners' Cemetery A | brick (red) | NIR |
| 6 | Sakamoto cho Foreigners' Cemetery B | brick (red) | NIR |
| 7 | Shoutoku Temple, Zenza machi | brick (red) | NIR, USA |
| 8 | Honren Temple, Chikugo machi | brick (red) | NIR |
| 9 | Hachiman Shrine, Shiroyama machi | brick (red) | NIR, NU |
| 10 | East Hongan Temple, Chikugo machi | brick (red) | NIR, NU |
| 11 | Water Department Office, Nishiyama machi | brick (red) | NIR, NU |
| 12 | Cemetery, Haruki machi | brick (black) | NIR, NU |
| 13 | Kurosaki Church | brick (red) | NIR, NU |
| 14 | Shitsu Church | brick (red) | NIR |
| 15 | Shiroyama Primary School | concrete | NIR, NU |

^aNIR = Japan National Institute of Radiological Sciences, Tokyo/Chiba; NU = Nagasaki University; USA = United States of America (University of Utah)

^bPrivate residence

various studies of calibration, standardization, and intercomparison. In addition, several other important sets of measurements of neutron activation, mostly published after DS86, came from samples included in this list:

- Samples were collected from the Chugoku Electric Co. building at the time of its demolition in 1984. A piece of concrete containing iron reinforcement rods and a piece of iron handrail from the smokestack were later supplied to G. Kerr of Oak Ridge National Laboratory as described below.
- Samples were collected from the Yokogawa Bridge at the time of its demolition in 1983 and supplied by the City of Hiroshima to RERF, which later supplied them to Dr. Kerr as described below.
- Samples collected from the Fukoku Life Insurance Co. building at the time of its demolition in 1982, in cooperation with Hiroshima University, were measured for DS86 by M. Hoshi and K. Kato of Hiroshima University and by a group led by T. Nakanishi of Kanazawa University, and have more recently been measured for DS02 as described in Chapter 8.

In addition to samples from buildings, in the early 1980s RERF field staff including T. Watanabe collected approximately 100 samples of pottery and other ceramic materials that had been in the interiors of homes of individual survivors with information sufficient to construct complete shielding histories. The original intent was to make TLD measurements and compare them to calculated doses for the survivors involved. Although some preliminary results were reported at the second dosimetry workshop in 1983 (Maruyama et al. 1983), the investigators felt that the results were affected by too many complicating factors to be useful. Most notably, the dates of manufacture of the items were unknown, which meant that only samples with expected doses far above possible accumulated background could give useful results. Furthermore, the provenance of these samples was doubtful, because they were donated by individual survivors. The import of this was clear from the observation that more than half of the samples gave results comparable to background, when a substantial contribution of A-bomb dose was expected (Maruyama et al. 1983).

Samples Collected by Investigators at Hiroshima University. Beginning in 1982, M. Hoshi and others at Hiroshima University collected numerous samples, which by the time of the first joint binational workshop on dosimetry in February of 1983 included: 1) iron structural materials from the Aioi Bridge (“T” Bridge), 2) stone materials from an underwater portion of the Aioi Bridge, concrete cores from the Fukoku Life Insurance Building, and similar materials for measuring neutron activation from about five other sites, and 3) tiles and bricks for TL measurements from about 26 sites (Hashizume 1983; Hoshi 1983).

Some of these samples were provided to other investigators, including T. Nakanishi of Kanazawa University as noted below. In 1985 a group led by H. Hasai of Hiroshima University obtained the permission of the Hiroshima city government to drill a number of cores from a large granite pillar of the Motoyasu Bridge for measurements of ^{152}Eu at various depths in granite, with assistance from H. Yamada and T. Watanabe of RERF in determining the map coordinates of the sample location (Hasai et al. 1987). In 1986, groups led by M. Hoshi and H. Hasai obtained ten samples of stone surfaces from rocks of walls along river embankments at Honkawa, Motomachi, Kakomachi, Kawaramachi, and Teramachi. In addition, Hiroshima University investigators collected samples from most of the Hiroshima sites listed in Table 1, in cooperation with collectors from RERF.

