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A BIBLIOGRAPHY OF ALUMINUM-NICKEL-URANIUM BONDING

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A BIBLIOGRAPHY OF ALUMINUM-NICKEL-URANIUM BONDING

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April 21, 1967

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A BIBLIOGRAPHY OF ALUMINUM-NICKEL-URANIUM BONDING

W. E. Gurwell

FORWARD

During the last 15 years much effort has been devoted to nuclear fuel elements clad by diffusion bonding. The aluminum-nickel-uranium bonding system has been studied and applied extensively for fuels operating at relatively low temperatures. The majority of this work was done by contractors of the United States Atomic Energy Commission. To date there has been no published compilation of work which included the USAEC classified reports. It is the purpose of this bibliography to furnish the compilation.

This bibliography resulted from a search of published literature pertinent to the atomic energy field, and was based on Abstracts of Classified Reports, 1953 to present, and Nuclear Science Abstracts, 1951 to present. It was not intended that the bibliography be exhaustive (leading to an unwieldy compilation), consequently, only major contributions are included. In a small number of instances, a reference is given only to show that some work was or is being done at a particular site.

Each entry is followed by a brief "abstract" to indicate the type or scope of work and any significant results. Where the title is sufficiently descriptive, the abstract is omitted. The bibliography itself is divided into six sections to facilitate quick reference. There are, naturally, cases where a particular document could have fit into more than one section.

It is the author's hope that the scope and form of this bibliography are such that it will spare the user many hours in the library.

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BONDING PROCESSES

- B-1 C. A. Strand. Interim Report on Hot die Sizing Variables Test, HW-76858, General Electric Company, Richland, Washington. May 1963. [Secret]
- Variables studied included preheat furnace time and temperature, can wall reduction, and ram speed. Evaluation made by tests for bond strength, diffusion layer thickness, bond count, and clad dimensions.
- B-2 C. A. Strand. End Closure of Hot Die Size Diffusion Bonded Fuel Elements, HW-78869, General Electric Company, Richland, Washington. January 1964. [Confidential]
- Describes development and testing of differential thermal expansion die concept for end bonding. Variables of the process studied.
- B-3 W. A. Blanton. Development Status and Incentives for the Hot Die Sizing Process, HW-79706, General Electric Company, Richland, Washington. November 1963. [Secret]
- B-4 W. W. West. Development of Hot Die - Size Bonding, DPST-61-464, Savannah River Laboratory. October 1961. [Confidential]
- Describes initial work on the hot - die sizing process. It was found that the aluminum deforms by laminar flow during the drawing operation, and that strong bonds could be achieved.
- B-5 W. W. West. Hot-Die Bonding 3rd Progress Report, DP-759, Savannah River Laboratory. July 1962. [Confidential]
- Continuing development work established the limits for several process variables.
- B-6 W. E. Faust. Hot Press Canning at Hanford, HW-48329, General Electric Company, Richland, Washington. February 1957. [Confidential]
- Summarizes hot press canning techniques and irradiation experience with fuels canned by the hot press technique up to 1957. 36 references.

- B-7 W. N. Rankin. Draw Canning Experiments - 2nd Progress Report - Hot Die Sizing, DP-697, Savannah River Laboratory. June 1962. [Confidential]

Preceding report to reference 5 above.

- B-8 W. W. West. Susceptor End Bonding, DP-934, Savannah River Laboratory. November 1964. [Confidential]

- B-9 R. C. May. Draw Canning Experiments, DP-604, Savannah River Laboratory. August 1961. [Confidential]

Describes work leading to the development of the HDSB process.

- B-10 E. A. Weakley. Proposed Solid State Diffusion Bonding (SSDB) Process - Gas Pressure Bonding, HW-65759, General Electric Company. June 1960. [Confidential]

- B-11 E. A. Smith. Engineering Aspects of Fabricating Slugs with Cold Pressure - Welded Closures, HW-34056, General Electric Company, Richland, Washington. December 1954. [Confidential]

- B-12 J. C. Tverberg. Specifications - Laboratory Hot-Press Process for "C" Size I&E Fuel Elements, HW-61995, General Electric Company, Richland, Washington. September 1959. [Secret]

- B-13 T. W. Gore. Solid State Diffusion Bonding Process - Building 313, B-42-F. March, 1962.

