Draft White Paper

REVIEW OF NIOSH WHITE PAPER ON PORTABLE RADIOGRAPHY SOURCES AT GSI

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Review of NIOSH White Paper on Portable Radiography Sources at GSI

In a NIOSH White Paper, Allen (2010) reviewed the portable radiography sources used at the General Steel Industries, Inc. (GSI) steel foundry in Granite City, Illinois, during the period that GSI was under contract to the Atomic Energy Commission (AEC) (1953–1966). Much of the information is from AEC licensing documents and correspondence which are posted on the Nuclear Regulatory Commission's Web site, and which can be accessed through ADAMS, the NRC document retrieval system. On May 20, 2010, during the course of the 69th meeting of the Advisory Board on Radiation and Worker Health, the Board, together with the Work Group on TBD-6000, tasked SC&A with reviewing the NIOSH White Paper. The Board recognized that such a review would require a review of the AEC documents. We have accordingly reviewed the White Paper and have a number of comments, observations, and findings.

1. SEQUENTIAL REVIEW

We will first present a sequential review of the White Paper, discussing each issue in the same sequence as presented by Allen (2010). The author first presented a discussion of the background of the White Paper and a timeline of the use of portable sources at GSI. These were followed by a discussion of the strength of the sources mentioned in the AEC documents—the two ^{60}Co sources with initial activities of 260 and 280 mCi, and the two 500-mg (~500-mCi) sources of ^{226}Ra—and the calculated exposure rates at a distance of 1 foot. We have verified this information and found it to be correct. Our comments on the rest of the White Paper are presented in the following subsections, which have the same headings as the corresponding sections in the White Paper.

1.1 Additional Sources

1.1.1 250 kVp X-ray Machine

One radiation source discussed in the White Paper is the 250 kVp x-ray machine. Since it was not licensed by AEC, it is not cited in the AEC documents. Allen (2010) stated:

> *Another difference is that the isotopic sources emit radiation in all directions, while the x-ray machine would emit a directional beam. While x-raying equipment, the beam would always be pointed at the material so the beam is always effectively shielded by the material being examined.*

The above statement implies that the x-ray machine would result in little or no exposure to the workers. The author implicitly assumed that the beam was sufficiently collimated so that the entire beam was intercepted by the metal object being radiographed. Although modern medical x-ray machines are required to be collimated so that the cross-section of the beam does not exceed the area of the film, in order to reduce the radiation exposure of the patient, this was not necessarily the case for an industrial radiography unit in the 1950s and 1960s. X-ray machines from a previous era (early decades of the 20th century) were not even shielded, exposing the operator who stayed near the machine to a significant dose of radiation.

Two 250-kV x-ray machines are listed in an auction notice involving the liquidation of the GSI Granite City facility (Rabin 1973). One is described as a "GE x-ray, model OX-250, industrial size," while the other was an "Andrex x-ray unit, model A1652 . . . 250 kV 8 mA directional unit." We can infer the tube current of the G.E. machine from Beatty and Clark (1955), who used a G.E. model OX-250 industrial x-ray unit operating at 250 kV and 15 mA to irradiate laboratory mice. Although they cited the dose rate administered to the mice, the source-to-receptor distance was not listed, so this report cannot be used to directly calculate the output of the unit. However, the dose rate can be calculated from the published dose rate of another x-ray tube, if we can derive a relationship between the dose rate, the tube potential, and the current.

According to Cosslett and Nixon (1960), the power of the x-rays generated by bremsstrahlung from a thick target is given by

$$P = I\,k\,V^2 Z$$

P = power in x-ray beam

I = tube current

k = constant (depends on units)

V = tube potential

Z = atomic number of target

This equation can be used to derive the dose rate of G.E. model OX-250 from the dose rate and other operating parameters of the ISOVOLT 225 M2/0.4-3.0 (GE 2004), if we assume that both tubes have targets made of the same metal (i.e., tungsten) and that the dose rate is proportional to the power, by the following relationship:

$$R_X = \frac{I_X V_X^2}{I_I V_I^2} R_I$$

R_X = dose rate at 1 m from G.E. model OX-250
= 18.42 Sv/h

I_X = tube current in G.E. model OX-250
= 15 mA

V_X = tube potential in G.E. model OX-250
= 250 kV

R_I = dose rate at 1 m from ISOVOLT 225 M2/0.4-3.0 at maximum tube potential and current
= 12.93 Sv/h