Samples Measured by Investigators at Kanazawa University. In 1983 a group led by T. Nakanishi at Kanazawa University published measurements of neutron activation products in samples of tiles and stone including samples provided by the Hiroshima Peace Memorial Museum, Nagasaki International Cultural Hall and a private donor, C. Takatani of Nagasaki, in addition to those mentioned above that were collected by S. Nagaoka and supplied by Y. Ichikawa (Nakanishi et al. 1983). The same group made a number of measurements that were published in the DS86 Final Report, using samples provided by the group at the Research Institute for Nuclear Medicine and Biology at Hiroshima University (Nakanishi et al. 1987).

Samples Collected by Investigators at Nagasaki University. Beginning about 1981, a group at Nagasaki University led by S. Okajima began collecting samples of rock from retaining walls built along the banks of rivers. They collected samples from sites in both Hiroshima (13 locations) and Nagasaki (76 locations) (Okajima and Miyajima 1983), although results were never published for the Hiroshima locations. The sample locations are shown on a map-type drawing in the workshop proceedings (Okajima and Miyajima 1983), but the drawing is not annotated with numbers and there is no other information to establish which dot on the drawing corresponds to which measurement. The situation is complicated by the fact that samples were taken from both sides of two rivers, the Shino and Urakami. The locations for a number of core samples taken from similar locations are shown in a map-type drawing in the DS86 Final Report that is annotated with sample numbers (Okajima and Miyajima 1987). These sample locations appear to be a subset of those in the 1983 publication (Okajima and Miyajima 1983) and were restricted to areas close to the estimated location of the hypocenter.

Post-DS86

RERF. After DS86, RERF and two groups at Hiroshima University led by M. Hoshi and H. Hasai (later K. Shizuma) participated in the collection of samples from many buildings as they were torn down to make way for new structures. In most cases sample materials and all relevant information were shared among these three groups. Table 3 gives a list of 15 structures in Hiroshima and 7 in Nagasaki from which samples were taken by RERF as part of this general effort. In most of these cases, a variety of samples were secured wherever available, in order to provide for various possible measurements, including concrete, brick, tiles, rock, iron and steel, and copper.

RERF has maintained a collection of these materials over the years, which is of historical and scientific interest. The collection includes materials collected before DS86, dating back to the collection efforts of the early 1960s. In 1996, S. Fujita and T. Watanabe of RERF made a report at a meeting on the dosimetry reassessment, summarizing the collected materials at RERF that might be of interest to investigators, and giving an idea of the prospects for future sample collection (Fujita and Watanabe 1996). They listed the sites from which tiles (Hiroshima, 9 sites; Nagasaki, 5 sites), concrete cores (Hiroshima, 10 sites; Nagasaki, 3 sites), iron or steel (Hiroshima, 7 sites; Nagasaki, 1 site), and copper (Hiroshima, 2 sites; Nagasaki, 0 sites) were in storage at RERF.

Fujita and Watanabe emphasized the very small number of remaining sites that had never been sampled and would be suitable for sample collection. They identified four remaining buildings in Hiroshima as potential sources of concrete samples: the Rest House in Peace Park

Sample Collection and Documentation

Table 3. Buildings from which RERF collected samples after DS86

| Location | Ground distance (m) | Materials collected |
|---|---------------------|------------------------------|
| Hiroshima | | |
| Motoyasu Bridge | 128 | concrete |
| Kirin Beer Hall | 679 | concrete, tile |
| Old NHK Building | 990 | concrete |
| Hiroshima University Primary School | 1279-1346 | concrete, iron, copper, tile |
| Teishin (Communications) Hospital "E" Building (Faculty of Science), Hiroshima University | 1375 | concrete tile |
| Animal Facility, Hiroshima University | 1428 | concrete, iron, tile |
| Seifu Dormitory, Hiroshima University | 1439 | concrete, tile |
| Radioisotope Building, Hiroshima University | 1470 | concrete, iron, copper, tile |
| Red Cross Hospital North Building | 1470 | concrete, iron |
| Red Cross Hospital Main Building | 1501 | concrete |
| Regional Postal Savings Office | 1591-1607 | concrete, iron, tile, rock |
| Misasa Credit Union | 1682 | concrete |
| Hiroshima Commercial High School | 2858 | concrete, rock |
| Hiroshima Army Food Warehouse | 4576 | iron, brick |
| Nagasaki | | |
| Nagasaki University Hospital | 655 | concrete, iron, tile |
| Yamada-Furukawa Family Graveyard Gatepost, Sakamoto cho Cemetery | 1040 | bricks |
| Mitsubishi Steel & Arms Works Office | 1075 | concrete |
| Fuchi Junior High School | 1156 | concrete |
| Charnel, Nagasaki University Medical School | 1452 | bricks |
| Anti-aircraft Gun Emplacement, Konpirasan | 1582 | concrete |
| Yamada Oil Co. Warehouse | 2045 | bricks |