- B-14 S. Storcheim and J. L. Zambrow. Preliminary Report on Canning of Electroplated Uranium Slugs, SEP-115, Sylvania Electric Products. March 1953 [Declassified]

A series of metals and alloys was investigated for use as a diffusion barrier and a bonding agent in aluminum jacketed aluminum slugs. Thin nickel films were selected for bonding by hot-press canning. Methods of plating, canning, and bond testing are described.

- B-15 P. Loewenstein et.al. Progress Report to E. I. duPont de Nemours and Company for the Period January 11, 1958 through April 17, 1958, NMI-4322, pp. 23-4. [Secret]

Basic principals of draw canning investigated.

B-16 Manufacturing Process Specifications Metallic Uranium Fuel Element Fabricated by the Hot Die Sizing Process, DUN-217, Douglas United Nuclear, Inc., Richland, Washington. December 1, 1965. [Confidential-Undocumented]

B-17 Engineering Specifications Hot Die Sizing Fuels Fabrication Process, DUN-180, Douglas United Nuclear, Inc., Richland, Washington. [Confidential - Undocumented]

B-18 Nuclear Reactor Fuel Elements - Metallurgy and Fabrication, edited by A. R. Kaufman. Interscience publishers, New York. 1962.

Contains a good introduction to the metallurgy and fabrication of diffusion bonded nuclear fuel elements.

B-19 G. V. Alm, M. H. Binstock and E. E. Garrett. Hot Pressure Bonding of OMR Fuel Plates, NAA-SR-3583, Atomics International. November 1959.

B-20 M. H. Binstock. Fuel Element Development for Piqua OMR, NAA-SR-5119, Atomics International. June 1960.

Describes fabrication of hot pneumatically bonded fuel elements with Al-Ni-U bonds.

B-21 G. E. Dieter, Jr. Mechanical Metallurgy. McGraw-Hill Book Co., Inc. New York, pp. 541-548. 1961.

Mechanics of hot die sizing (draw canning) technique examined.

B-22 B. J. Borgmier. Coating, Canning. and Testing Methods for Natural Uranium Fuel Elements - A Bibliography, HW-25365, General Electric Company, Richland, Washington. July 1952. [Secret]

A bibliography compiled of work reported through July 1952.

B-23 G. W. Beckman. Status Report on the Extrusion Cladding and Fluid Pressure Bonding Programs at SRL, DPST-60-282, Savannah River Laboratory. April 1960. [Confidential]

Describes cable cladding and gas pressure bonding over nickel plated cores. See also DP-462 for more on fluid pressure bonding.

- B-24 G. F. Jacky and J. H. Johnson. Status of Off-Site Extrusion Cladding Development, HW-56018, General Electric Company, Richland, Washington. May 1958. [Confidential]

Detailed data accumulated from visits to several sites where cable cladding was being developed.

- B-25 S. Storcheim and J. L. Zambrow. Review and Status of Hot-Pressure Cladding, SEP-186, Sylvania Electric Products, Inc. June 1956. [Confidential]

Reviews the development of hot pressure canning at Sylvania and also refers to work done at other sites. See also SEP-181 and DP-458.

- B-26 H. T. Suneson, C. J. Beck and L. S. DeLuca. Aluminum Canning of Nickel-Plated, Hanford Four-Inch Uranium Fuel Slugs by Hot Pressing, KAPL-1335, Knolls Atomic Power Laboratory. May 1955.

Conditions of time, temperature and pressure for bonding Al-Ni and Ni-U couples were determined as well as a process for canning 4-inch Hanford slugs. Growth of the brittle intermetallic γ (Al_3Ni_2) was deleterious to bond strength.

- B-27 Literature Survey on Aluminum Cladding of Nickel-Plated Uranium Reactor Fuel Elements, LS-62. Israel. Atomic Energy Commission, Tel-Aviv. August 1959.