I_I = maximum tube current in ISOVOLT 225 M2/0.4-3.0
= 13 mA

V_I = maximum tube potential of ISOVOLT 225 M2/0.4-3.0
= 225 kV

Because the ISOVOLT tube output is rated for an inherent filtration of 1 mm Be, the output of the OX-250 unit could be somewhat less than listed above due to greater filtration. Nevertheless, we see that the output, which is estimated to be approximately 30 rem/min, is significant. It falls between the exposure rates from the 25-MeV betatron (160 R/min at 3 ft from the target) and an 80-Ci ^{60}Co source (1.76 R/min at 1 m, based on a value of $\Gamma = 1.32$ R h^{-1} Ci^{-1} m^{-2}).

Although the operator of the x-ray machine normally stayed in the betatron control room during exposures, the machine was operated in an open area: the betatron shooting room. There were no safety interlocks that could prevent someone from entering the shooting room while the machine was on. There were at least two reports of the machine being activated while workers were in the shooting room performing other duties. One or more workers were reportedly exposed when the machine was turned on without the area being cleared (SimmonsCooper 2006).

We agree with Allen's statements that the x-ray machine produced radiation that was less penetrating than that from the ^{60}Co or ^{226}Ra sources, and that it was used less frequently. However, we do not agree that the exposures to the x-ray machine are necessarily bounded by the exposures to the small (260–280 mCi) ^{60}Co sources.

1.1.2 Iridium-192 and ^{60}Co Sources Used by St. Louis Testing

According to Paul Sinn, former administrator of St. Louis Testing, his company utilized a 50-Ci ^{192}Ir source as well as a 10-Ci ^{60}Co source at GSI (Dr. Robert Anigstein . . . 2007). The ^{60}Co source may have been stronger than any ^{60}Co source used at GSI during the period of AEC operations. Even if GSI did posses a high-activity ^{60}Co source during this period, it would have most likely been used inside the betatron shooting room, as was the 80-Ci source procured under an AEC license in 1968.[1] However, the St. Louis Testing sources were used outdoors on the GSI property. Mr. Sinn stated that his men set up an exclusion area boundary where the exposure rate was 2 mR/h, and that "two radiographers working 12-hour shifts kept the secured area under constant surveillance." Mr. Sinn later explained that he meant that there was one radiographer on each shift. He added that the sources were always inside a 4-in-thick casting that was being radiographed.[2] With only one radiographer on duty, there would have thus been times when the area was unattended while he took necessary breaks. Some GSI workers could have intruded into the exclusion area and received exposures from these sources that were greater than those from the 260 and 280 mCi ^{60}Co sources possessed by GSI. We therefore do not agree that the exposures of GSI workers to radioactive sources used by St. Louis Testing would be bounded by their exposures to the sources used by GSI.

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[1] Some former workers recall a high-activity ^{60}Co source being at GSI prior to 1968.

[2] Paul Sinn, September 27, 2010, private communication with Robert Anigstein, SC&A, Inc.

1.2 Radium Sources (1953 to 1962)

Allen (2010) discussed the use of two ^{226}Ra sources at GSI prior to the acquisition of the ^{60}Co sources on May 21, 1962.[3] The exposure scenarios that he developed were based on the account of [redacted], a former GSI radiographer, who recounted his recent conversation with "the [redacted]" who told him it was common practice to perform ^{60}Co radiography in open areas of the plant, and to rope off a perimeter at 1½ times the distance to a safe level of radiation (Neal R. Gross 2009). Allen assumed that the "safe level" was 2 mR/h, which corresponds to the dose limit of 2 mrem/h for an unrestricted area that is specified in 10 CFR 20.1301. Applying the inverse-square law, he derived an exposure rate of 0.89 mR/h at the perimeter. He further assumed that the radiographer remained at the perimeter for the duration of the radiographic exposure, and that the total duration of such exposures was equal to 30% of a work shift. This 30% "utilization factor" is based on the initial AEC license application, which states that "[a] maximum of 30% of each shift is used for actual exposure" (NRC 2009c, p. 12). Based on these assumptions, Allen estimated the annual exposure of radiographers to be 868 mR. We agree that such an exposure would have been experienced by a worker whose only duty was to monitor the exclusion area while radiography was in progress, and who remained at the perimeter of this area. It does not account for the exposure of an actual radiographer who would have removed the source from its shielded container, positioned it for the radiographic exposure, placed the film in position once the source was in place, and reversed the procedure at the end of the exposure.[4]