(formerly the Fuel Administration Building, or Nenryo Kaikan, during the war) at 158 m ground distance, the Bank of Japan building at about 400 m ground distance, the former Kannon Bridge at about 1,630 m ground distance, and an external wall of the former Yoshijima Prison at about 1,800 m ground distance. Only one sample was identified as a possible additional source of tiles: the Bank of Japan, and the same building as a possible source of copper. No remaining buildings were identified as possible sources of iron and steel in Hiroshima, and no remaining buildings were identified as sources of any of these materials in Nagasaki. It was further noted that even the potential sources that had been identified would be subject to various impediments to sample collection, particularly historical preservation efforts and related restrictions. All of these observations served to underscore the increasing difficulty of obtaining samples in later years after the bombings.

Various samples from this collection were made available to investigators and were used for measurements related to dose reassessment efforts after DS86.

- The samples collected in 1983 and 1984 from the Yokogawa Bridge and the Chugoku Electric Co., respectively, were supplied to G. Kerr of Oak Ridge National Laboratory as described above and were reflected in important measurements (Kerr et al. 1990). T. Kimura and T. Hamada measured the same samples (Kimura et al. 1990; Kimura and Hamada 1993).
- Of particular note to this work are a series of concrete cores that were made available to T. Straume of the University of Utah for ^{36}Cl measurements (see Chapter 8), who later provided two of them to W. Rühm of the Technical University of Munich, Germany, for work also reported in that chapter, and
- A number of tile and brick samples that were made available to T. Maruyama at JNIRS for new TL measurements reported in this work (see Chapter 7).
- A large set of concrete cores from anti-aircraft gun emplacements on top of Konpira mountain in Nagasaki was provided to T. Nakanishi of Kanazawa University for a large-sample measurement of ^{152}Eu at this relatively distant location. Although preliminary results have been reported at meetings (Nakanishi 2004), this measurement was still in process at the time of this writing.
- A number of granite cores were obtained from the front steps of the Postal Savings Building just before the final razing of the site in 2001, and several of these were supplied to T. Straume of the University of Utah and W. Rühm of the Technical University of Munich, Germany for ^{36}Cl measurements also reported in Chapter 8.

As the efforts of the working group progressed, it became clear that investigators had a very strong interest in identifying copper samples that could be measured for ^{63}Ni . RERF collaborated with Hiroshima University researchers and other working group members and contributors in redoubled efforts to identify and secure such samples. Announcements were placed in local newspapers soliciting donations of possible samples (e.g., Chugoku Shimbun of September 20, 1999), and the Chairman of the RERF Board of Directors, S. Nagataki, appealed to the Nagasaki Peace Museum and other institutions to cooperate in obtaining samples. In 2000, W. Rühm of the Technical University of Munich, Germany, with support from the U.S. National Academy of Sciences and RERF, came to Japan and conducted a search for additional copper samples. Table 4 gives a list of copper samples that were eventually identified, collected, and supplied to interested investigators by RERF and Hiroshima University, including a number of background samples. Although some of these samples were not suitable for measurement due to their content of stable nickel as an impurity or for other reasons, many of them are reflected in the ^{63}Ni measurements of this work (Chapter 9).

RERF maintains a computerized database of sample materials collected since DS86, which is described below in this chapter. Since the late 1980's, T. Watanabe in Hiroshima and T. Yamasahita in Nagasaki have continued to have major responsibility for sample map documentation, while S. Fujita has continued to maintain a central repository of sample information.