NICKEL DEPOSITS ON URANIUM

- P-1 P. Chiotti, P. F. Woerner, H. H. Klepfer, K. J. Gill, R. E. Cutrell. Application of Metal Coatings on Uranium, ISC-640, Iowa State University. September 1955. [Confidential - Undocumented]

Coatings of Zn, Cu, Mg, Ni, Si, Zr, and Cr were applied to uranium by hot dipping and an electroplating. Coatings were evaluated by testing in boiling water and molten Al-Si. Hot-press bonding between Al and coatings was studied. Some diffusion data given.

- P-2 W. H. Roberts. A Method of Stripping and Replating Nickel Electroplated Uranium, RFP-342, Dow Chemical Company. March 1964.

- P-3 J. G. Beach and C. L. Faust. Electroplates on Uranium and Thorium for Corrosion Protection and to Aid Joining, BMI-1537, Battelle Memorial Institute, Columbus. August 1961.

- P-4 R. L. Braun and R. W. Stromatt. Uranium Surface Electrochemistry and Nickel Plating - Interim Report, HW-79582, General Electric Company, Richland, Washington. November 1963. [Declassified]

Basic approach to surface preparation.

- P-5 J. R. Lundquist and R. W. Stromatt. Nickel Electroplating on Uranium: Surface Preparation and Plating Studies, BNWL-124, Battelle-Northwest, Richland, Washington. October 1965.

Significant advances in surface preparation and plating through basic approach to problem.

- P-6 J. R. Lundquist, R. L. Braun and R. W. Stromatt. Nickel Plating Uranium: Review of Laboratory Studies, BNWL-SA-1030, Battelle-Northwest, Richland, Washington. January 16, 1967.

A review of work reported separately in references P-4 and P-5 above.

- P-7 J. J. Katz and E. Rabinowitch. The Chemistry of Uranium. McGraw-Hill Book Company, Inc., New York. 1951. 1st Ed.

- P-8 R. L. Andelin. Nickel Plating of Uranium, HW-30243, General Electric Company, Richland, Washington. December 1953. [Confidential]

- P-9 R. G. Post and W. B. Kerr. Semi-Production Nickel Plating of Fuel Elements, HW-35609, General Electric Company, Richland, Washington. July 1955. [Confidential]

Anodic etch severity controlled by Cl ion content in H_3PO_4 bath. Mechanical keying recognized as necessary for good Ni-U bonding.

- P-10 G. Chauvin, H. Coriou and J. Hure. "Protection of Uranium by Electrolytic Nickel and Diffusion," Electrochimica Acta, Vol. 1, pp. 177-189. 1959. [In French]

The production of nickel deposits on uranium and diffusion between the nickel and uranium are described. Nickel deposited from a bath free from boric acid avoids production of 400-500 ppm boron found in deposits from conventional baths.

- P-11 R. C. May. Electroplating of Nickel on Uranium, DP-273, Savannah River Laboratory. May 1958. [Confidential]

Watts and high-sulfate baths compared.

- P-12 J. G. Beach and C. L. Faust. Electrodeposited Nickel Coatings on Thorium and Uranium for Corrosion Protection and to Aid Joining, BMI-1584, Battelle Memorial Institute, Columbus, Ohio. July 1962. [Confidential]

- P-13 J. D. Salzman. Part II - Dissolution of Uranium in Nitric Acid, University of Colorado. 1961. (PhD Thesis).

Effects of impurities, cold work, acid concentration, temperature, surface area, stirring and other variables on the dissolution of uranium in nitric acid were studied.

- P-14 W. B. Kerr. A Process for Nickel Plating Uranium, HW-33813, General Electric Company, Richland, Washington. November 1954. [Confidential]

This is a "recipe" using a high sulfate bath.

- P-15 J. B. Beach, W. C. Shickner, Delores Hopkinson and C. L. Faust. Electroplated Metals on Uranium for Aluminum Cladding, BMI-996, Battelle Memorial Institute, Columbus, Ohio. May 1955.

- P-16 J. G. Beach, W. C. Schickner, C. R. Konecney and C. L. Faust. Electroplated Metals on Uranium, BMI-912, Battelle Memorial Institute, Columbus, Ohio. May 1954. [Confidential]
- P-17 J. K. Gore, R. Seigmiller, J. M. Taub, A. Pinkerton and L. Quintana. Surface Treatments of Uranium and Their Application to Uranium Technology, LA-2190, Los Alamos Scientific Laboratory. August 1957.