By assuming that some nonradiographers also remained at the perimeter, except when they occasionally walked inside this boundary, Allen estimates their annual exposure to be 1,353 mR. His assumption that radiographers always remained at the perimeter, while nonradiographers sometimes approached nearer to the source, leads to the paradoxical conclusion that nonradiographers had higher exposures than radiographers.

We do not believe that it is reasonable to extrapolate Mr. [redacted]'s account to the practices used for ^{226}Ra radiography prior to 1962. First, Mr. [redacted] had stated that he began work at GSI at about the end of 1963 or the beginning of 1964. His first film badge report is for the week of [redacted] 1964—we assume that that is when he began working as a radiographer. This would be consistent with statements from Mr. [redacted] and other workers that it was the practice at GSI to first assign new employees in the NDT department to working with the Magnaflux (a magnetic testing device), later progressing to radiography. Mr. [redacted] later identified the supervisor as [redacted].[5] Mr. [redacted] s first film badge report is for the week of [redacted] 1964. However, in its application to the AEC for a renewal of its byproduct materials license (NRC 2009b, p. 8), GSI identified Mr. [redacted] as a [redacted] who had several months of experience with the betatron and radium, indicating that he probably started work in late 1961 or early 1962. According to

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3 Allen cites this date on the basis of information in the AEC compliance inspection report (NRC 2009a). However, in a letter to AEC, Gordon McMillin, vice-president and general manager of the GSI Commonwealth Division (i.e., the Granite City foundry) reported the acquisition date as April 24, 1962, which is most likely correct.

4 It is reasonable to assume that the film was positioned and removed while the source was in position. Otherwise, the film would be fogged by the source being moved to and from the casting.

5 [redacted] September 20, 2010, private communication with Robert Anigstein, SC&A, Inc.

Mr. [redacted] Mr. [redacted]. Thus, the description of ^{60}Co radiography in open areas of the plant is based on a second-hand account that cannot be independently corroborated. Furthermore, there is no basis for extrapolating the practice described by Mr. [redacted] to ^{226}Ra radiography performed years earlier.

The scenario developed and assessed by Allen (2010) is also not supported by available information on the use of ^{226}Ra sources at GSI. In the following two subsections, which do not correspond to section headings in the White Paper, we first discuss the limited information on radiography using ^{226}Ra sources at GSI and then analyze and discuss possible exposures of workers from such a procedure.

1.2.1 Available Information on Use of ^{226}Ra Sources at GSI

The only descriptions of practices in the use of radium as a radiographic source at GSI are in the initial application for an AEC Byproduct Materials License, submitted on March 7, 1962 (NRC 2009c). In the cover letter, L. A. Kleber, vice-president, manufacturing, of GSI, states: The State of Illinois has requested that we take immediate steps to discontinue the use of our radium sources using the fishpole technique. Further in the application is the statement:

> *To date, we have used quite satisfactorily two 500 mg radium sources. These have been used with a fish pole technique with little radiation exposure to our personnel*. (NRC 2009c, p. 8)

There is little information on radiation safety practices related to the use of radium sources prior to the date of the AEC application. Prior experience of GSI workers in performing radiography and their radiation exposures are summarized in the following statement, which appears in the application for Amendment 1 to the AEC license:

> *Up to this time February 1, 1963 no formal written tests have been given. Most of the present radiographers have worked with radium, cobalt, and a 24 M.E.V. Betatron for 2 - 15 years. They are competent in manipulation of all equipment and cognizant of health physics. During this period the exposure limits published by the A.E.C. at the applicable time were followed. They were never exceeded and averaged under 25%*. (NRC 2009b, p. 26)

The only other document pertaining to the history of radiation exposures at GSI prior to 1963 is an Occupational External Radiation History, AEC Form 4, for [redacted] a former GSI employee ([redacted] 2009). That form, dated March 19, 1962, prepared by the Nuclear Consultants Corporation, presents Mr. [redacted] total external radiation exposure at GSI from February 2, 1953, until the date of the report, based on "Record." There is no indication of how the doses listed on the form were determined.