Hiroshima University. Hiroshima University has two major groups involved in sample collection. One, headed by M. Hoshi, is in the Radiation Information Center of the Research Institute for Radiation Biology and Medicine. Formerly known as the “atomic bomb specimens center” and reorganized in 1996, this center has a large collection of many items of historical and scientific interest related to the bombings, including newspaper articles, tissue specimens, books,

Table 4. Copper samples collected and distributed for ^{63}Ni measurements

| Location | Ground distance (m) | Materials collected |
|---|---------------------|-----------------------------|
| Hiroshima | | |
| Motoyasu Bridge Pillar No. 1 | 128 | electrical wire |
| Bank of Japan | 391 | lightning rod conductor |
| San'in Gohdoh Bank | 621 | lightning rod conductor |
| Soy Sauce Brewery | 964 | lightning rod conductor |
| City Hall | 1018 | lightning rod conductor |
| (warehouse) | 1050 | copper vase |
| (private house) | 1300 | copper keychain |
| Hiroshima University Primary School | 1308 | rain gutter |
| "E" Building (Faculty of Science), Hiroshima University | 1386-1475 | rain gutter |
| Radioisotope Building, Hiroshima University | 1470 | rain gutter |
| Sumitomo Bank, Higashi-Matsubara Branch | 1880 | rain gutter |
| Ohban Shrine | 3392 | entrance pillar rope hanger |
| Kusatsu-Hachiman Shrine | 5062 | copper roof |
| Kamesaki Shrine | 7500 | ornament on portable shrine |
| Nagasaki | | |
| Yanase Bridge | 310 | name plate |
| (Shimoo?) Bridge | 530 | name plate |
| Minori-en | 3931 | lightning rod conductor |
| Hongkong-Shanghai Bank, Nagasaki Branch | 4187 | rain gutter |
| Oura-Tennshuudou Church | 4228 | rain gutter |

etc., in addition to potentially bomb-exposed materials of rock, concrete, bricks, tiles, glass, iron, copper, other metals, etc., numbering more than 2,000 items. A database containing information on some 270,000 people related to the bombing is also maintained. Another group, formerly headed by H. Hasai and now headed by K. Shizuma, is located in the Graduate School of Engineering and has made extensive sample collection efforts.

In addition to participating in sample collection jointly with RERF as described above for buildings undergoing demolition, Hiroshima University investigators have obtained samples from other sources. As noted above, a collection of samples from the 1945 geological survey led by T. Watanabe was found in a warehouse at Hiroshima University. A total of 44 samples from 30 locations were identified and were used to measure ^{137}Cs concentrations that would have been associated with fallout, being a particularly important set of samples in this regard, because they had been in storage and were thus not exposed to the weather in the intervening decades of worldwide fallout from atmospheric nuclear testing (Shizuma et al. 1997). In addition, 25 of these 44 samples were determined to be suitable for measurement of thermal neutron activation via ^{152}Eu (Shizuma et al. 1993).

K. Kato of the Research Institute for Radiation Biology and Medicine and collaborators

reported measurements of both ^{152}Eu and ^{36}Cl on a granite tombstone from a location near the hypocenter, which was donated to the institute (Kato et al. 1990).

In 1990, when the Atomic Bomb Dome was being structurally strengthened to slow down its disintegration due to weathering, investigators from Hiroshima University were able to obtain a number of samples of steel plates from the superstructure of the dome and five granite cores from various parts of the structure (Shizuma et al. 1992).

In the late 1980s a group led by K. Shizuma obtained two core samples of concrete and two of granite to measure ^{152}Eu at various depths (Shizuma et al. 1997): 1) In 1988, the city government allowed another set of cores to be taken from a different pillar of the Motoyasu Bridge than had been sampled earlier by the Hasai group, 2) In 1988, the Hiroshima Youth Center found a concrete foundation of a torii gate of the former Gokoku Shrine location during construction activities and allowed a core to be taken, 3) A concrete core was taken from a portion of a pillar from the facade of Hiroshima Bank (formerly Geibi Bank) that was preserved when it was demolished in 1962 and later given to the Research Institute for Radiation Biology and Medicine, 4) In 1988, the Shirakami shrine allowed a core to be taken from a large granite rock on its property.

Hiroshima University has also supplied a large number of samples to other investigators. In 1989, a selection of 30 samples of tile, granite, and concrete were supplied by M. Hoshi to T. Straume of the University of Utah for ^{36}Cl measurements. A core of granite and concrete from the Fukoku Life Insurance Building was supplied to W. Rühm of the Technical University of Munich, Germany for measurement of ^{36}Cl , as described in Chapter 8. A selected set of 18 granite samples, including 5 background samples, mostly from gravestones, were cut into sections with careful attention to geometry and were supplied to Y. Nagashima of Tsukuba University, K. Komura of Kanazawa University, W. Rühm of the Technical University of Munich, Germany, and T. Straume of the University of Utah for an intercomparison of ^{152}Eu and ^{36}Cl measurements as reported in Chapter 8, Part H.