Nonelectrolytic surface roughening is described.

- P-18 D. E. Couch and A. M. Brown. Coatings for Uranium, Final Report NBS Project 0506-20-05465 (3262) to the Sandia Corporation, March through July 1960.
- P-19 D. Wood. "A Simple Method for Plating Nickel on Stainless Steel," Metal Industry, Vol. 36, pp. 330-331. 1938

The use of a "nickel strike" improves adhesion and eliminates special racking problems.

- P-20 L. W. Owen. "Protective Coatings for Uranium," J. Less Common Metals, Vol. 4, pp. 35-39. 1962.

Carbonyl nickel coatings were found superior to electrolytic nickel coatings in boiling water and 150°C air.

- P-21 L. W. Owen. "Vapor Plating of Nickel," Metal Industry, Vol. 92, pp. 227-230. 1958.

Production and properties of carbonyl nickel deposits are discussed.

- P-22 "Metal Plating from Carbonyl Gases," Chemical Engineering, October 1949. pp. 118-119.

Disadvantages and advantages of carbonyl plating are discussed.

- P-23 A. K. Graham. Electroplating Engineering Handbook. Reinhold Publishing Corp., New York. 1962.

- P-24 R. L. Hoyle, "Plating by Thermal Decomposition - Bibliography and Abstracts," AES Research Report No. 20, Plating, Vol. 49, pp. 1173-1175, pp. 1264-1268, and in later issues. 1962 -.

An extensive bibliography.

- P-25 Metals Handbook 8th Edition, Vol. 2, American Society for Metals, Metals Park, Ohio. 1964, pp. 432-443.

The types and uses of nickel plating baths are described.

- P-26 F. A. Lowenheim. Modern Electroplating, 2nd Edition. John Wiley and Sons, Inc., New York. 1963.

- P-27 A. Brenner, V. Zentner and C. W. Jennings. "Physical Properties of Electrodeposited Metals - I. Nickel - 3. The Effect of Plating Variables on the Structure and Properties of Electrodeposited Nickel," Plating, Vol. 39, pp. 865-933. 1952.

An exhaustive compilation of nickel plate properties as a function of plating variables. AES Research Project No. 9. Extensive bibliography given.

- P-28 E. J. Roehl. "Mechanical Properties of Nickel Deposits," Plating, Vol. 35, p. 452. 1948.

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- P-29 A. Brenner and C. W. Jennings. "Physical Properties of Electrodeposited Metals - I. Nickel - A Progress Report," Plating, Vol. 35, p. 1228. 1948.

Progress report. Final report is reference P-27.

- P-30 A. Brenner and C. W. Jennings, "Physical Properties of Electrodeposited Metals - Nickel - Annual Report on AES Research Project No. 9," Proc. Am. Electroplater's Soc., Vol. 35, p. 31. 1948.

Annual report. Final report is reference P-27.

- P-31 C. E. Heussner, A. R. Balden, and L. M. Morse. "Some Metallurgical Aspects of Electrodeposits," Plating, Vol. 35, p. 554 and p. 719. 1948.

Microstructure and mechanical properties of electrodeposits were studied.

- P-32 D. J. Macnaughton, G. E. Gardam, and R. A. F. Hammond. "The Influence of the Composition and Acidity of the Electrolyte on the Characteristics of Nickel Deposits," Trans. Faraday Soc., Vol. 29, p. 729. 1933

An account of a general investigation into the causes and prevention of pitting in electrodeposited nickel.

- P-33 A. W. Hotherhall and G. E. Gardam. "Electrodeposition of Nickel in the Bores of Tubes Using Insoluble Anodes," J. Electroplater's Tech. Soc., Vol. 27, pp. 181-199. 1951.

- P-34 "Metal Deposition on Uranium to Inhibit Corrosion," Corrosion Technology, Vol. 10, No. 2, p. 43. 1963.

Anhydrous zinc deposition reported. Porosity determined by heating to 200°C in H₂.