It appears that the Nuclear Consultants Corporation and its president, Wilfred R. Konneker, PhD, CHP, were only retained by GSI at the time of the initial application for an AEC license. We base this conclusion on the following excerpt from the cover letter to the initial AEC license application, dated March 7, 1962: We have retained Dr. Konneker and his group at Nuclear

Consultants Corporation to assist us in establishing our health physics program (NRC 2009c, p. 3). This statement also calls into question whether there was *any* health physics program prior to the use of ^{60}Co under the AEC license.

The initial AEC license application includes a detailed description of a concrete block building constructed specifically for radiography using sealed sources (NRC 2009b, p. 8). There is no indication if there was any such structure during the period that ^{226}Ra sources were used. There is likewise no record or any mention of any measurements of radiation levels inside or outside this room from exposed ^{226}Ra sources. The following operating procedure, described in the application, could apply only to the ^{60}Co sources: The operator of the radiographic units will be some 25 to 35 feet away from the exposed sources and will operate behind 4 inches of armor plate steel. Such a procedure could not be carried out using the fishpole technique. It cannot therefore be assumed that the ^{226}Ra sources were used inside a shielded structure; furthermore, these sources were apparently not stored in a secure location, as witnessed by the fact that one source was taken home by a worker [redacted] An illustration of such a source is shown in Figure 1. Since Ra, x-ray machines, and betatrons were not subject to AEC regulations, the AEC was not involved in the use of radiation at GSI prior to 1962. Even if GSI had voluntarily adhered to AEC radiation protection regulations, despite the fact that they did not apply to ^{226}Ra sources, 10 CFR 20, "Standards for Protection Against Radiation," did not go into effect until February 1957, so there were no AEC regulations to adhere to prior to that time.

Figure 1. Radium Industrial Radiography Source (ca. 1940s) (ORAU 1999)

The State of Illinois did exercise some oversight over the use of ^{226}Ra sources, as evidenced by the fact that the application for the use of ^{60}Co sources was triggered by the State's request that GSI discontinue the use of radium with the fishpole technique. We made several inquiries to the State of Illinois, including a request under the Illinois Freedom of Information Act, which elicited the responses that the state had no records pertaining to radiation sources at General Steel Industries, Inc., under that name nor under its earlier name of General Steel Castings Company.

We also requested and obtained copies of Illinois radiation safety regulations of that era. The earliest rules that we received were promulgated on April 18, 1961, under "An Act relating to radiation protection and prescribing functions, powers and duties relating to the uses of sources of ionizing radiation which are or may be detrimental to health," approved July 17, 1959 (Illinois 1961). Although the Illinois Department of Public Health was "assigned the task of registering radiation installations, identifying radiation hazards and appraising the risk of radiation from x-rays" in 1957 (A History Public Health in Illinois - 1950s), there is no record of the department's having enforcement powers until the passage of the 1959 law, or of its issuing any rules or regulations until April 18, 1961.

Article XI: "Industrial Radiographic Installations," of the 1961 Illinois rules and regulations restricts and regulates the use of radiation sources in open areas (Illinois 1961). It is likely that a period of months would have elapsed before these rules could be implemented throughout the state. Thus, the request by the state that GSI discontinue the use of ^{226}Ra using the fishpole technique, cited in GSI's March 7, 1962, AEC Byproduct Materials License application, was most likely part of the initial enforcement program and not a change of policy. There was most likely no state or federally supervised radiation safety program at GSI prior to issuance of the AEC license in 1962, nor any effective in-house program, despite claims to the contrary in the excerpt from the license application cited on page 7 of this review. Not only was the radium source that a worker took home not stored in a secure location, it was most likely not marked or labeled as a radioactive source.