Kanazawa University. In 1991, a group led by T. Nakanishi of Kanazawa University collected large samples of roof tiles from a private house and a temple for measurement of ^{152}Eu at somewhat longer distances than had previously been measured (about 1,000 m ground distance) (Nakanishi et al. 1998). Portions of these samples were also provided to a group at the University of Tokyo for independent measurements (Iimoto et al. 1999).

Nagasaki University. Y. Okumura and T. Shimasaki of Nagasaki University reported in 1997 that they had collected a total of 135 rock samples from Nagasaki, mostly from walls along river embankments but some from gardens, along with four iron samples and 2 concrete samples (Okumura and Shimasaki 1997)

Hiroshima Prefectural College of Health Sciences and Technical University of Munich, Germany. In the period 1998-2002, a group led by K. Kato of Hiroshima Prefectural College of Health Sciences collected (~12) samples of granite gravestones and samples of granite and cores of tile and concrete from the former Hiroshima University Faculty of Science building for measurement of ^{36}Cl , as detailed in Chapter 8.

Methods of Location Determination

Manual Method Using Maps

The original maps used to locate samples by most investigators were the U.S. Army maps. A sample was located to a point on the paper map, based on the available information, i.e., by placing the point in some relationship to a depicted feature such as a building, a portion of a street plan (e.g., city block or “banchi”), or another landmark on the map. Then the U.S. Army map coordinates were measured manually by drawing lines perpendicular to the grid lines of the map’s 1,000-yard plane rectangular coordinate system and manually measuring the coordinate on each axis. The first and most immediately apparent disadvantage of the U.S. Army maps is their limited scale, 1:12,500, which does not allow sufficient detail for the depiction of all of the buildings and other features that would be useful in this application. As many buildings and other structures from which samples were taken are not depicted on the U.S. Army maps, positioning a sample on the map often involved considerable judgment. In retrospect, it is also now understood that the U.S. Army maps contain some inaccuracies in the placement of various features (Chapter 5).

The new Japanese city plan maps that were produced in 1979 (Hiroshima) and 1981 (Nagasaki) represent a considerably better alternative. They can of course be used to locate samples in exactly the same manner as described above for the U.S. Army maps, except that their plane rectangular coordinate system is the 1,000-meter grid of the Japan land survey system. They are five times larger in scale than the U.S. Army maps (i.e., 1:2,500), and contain depictions of almost all permanent structures, including all buildings and other structures such as, for example, stone retaining walls along riverbanks and on hillsides, and accurate depictions of the layouts of cemeteries. Their depictions of buildings and bridges are more correct in shape and scale than those of the U.S. Army maps for features depicted on both maps. Their accuracy and detail considerably simplify and improve the accuracy of sample locations. The disadvantage of the newer city plan maps is that they do not contain appropriate depictions of 1945-era features that were removed or altered before 1979/1981. However, this is a relatively minor problem, because the large majority of sample collection was done in the 1980s and later, as detailed in this chapter (e.g., Table 5), and the corresponding buildings and other sites are therefore depicted on the newer maps. Furthermore, older buildings can be located on pre-bombing aerial photographs using the GIS.

The other problem presented by sample locations that can only be documented in reference to the U.S. Army maps was to determine how the coordinates of the U.S. Army map relate to those of the newer city plan maps, because there has never been an established and straightforward basis for such coordinate conversions. Two major efforts were made to reconcile sample locations on the two sets of maps in the time period of DS86. The Japanese firm Fukuken Choosa Sekkei (FKE) was contracted by RERF to provide a detailed report as described in detail in Chapter 5, and the U.S. firm Science Applications International Corporation (SAIC) performed a detailed analysis of the locations of TL samples that is reflected in Table 2 of the TL chapter in the DS86 Final Report (Maruyama et al. 1987). The details of this problem are discussed at length in Chapter 5.

Unfortunately it remains true that neither set of maps, U.S. Army or “new city,” can be used exclusively for all samples. Prior to the advent of the Geographical Information System (GIS), the same sort of manual alignment that was used to produce an estimate of the hypocenter locations on the new city map could be used to transform coordinates from one map to the other. However, this was a laborious task and subject to questions about the accuracy obtained, for which good uncertainty estimates were not available.