- P-35 J. Matulis and R. Slizys. "On Some Characteristics of Cathodic Processes in Nickel Electrodeposition," Electrochimica Acta, Vol. 9, pp. 1177-88. 1964.

- P-36 G. Chauvin and H. Coriou. "Applications of Some Electrolytic Deposits in the Nuclear Energy Domain," Corrosion et Anticorrosion, Vol. 12, No. 4, p. 153. 1964. [In French]

Technique for plating uranium with nickel and chromium, Zircaloy with copper, etc. given.

- P-37 D. E. Couch. "Preparation of and Electroplating on Uranium," Plating, Vol. 49, pp. 363-367.

A list of 59 uranium cleaning solutions and their results is given. Black films under electroplates avoided in non-aqueous solutions. Porosity tested by heating in hydrogen to 200°C.

- P-38 E. W. Rebol and R. F. Wehrmann. "Method of Electroplating on Uranium," U.S. Patent 2,884,364. April 28, 1959.

Trichloroacetic plus HCl etch bath.

- P-39 O. Flint, "Surface Treatment of Uranium," U.S. Patent 2,853,441. September 23, 1958.

Anodic etch in weak organic acids.

- P-40 R. Huddle and A. O. Flint. "Treatment of Metals Prior to Electroplating," U.S. Patent 2,835,630. May 20, 1958.

Shot blasted surface followed by thin copper deposit.

- P-41 A. G. Gray. "Surface Treatment of Metallic Uranium," U.S. Patent 2,836,548. May 27, 1958.

Hydrochloric acid etch.

- P-42 A. G. Gray. "Electrodeposition of Nickel on Uranium," U.S. Patent 2,849,348. August 26, 1958.

Etch bath of molten ferric chloride hexahydrate
($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) at 50 to 70°C.

- P-43 A. G. Gray. "Nickel Coated Uranium Article," U.S. Patent 2,854,738. October 7, 1958.

Nickel coated uranium subsequently coated with copper, chromium, or Al-Si alloy.

- P-44 R. J. A. Potvin. "Protective Coating of Uranium and Thorium," U.S. Patent 2,915,417. December 1, 1959.

Aqueous solution of arsenious oxide deposits
arsenic on uranium surface.

- P-45 C. J. Slunder. "Treatment of Uranium Surfaces," U.S. Patent 2,872,389. February 3, 1959.

Anodic etch in phosphoric acid - hydrochloric bath.

- P-46 "Electroplating Uranium with Protective Metals," U.S. Patent 853,521. November 9, 1960.

- P-47 "Nickel Coatings and Method of Applying," U.S. Patent 853,522. November 9, 1960.

- P-48 "Method of Applying Nickel Coatings on Uranium," U.S. Patent 2,294,884. July 14, 1959.

- P-49 "On Coating Fuel Elements," NYO-2801, Nuclear Materials and Equipment Corp., Apollo, Pennsylvania. November 1959.
- P-50 C. Sella and J. J. Trillat. Influence of the Surface State on Some Properties of Uranium, HW-tr-5. July 1959. Translated from Rev. Met., Vol. 56, pp. 105-21. 1959.
- Electron diffraction studies of uranium surfaces as a function of surface treatments.
- P-51 W. N. Rankin. Electroplating Nickel on Uranium for the Hot Die Size Bonding Process, DD-909, Savannah River Laboratory. August 1964. [Confidential - Undocumented]
- Electroplating variables using Watt's bath studied. Effects of variables established.
- P-52 R. S. Ondrejcin. Evaluating Uranium Surfaces by Measurements of Potential, DP-1073, Savannah River Laboratory. December 1966.