1.2.2 Potential Exposures From ^{226}Ra Radiography Using the Fishpole Technique

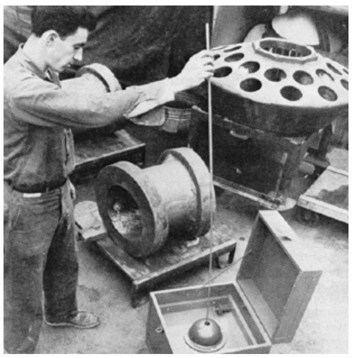

Figure 2. Source Being Removed from its Shield ("pig") (ORAU 1999)

Figure 3. Fishpole Radiography (ORAU 1999)

Figure 4. The "Fishpole" Technique (Hellier 2001)

Figures 2–4 illustrate the early use of the fishpole technique for industrial radiography using ^{226}Ra. In none of the illustrations does the worker stand behind a shield. The distance from the worker's torso to the source appears to range from 1–2 m. Although we cannot construct a plausible bounding exposure scenario for the exposure of a worker performing ^{226}Ra radiography with the fishpole technique, we can perform a sample calculation to indicate the potential exposure from such a source.

At a distance of 1 m, the exposure rate from a 500-mCi ^{226}Ra source is 412.5 mR/h, assuming a point source, no attenuation or scatter, and a value of $\Gamma = 0.825$ R h^{-1} Ci^{-1} m^{-2} (0.5 Ci × 0.825 = 0.4125 R/h). According to a "Compliance Inspection Report" dated November 2l, 1962, Robert Ripley, GSI Radiation Protection Officer, informed the inspector that about 10 radiographic exposures using ^{60}Co sources were made per shift (NRC 2009a, p. 3). Let us assume the same frequency for the earlier ^{226}Ra radiography. Absent any detailed knowledge of the technique, we will assume that the radiographer is exposed to the unshielded source for a total of 1 minute during each exposure—this includes the time it took to remove the source from its shielded container, carry it to the steel casting, and the time to replace it in the shield. Thus, the exposure duration is 10 min per shift, or about 68 h/y. The annual exposure would be 28 R/y. Our sample calculation, which addresses only a part of the procedure, shows that the exposure could be more than 30 times higher than the 868 mR/y estimated by Allen (2010). None of the former GSI workers who provided information to NIOSH or to SC&A gave any accounts of the practice of ^{226}Ra radiography at GSI—few of them were even employed at GSI during that period. We thus have no detailed knowledge of either the duration of the worker's exposure to the source or the actual distance of the source to the worker's body. The purpose of the sample calculation is to demonstrate that the exposure could be far higher than estimated by Allen.

In the absence of any documentation that the fishpole radiography was performed in a restricted area and that nonradiographers were excluded from the vicinity, we believe that such workers could also have received substantial exposures during the time the source was used outside its shield.

We further observe that industrial radiography using the fishpole technique is currently prohibited (unless specifically authorized) by the radiation safety regulations of the States of Delaware, Georgia, Iowa, Massachusetts, New Mexico, North Dakota, and West Virginia, and totally prohibited in Minnesota. This observation, coupled with the action taken by Illinois, is a strong indication that the technique is not considered safe, and that the resulting radiation exposures cannot be bounded by those from the use of small ^{60}Co sealed sources. The latter sources were in a shielded housing and exposures were performed by an operator using a remotely controlled mechanical device from behind a shield wall.

1.3 Cobalt Sources (1962 to 1966)

Allen (2010) describes a radiation protection survey of the concrete block building housing the ^{60}Co sources that was performed by Wilfred R. Konneker, president of the Nuclear Consultants Corporation. While Allen correctly cites the measurements reported from the survey, we disagree with some of his conclusions regarding the exposures to GSI workers from these sources.

The highest reading outside the secured area (i.e., the concrete block building housing the sources) was 1.2 mR/h at a height of 1 m above the floor. According to the survey report, the level could be reduced to ¼ if the partial occupancy factor were applied to this unrestricted area (NRC 2009e, p. 6). The exposure would be further reduced by the 30% utilization factor cited on page 6 of this review. Thus, the maximum likely exposure of an individual working 65 hours per week, 50 weeks per year, would be 292 mR/y (1.2 mR/h × 0.25 × 0.3 × 65 h/wk × 50 wk/y = 292 mR/y). This exposure is in addition to exposures to other sources of radiation, including the betatron, during the remaining 6 hours of each 8-hour shift. This exposure should be assigned to nonradiographers in a claimant-favorable dose reconstruction.