Sample Collection and Documentation

**Table 5A. Complete list of samples for which measurements were considered in DS02: Hiroshima
(GR = ground distance from DS02 hypocenter at 27.721, -178.395)**

| Site name ^a | Y, km | X, km | GR, m | Sample type | Collector ^b | Year collected | Architectural Ref | Measurement Ref |
|---|--------|----------|-------|-------------------------------------|------------------------|----------------|-------------------|-------------------|
| Shima Hospital | 0 | 0 | 0 | china | TW | 1945 | 1-5 | 36, 43 |
| Shima Hospital | 26.719 | -178.38 | 15 | tile, roof or floor of roof | HPM | 1963 | 1-5 | 25, 27, 28 |
| Shima Hospital | 26.719 | -178.38 | 15 | tile, wall | TW | 1945 | 1-5 | 36 |
| Hiroshima Post Office | 26.686 | -178.388 | 36 | tile, roof or floor of roof | TW | 1945 | - | 36 |
| Sei Hospital | 26.695 | -178.347 | 55 | concrete | TW | 1945 | - | 36 |
| Sei Hospital | 26.695 | -178.347 | 55 | tile, roof or floor of roof | TW | 1945 | - | 36 |
| Sei Hospital | 26.695 | -178.347 | 55 | tile, wall | TW | 1945 | - | 36 |
| Saikou Temple | 26.655 | -178.346 | 82 | concrete | TW | 1945 | 1-25 | 36 |
| Saikou Temple | 26.655 | -178.346 | 82 | tile, roof or floor of roof | TW | 1945 | 1-25 | 36 |
| E13 Motoyasu bashi, east end | 26.641 | -178.441 | 92 | sulfur paste in porcelain insulator | YS | 1945 | 1-15 | 1 |
| Motoyasu Bridge Pillar 2 core | 26.639 | -178.438 | 93 | granite | HU | 1988 | 1-15 | 35, 36 |
| Saikou Temple gravestone | 26.629 | -178.375 | 94 | granite | HU | 1988 | 1-25 | 12, 13, 40, 43 |
| Daiichi Bank (Forestry Savings Bank) | 26.83 | -178.45 | 122 | tile, wall | TW | 1945 | 2-2 | 36 |
| Atomic-Bomb Dome G5 | 26.626 | -178.314 | 125 | granite | HU | 1990 | 1-1 | 36, 39 |
| A-bomb Dome | 26.619 | -178.317 | 128 | tile, roof or floor of roof | AB | 1963 | 1-1 | 5, 6 |
| Motoyasu Bridge Pillar 1 | 26.605 | -178.45 | 128 | granite | HU | 1985 | 1-15 | 2, 27, 28, 36, 43 |
| Chiyoda Life Insurance Building | 26.852 | -178.378 | 132 | tile, wall | TW | 1945 | 2-1 | 36 |
| Motoyasu Bridge, Railing | 26.604 | -178.461 | 134 | granite | HU/RE | 1983 OR 1992 | 1-15 | 36, 43 |
| Atomic-Bomb Dome G1 | 26.609 | -178.301 | 146 | granite | HU | 1990 | 1-1 | 36, 39 |
| Atomic-Bomb Dome | 26.607 | -178.302 | 147 | steel plate | HU | 1990 | 1-1 | 15, 38, 39, 43 |
| Atomic-Bomb Dome | 26.608 | -178.298 | 149 | steel plate | HU | 1990 | 1-1 | 37 |
| Atomic-Bomb Dome G4 | 26.605 | -178.301 | 149 | granite | HU | 1990 | 1-1 | 39 |
| Atomic-Bomb Dome G2 | 26.609 | -178.296 | 149 | granite | HU | 1990 | 1-1 | 39 |
| Atomic-Bomb Dome, Water Trough | 26.605 | -178.3 | 150 | iron | NZ | ≤1960 | 1-1 | 33 |
| Atomic-Bomb Dome G3 | 26.604 | -178.297 | 153 | granite | HU | 1990 | 1-1 | 39 |
| Atomic-Bomb Dome | 26.603 | -178.298 | 153 | steel plate | HU | 1990 | 1-1 | 39 |
| Atomic-Bomb Dome | 26.605 | -178.295 | 153 | steel plate | HU | 1990 | 1-1 | 39 |
| Nenryo Kaikan (Fuel Authority Building) | 26.580 | -178.468 | 158 | tile, wall | AB | 1963 | 1-2 | 5, 6 |