BOND CHARACTERISTICS AND EVALUATION

- C-1 F. R. Zaloudek, The Effect of Bond Defects on Temperature Within I&E Fuel Elements During Irradiation, HW-64436, General Electric Co., Richland, Washington. March 1960. [Confidential]
- Effects of bond defects on temperature distribution in I&E elements investigated analytically.
- C-2 R. L. Brown, Jr. Hot Die Sized Fuel Tester UE-3, HW-82388, General Electric Co., Richland, Washington. May 22, 1964.
- C-3 C. L. Angerman and E. C. Hoxie. "Aqueous Corrosion of Aluminum-Nickel-Uranium Bonds," Aqueous Corrosion of Reactor Materials, TID-7587. July 1960.
- Pinhole corrosion tests showed that a continuous oxide layer in the Ni-U bond zone accelerated undercutting corrosion.
- C-4 H. A. Saller, R. F. Dickerson and R. J. Carlson. The Tensile Strength of Solid State Bonded Aluminum and Nickel Plated Uranium, BMI-956, Battelle Memorial Institute, Columbus, Ohio. October 1954.
- C-5 C. L. Angerman and E. C. Hoxie. Pinhole Corrosion Testing of Aluminum Clad Nickel-Bonded Fuel Elements, DP-269. Savannah River Laboratory. February 1958.
- See reference C-3 above for abstract.
- C-6 E. A. Evans and H. C. Bowen. Secondary Corrosion Behavior of Nickel and Iron-Nickel Coatings, HW-37439. General Electric Co., Richland, Washington. August 1955. [Confidential]
- Sweater coatings were applied to U slugs by electroplating, gas plating and wrapping in foil. Coated slugs were hot press canned in Al. Canned slugs were defect corrosion tested in stagnant and flowing water.
- C-7 K. Hauffe. "The Mechanism of Oxidation of Metals and Alloys at High Temperatures," Progress in Metal Physics, Pergamon Press, London, 1953. Vol. 4, pp. 71-104.

- C-8 R. I. Nazarova. Electron Diffraction Study of the Oxidation Process of Thin Films of Intermetallic Compounds of the System Nickel-Aluminum, NASA-TT-F-10, 156 (N66-33704). May 1966.

The phase composition of oxide films formed on heating to 900°C was determined for five specimens with varying nickel and aluminum contents.

- C-9 C. L. Angerman and M. E. Berstreser. Bonding of Uranium Fuel Elements, DPST-63-278. Savannah River Laboratory. May 1963.
[Secret]

Discuss properties of U that affect the quality of U-Al bonds formed with Al-Si and with Ni, and the effects of irradiation on the bonds.

- C-10 G. R. Caskey. Bond Strength of Irradiated Fuel Elements, DPST-60-286. Savannah River Laboratory. April 1960. [Secret]

Irradiation has no significant effect on the bond strength of Al-Si bonded fuel elements, but decreased the bond strength of nickel bonded elements.

- C-11 K. P. Bokish. Ultrasonic Bond Testing of Irradiated Fuel Elements, HW-56028. General Electric Co., Richland, Washington. May 1958.
[Confidential]

Ultrasonic bond test equipment, installed in the 105-C Metal Examination Facility is described and evaluated.

- C-12 A. B. Tripler, Jr., J. G. Beach, and C. L. Faust. Potential Measurements of Aluminum-Clad Uranium Systems, BMI-997, Battelle Memorial Institute, Columbus, Ohio. May 1955.

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- C-13 Paul E. Mix. "Nondestructive Detection and Thickness Measurement of Nickel Plating on Uranium Fuel Cores," Materials Evaluation, Vol. 24, pp. 253-6. 1966. See also DPSPU-64-30-13, Savannah River Plant. 1966.

Hall effect device.

- C-14 H. W. Woods. Metallographic Techniques for Bond Study of Aluminum-Clad Nickel-Plated Uranium Fuel Elements, SEP-238, Sylvania Electric Products, Inc. March 1957.

Recommended procedure for best results in shortest time.

ALUMINUM-NICKEL-URANIUM DIFFUSIONAluminum-Nickel Diffusion

- A-1 Takao Konishi, "Some Studies on the Cladding Techniques for Metallic Uranium Fuel. II - Diffusion Behavior of Aluminum in Metallurgical Bonding," Nippon Genshiryoku Gakkaishi, Vol. 6, pp. 700-6, 1964. [In Japanese]

Aluminum-nickel diffusion studied. Aluminum-copper diffusion zones form 3 layers and aluminum-niobium couples form no detectable intermetallics.

- A-2 S. Storcheim, J. L. Zambrow, and H. H. Hausner. "Solid State Bonding of Aluminum to Nickel," Journal of Metals, Vol. 6, pp. 269-274 and pp. 1330-1334. 1954.

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