The maximum level at 1 m above the floor inside the radiographic facility was 1.15 mR/h. The maximum likely exposure of a radiographer would be 1.12 R/y, using the same work hours and the same 30% utilization factor.

Allen (2010) lists an annual exposure to a nonradiographer as 1,170 mR, based on the maximum exposure rate and a 30% utilization factor, and annual "doses" of 224 mR to a nonradiographer and 254 mR for a radiographer based on average exposure rates in the unrestricted and restricted areas, as cited in the survey report. Our estimate of the nonradiographer's annual exposure is

30% higher than the "average" value presented by Allen, while our estimate of the radiographer's exposure is more than 4 times higher than Allen's. The survey reports do not indicate how the average levels were determined. Since there is no assurance that the workers would have occupied the "average" locations, we believe that the exposures based on the maximum levels at 1 m above the floor in each location and the occupancy factor for locations outside the facility, estimated by the surveyor, should be used for a claimant-favorable assessment.

Allen also calculates annual doses to a crane operator and to a worker on the roof, assuming that the sources were shielded by a casting. Since the size and shape of the casting and its position with respect to the sources may not be representative of the castings radiographed over the course of a year, a claimant-favorable assessment should utilize the measurements made with no casting in place, which are 50–100% higher. That said, the occupancy factors for the crane and for the roof directly above the source were very small. According to the initial license application:

> *The large overhead crane is never operated over the area where the radiographers' room is located except to place the castings to be radiographed into the room. . . . Since the occupancy factor in this position is virtually zero we consider this to be an unrestricted area*. (NRC 2009c, p. 12)

In an internal memorandum, Robert W. Ripley, the GSI Radiation Protection Officer, states that the maximum occupancy of the area of the roof above the radiographic facility is estimated to be 24 man-hours per year (NRC 2009b, p. 10). Therefore, the bounding doses cited by Allen (2010), based on 100% occupancy, are implausible. These two exposure scenarios make no significant contribution to the radiation exposures of GSI workers.

1.4 Summary

In the summary section, Allen (2010) lists bounding estimates of annual doses from sources other than the betatron apparatus, induced activity from betatron radiography, and uranium metal. The annual doses to radiographers during 1953–1962 are listed as 868 mrem, and to "others working near radiography area" as 1,353 mrem. These values are based on the exposures discussed in Section 1.2.2 of this review, where we presented our findings which disagree with these conclusions.

For 1962–1966, Allen (2010) listed the dose to radiographers as 1,170 mrem/y. This dose is based on the exposure rate on the *exterior* wall of the room, a location occupied by workers other than radiographers. Our calculation, presented on page 10 of this review, yields an exposure of 1.12 R/y, which fortuitously results in approximately the same dose as cited by Allen in his "Summary" section. The dose to "others working near radiography area" is listed as 1,347 mrem/y, based on an assumed scenario in which ^{60}Co radiography was performed outside the radiographic facility and workers walked through the exclusion area.[6] These are much higher than the dose corresponding to an exposure of 292 mR/y which we calculated, based on the workers' occupancy of a location outside the radiography facility, as shown on page 10 of this review. Allen assigned doses to the overhead crane operator and to individuals working on the

[6] See discussion on page 6 of this review.

roof based on scenarios which disregard the very low occupancy factors for these locations. We agree that the doses assigned to these workers are bounding, but we question whether they are realistic.

2. FINDINGS AND DISCUSSION

Our most significant finding is that Allen (2010) does not present a limiting scenario for estimating bounding doses to radiographers and other workers during the "radium era" (1953–1962).

We believe that NIOSH should address possible exposures from the 250 kVp x-ray machines. Although, under proper operating conditions, the exposures of radiographers would be bounded by those from the betatron, the incidents of the machine being activated while workers were in the shooting room should be further investigated and evaluated.

NIOSH should also address possible exposures of GSI workers to high-activity sources used by St. Louis testing in open areas of the GSI property due to possible incursions of workers into the exclusion area.

We believe that, under proper operating conditions, the exposures of radiographers to the ^{60}Co sources listed on the AEC license during the covered period (1962–1966) would also be bounded by those from the betatron. However, NIOSH should evaluate the reported incident(s) when a source failed to retract into its shield, resulting in unexpected exposures to personnel in the vicinity.

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